Texas Forensic Science Commission

Justice Through Science

FINAL REPORT ON COMPLAINT NO. 15.07, NATIONAL INNOCENCE PROJECT ON BEHALF OF STEVEN MARK CHANEY (BITE MARK ANALYSIS)

April 12, 2016

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I. SUMMARY OF THE COMMISSION'S STATUTORY AUTHORITY

A. Legislative Background and Jurisdiction

The Texas Legislature created the Texas Forensic Science Commission ("Commission") during the 79th Legislative Session by passing House Bill 1068 (the "Act"). The Act amended the Texas Code of Criminal Procedure to add Article 38.01, which describes the composition and authority of the Commission.[1] During the 83rd and 84th Sessions, the Legislature further amended the Code of Criminal Procedure to clarify and expand the Commission's jurisdictional authority.[2]

The Commission has nine members appointed by the Governor of Texas.[3] Seven of the nine commissioners are scientists and two are attorneys (one prosecutor nominated by the Texas District and County Attorney's Association, and one criminal defense attorney nominated by the Texas Criminal Defense Lawyer's Association).[4] The Commission's Presiding Officer is Dr. Vincent J.M. Di Maio.[5]

1. <u>Accreditation Jurisdiction</u>

Texas law prohibits a forensic analysis from being admitted in a criminal case if the entity conducting the analysis is not accredited by the Commission:[6]

> "…a forensic analysis of physical evidence under this article and expert testimony relating to the evidence are not admissible in a criminal action if, at the time of the analysis, the crime laboratory conducting the analysis was not accredited by the commission under Article 38.01."[7]

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[1] *See* Act of May 30, 2005, 79th Leg., R.S., ch. 1224, § 1, 2005.
[2] *See* Acts 2013, 83rd Leg., ch. 782 (S.B.1238), §§ 1 to 4, eff. June 14, 2013; Acts 2015, 84th Leg., ch. 1276 (S.B.1287), §§ 1 to 7, eff. September 1, 2015, (except TEX. CODE CRIM. PROC. art. 38.01 § 4-a(b) which takes effect January 1, 2019).
[3] *Id.* at art. 38.01 § 3.
[4] *Id.*
[5] *Id.* at § 3(c).
[6] Until the 84th Legislative Session, the accreditation program was under the authority of the Department ofPublic Safety ("DPS").
[7] TEX. CODE CRIM. PROC. § 38.35(a)(4).

The term “forensic analysis” is defined as follows:

> “Forensic analysis” means a medical, chemical, toxicologic, ballistic, or other expert examination or test performed on physical evidence, including DNA evidence, for the purpose of determining the connection of the evidence to a criminal action, except that the term does not include the portion of an autopsy conducted by a medical examiner or other forensic pathologist who is a licensed physician.[8]

The term “crime laboratory” is broadly defined, as follows:

> “Crime laboratory” includes a public or private laboratory or other entity that conducts a forensic analysis subject to this article.[9]

Texas law exempts certain forensic disciplines from the accreditation requirement—either by statute, administrative rule, or by determination of the Commission.[10] A key threshold question is whether bitemark comparison[11] is subject to the accreditation requirement. Neither the statute nor the administrative rules (carried over from DPS) mention forensic odontology specifically. The term “forensic analysis” undoubtedly includes bitemark comparison, but no national accreditation body recognized under Texas law (e.g., ASCLD/LAB, ANAB, etc.) offers accreditation in bitemark comparison. Accreditation by one of these nationally recognized bodies is mandatory for entities seeking to be accredited under Texas law.[12]

Under a strict reading of the statute, bitemark comparison should <u>not</u> be admissible in Texas criminal courts because it does not meet the accreditation

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[8] *Id.* at § (a)(4).
[9] *Id.* at § (d)(1).
[10] *Id.* at 38.01 § 4-d(c).
[11] The Commission specifically uses the term “bitemark comparison” to refer to the act of analyzing a patterned injury for purposes of either associating or excluding a suspect or group of suspects based on the observable characteristics of the patterned injury. The Commission has no concerns regarding the components of bitemark analysis that include swabbing a patterned injury site for possible DNA analysis or to determine the presence or absence of salivary amylase.
[12] 37 Tex. Admin. Code § 651.4.

requirement set forth in the Code of Criminal Procedure and neither DPS nor the Commission has ever exempted forensic odontology by administrative rule. In an abundance of caution, the Commission has instructed staff to seek confirmation of this interpretation through a legal opinion request to the Attorney General's office. This report will be updated to reflect the Attorney General's opinion once it is received.

Most Texas judges are unlikely to be aware of the statutory requirement for accreditation outside of traditional forensic disciplines such as toxicology, drug chemistry, DNA, etc. This is especially true considering the small number of bitemark cases in Texas. Because bitemark comparison has been admitted in Texas courts since 1954 (with the *Doyle* case involving a bitemark in cheese), it continues to be admitted.[13]

2. Investigative Jurisdiction

Texas law requires the Commission to "investigate, in a timely manner, any allegation of professional negligence or professional misconduct that would substantially affect the integrity of the results of a forensic analysis conducted by an accredited laboratory, facility or entity."[14] The Act also requires the Commission to: (1) implement a reporting system through which accredited laboratories, facilities or entities may report professional negligence or professional misconduct; *and* (2) require all laboratories, facilities or entities that conduct forensic analyses to report professional negligence or misconduct to the Commission.[15]The Commission is also expressly authorized to investigate allegations of professional negligence and misconduct for

[13] *See Doyle v. State*, 159 TEX. CRIM. 310, 263 S.W.2D 779 (JAN. 20, 1954).
[14] TEX. CODE CRIM. PROC. art. 38.01 § 4(a)(2).
[15] *Id.* at § 4.

disciplines not subject to accreditation, such as the forensic bitemark comparison at issue in this case.[16] However for cases involving forensic disciplines not subject to accreditation, the Commission's reports are limited to the following:

- Observations regarding the integrity and reliability of the forensic analysis conducted;
- Best practices identified by the Commission during the course of the investigation; and
- Other recommendations deemed relevant by the Commission.[17]

II. INVESTIGATIVE PROCESS

A. Complaint Process

When the Commission receives a complaint, the Complaint Screening Committee conducts an initial review of the document at a publicly noticed meeting.[18] After discussing the complaint, the Committee votes to recommend to the full Commission whether the complaint merits any further review.[19]

In this case, the Committee discussed the complaint (*See* **Exhibit I**) at a publicly noticed meeting of the Complaint and Disclosure Screening Committee in Austin, Texas on August 13, 2015. The Commission discussed the complaint again the following day, on August 14, 2015, at its quarterly meeting, also in Austin, Texas. After deliberation, the Commission voted unanimously to create a four-member investigative panel to review the complaint pursuant to Section 4.0(b)(1) of the Policies and Procedures. Members voted to elect Dr. Harvey Kessler, Dr. Vincent Di Maio, Dr. Ashraf Mozayani and Mr. Richard Alpert as members of the panel, with

[16] *Id.* at § 4(b-1).
[17] *Id.*
[18] *See* Policies and Procedures at 3.0.
[19] *Id.*

Dr. Harvey Kessler (Director of Pathology and Professor at the Texas A&M University Baylor College of Dentistry) serving as Chairman.

Once a panel is created, the Commission's investigations include: (1) relevant document review; (2) interviews with stakeholders as necessary to assess the facts and issues raised; (3) collaboration with affected agencies; (4) requests for follow-up information where necessary; (5) hiring of subject matter experts where necessary; and (6) any other steps needed to meet the Commission's statutory obligations.

B. Other Important Limitations on the Commission's Authority

In addition to the limitations described above regarding reports involving disciplines not subject to accreditation, the Commission's authority contains other important statutory limitations. For example, ***no finding contained herein constitutes a comment upon the guilt or innocence of any individual.*** [20] Additionally, the Commission's written reports are not admissible in a civil or criminal action.[21]

The Commission also does not have the authority to issue fines or other administrative penalties against any individual, laboratory or entity. The information the Commission receives during the course of any investigation is dependent upon the willingness of stakeholders to submit relevant documents and respond to questions posed. The information gathered has ***not*** been subjected to the standards for admission of evidence in a courtroom. For example, no individual testified under oath, was limited by either the Texas or Federal Rules of Evidence (*e.g.,* against the admission of hearsay) or was subjected to formal cross-examination under the supervision of a judge.

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[20] TEX. CODE CRIM. PROC. 38.01 at § 4(g).
[21] *Id.* at § 11.

The Commission has no jurisdiction in civil cases or administrative proceedings such as case falling within the jurisdiction of the Texas Department of Family and Protective Services. The recommendations in this report apply exclusively to bitemark analyses performed in the context of criminal actions. Moreover, the recommendations are specific to the bitemark comparison sub-discipline of forensic odontology, and do not apply to human identifications, age estimations or other areas of forensic odontology unrelated to the analysis of patterned injuries on skin. Finally, as previously noted the Commission is not concerned about the components of bitemark analysis that are limited to swabbing a patterned injury site for possible DNA analysis or to determine the presence or absence of salivary amylase.

III. Summary of Steven Mark Chaney Criminal Case

Steven Mark Chaney was convicted of the murder of John Sweek and sentenced to life in prison on December 14, 1987. John Sweek and his wife, Sally, sold cocaine from their East Dallas apartment and were found brutally murdered in June 1987, with autopsy reports indicating multiple stab wounds and slit throats. Despite suspicions pointing to the couple's Mexican drug supplier, Mr. Chaney became a suspect when another customer of the Sweeks informed police that Chaney had a motive because he owed the Sweeks $500 for drugs he had purchased. Mr. Chaney offered nine alibi witnesses but was still found guilty.

At trial, two forensic odontologists, Drs. Jim Hales and Homer Campbell, testified the mark on John Sweek's forearm was a human bitemark that matched Chaney's dentition. Dr. Campbell testified that Chaney made the bitemark to a reasonable degree of dental certainty while Dr. Hales testified that there was a "one to a million" chance someone other than Mr. Chaney could have left the bitemark. This testimony was compelling to the jury. As one juror stated after the verdict, "Do you want me to tell you what made my decision? […] The bitemark." Mr. Chaney unsuccessfully appealed his case and his conviction became final in December of 1989.

In 2015, Mr. Chaney's lawyers filed a writ of habeas corpus challenging his conviction. On October 12, 2015, after Dr. Jim Hales recanted his testimony and the Dallas County District Attorney's Office agreed the bitemark evidence was unsupportable, Mr. Chaney was released from prison. Mr. Chaney's writ is pending with the Texas Court of Criminal Appeals where additional writ grounds are being litigated.

IV. BITE MARK PANEL: PROCESS

The Commission formed a Bite Mark Investigation Panel at the August 14, 2015 quarterly meeting. Since that time the Panel has met three times to conduct its inquiry. Under Dr. Kessler's leadership, the Bite Mark Panel focused its efforts on collecting and reviewing the existing scientific literature and data underlying bitemark comparison and providing recommendations to the full Commission as a result of the review. Dr. Kessler sought input from the American Board of Forensic Odontology ("ABFO") and its members, as well as other interested forensic odontologists and criminal justice stakeholders.

The first Panel meeting was held on September 16, 2015, in Dallas, Texas at the Dallas County District Attorney's Office. The Panel discussed correspondence with the ABFO regarding Dr. Kessler's request for scientific data along with the other materials that had been submitted prior to meeting. The Panel also heard from Chris Fabricant on behalf of Mr. Chaney. Mr. Fabricant provided a summary of the case facts and key issues contained in the complaint. Following Mr. Fabricant was Dr. David Senn, DDS, Clinical Assistant Professor at the University of Texas Health Science Center at San Antonio. Dr. Senn gave a summary response to the complaint, provided information and answered questions concerning the ABFO's historical and current initiatives. Dr. Senn expressed his belief that the Chaney complaint contained some "truths, half-truths, and non-truths." Dr. Kessler requested that Dr. Senn delineate each of the categories in a written document. The Panel also discussed the best way to approach case identification and review with input from the ABFO and other stakeholders. In addition to Chris Fabricant and Dr. Senn, the Panel also received public comment from Dr. Roger Metcalf, DDS/JD, Patricia Cummings of the Dallas County Conviction Integrity Unit and Julie Lesser of the Dallas County Public Defender's Office, co-counsel for Mr. Chaney.

The Panel held its next meeting on November 16, 2015 at the Tarrant County District Attorney's Office in Fort Worth, Texas. The Panel sought and received numerous research studies, presentations and related information concerning the state of scientific research and data underlying bitemark comparison. Mr. Chaney, who had his conviction set aside and was released from prison on October 12, 2015, was present at the meeting. The Panel then heard from an impressive list of experts in the field of forensic odontology. To begin, Dr. David Senn presented a PowerPoint (*See* **Exhibit D**) in which he focused on agreements and disagreements with the original complaint as well as his observations regarding cadaver research conducted by Mr. Peter and Dr. Mary Bush and current research in his program at UTHSC San Antonio. The Panel next welcomed Dr. Frank Wright who gave a presentation on the appropriate use, role and limitations of bitemark evidence and his perspective on needed research and next steps. (*See* **Exhibit E**.)

Drs. Iain Pretty and Adam Freemen also presented their Construct Validity of Bitemark Assessments study using the ABFO Decision Tree that was originally presented at the American

Academy of Forensic Sciences ("AAFS") Annual Scientific Meeting in February 2015. (*See* **Exhibit B.**) The presentation included lessons learned and the scientific implications of the results. Participants further commented on the various action items from the study including their opinions on the next steps needed in research, scientific reporting and a possible moratorium recommendation. Finally, the Panel heard a presentation from Mr. Peter Bush regarding the current context of research and limitations in bitemark comparison, including numerous clinical studies he conducted at SUNY Buffalo with Dr. Mary Bush and colleagues.

Panel members, staff and stakeholders asked questions of the presenters and engaged in a spirited discussion regarding the implications of the research. Upon conclusion of the presentations, the Panel agreed that due to the volume and breadth of materials, members needed further time to thoroughly review the data before making any recommendations. Forensic odontologists in attendance, specifically Drs. Pretty, Freeman, Wright and Senn discussed a possible follow-up study to the Freeman/Pretty study that could help more clearly identify threshold criteria for determining human bitemarks.

The Panel also discussed the retroactive case identification and review process, including a list of 33 cases developed through stakeholder input and staff research. The Panel discussed obtaining further case information directly from the ABFO Diplomates along with historical data from the National Museum of Health and Medicine archives. The Panel decided to wait to establish a case review subcommittee until further input wassought from the full Commission.

The Panel held its third meeting on February 11, 2016 in Austin, Texas. The Panel heard from Dr. Senn who gave a brief presentation on the ABFO's progress since the Panel's November 16, 2015 meeting in Fort Worth. Dr. Senn explained the research related to bitemark comparison is slow going but being developed. (*See* **Exhibit D**.) Dr. Senn also offered the assistance of all nine Texas ABFO-certified members in any multidisciplinary bitemark case review conducted by the Commission.

The Panel next heard from General Counsel Lynn Garcia regarding jurisdictional issues under Texas law and possible recommendations for the full Commission. Garcia summarized the actions taken, presentations given, and research provided to the Panel. The Panel discussed a number of recommendations to be made to the full Commission. Dr. Frank Wright addressed the Panel regarding his longstanding quest for meaningful proficiency testing in the discipline, as well as his agreement regarding the need for foundational research using agreed upon criteria to test proficiency and reliability.

The Panel unanimously voted to make several recommendations to the full Commission, all of which were accepted and are outlined in Section VI below.

V. COMMISSION OBSERVATIONS: INTEGRITY & RELIABILITY

A. Scientific Research

The Commission makes two threshold observations that should be universally accepted among forensic odontologists and stakeholders in the broader criminal justice community. First, there is no scientific basis for stating that a particular patterned injury can be associated to an individual's dentition. Any testimony describing human dentition as "like a fingerprint" or incorporating similar analogies lacks scientific support. Second, there is no scientific basis for assigning probability or statistical weight to an association, regardless of whether such probability or weight is expressed numerically (*e.g.,* 1 in a million) or using some form of verbal scale (*e.g.,* highly likely/unlikely). Though these types of claims were once thought to be acceptable and have been admitted into evidence in criminal cases in and outside of Texas, it is now clear they have no place in our criminal justice system because they lack any credible supporting data.

After addressing these historical issues, the Commission turned its focus to the remaining questions facing the community. First, can forensic odontologists reliably and accurately identify whether a patterned injury is a human bitemark? Second, if they are able to determine that the patterned injury is a human bitemark, can they reliably and accurately distinguish between patterned injuries made by adults versus those made by children? Third, is there any support for the contention that where the forensic evidence is of high enough quality, a well-trained forensic odontologist can reliably and accurately *exclude an individual* from having been the source of the bitemark?

At the current time, the overwhelming majority of existing research does not support the contention that bitemark comparison can be performed reliably and accurately from examiner to examiner due to the subjective nature of the analysis. While the research is too extensive to repeat in the body of this report (*See* **Exhibits A-G**), one recent study by Drs. Iain Pretty and Adam Freeman was of tremendous concern to the Commission. (*See* **Exhibit B**.) Because the Bitemark Panel spent significant time reviewing the study and consulting with its authors and critics, it is summarized here.

The study, entitled *Construct Validity Bitemark Assessments Using the ABFO Bitemark Decision Tree* ("Freeman/Pretty Study") asked ABFO board-certified Diplomates to review photographs of 100 patterned injuries. The Diplomates were asked to answer the following 3 questions: (1) Was there sufficient evidence to render an opinion on whether injury was a human bitemark? (2) Using the ABFO decision tree as a guide, was the injury a human bitemark? (3) If a human bitemark, did it have distinct, identifiable arches and individual tooth marks?

Thirty-eight ABFO Diplomates completed the whole study and an additional six partially completed the study. The study revealed an enormous spread of decisions among the Diplomates *on the basic question of whether the patterned injury was a human bitemark.* The Diplomates agreed unanimously in only four of the cases. They achieved 90% agreement in eight of the cases.

The inability of ABFO Diplomates to agree on the threshold question of whether a patterned injury constitutes a human bitemark was of great concern to the Commission. Also of significant concern (and discussed extensively at the November 2015 meeting in Fort Worth) is the fact that the Freeman/Pretty Study was not published in a timely manner due to various political and organizational pressures within the ABFO. For many Commissioners who have experience in other areas of forensic science, such a resistance to publish scientific data contradicts the ethical and professional obligations of the profession as a whole, and is especially disconcerting when one considers the life and liberty interests at stake in criminal cases.

B. Lack of Quality Control and Organizational Inflexibility

In addition to the foundational science and research issues described above (as well as in the Exhibits to this report) the Commission noted significant quality control and infrastructure differences between forensic odontology and other patterned and impression disciplines subject to the Commission's jurisdiction. The following is a non- exhaustive list of those issues:

1. There is no ISO-accrediting body (like ASCLD/LAB or ANAB) that offers an accreditation program in bitemark comparison;
2. The criteria for identification published on the American Board of Forensic Odontology (ABFO) website, including the decision tree, was outdated until recently and included the use of terms like "The Biter" and "The Probable Biter." Though the terms were recognized as unsupportable, they remained on the website until the 2016 AAFS meeting when the ABFO Diplomates voted to remove the decision tree and replace it with a new one.

3. There is significant disagreement among ABFO members about how to establish criteria for the identification of bitemarks, and how to test that criteria through research studies;

4. There is no system for outside auditing of the analytical criteria as applied in casework;

5. There is no systemic requirement for peer review or technical review;

6. There is no consistency in the way analytical results are reported;

7. There is no meaningful proficiency testing system; and

8. There is no system for identifying or providing notification of non-conformances, or a method for conducting retroactive case reviews when necessary to protect against miscarriages of justice.

While the ABFO is accredited by the Forensic Specialties Accreditation Board ("FSAB"),[22] it is a voluntary process; certification bodies are invited to participate in FSAB accreditation if they meet basic eligibility requirements."[23] Programs accredited by FSAB vary greatly in certain key areas, such as: "eligibility, use of proficiency tests, practical exercises, training, continuing education, recertification requirements, etc."[24] There are "vast differences in the certification examination processes and essential elements for forensic science disciplines which leads to fragmentation of the various certification programs accredited by the same entity."[25]

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[22] White House Subcommittee on Forensic Science, *Interagency Working Group on Accreditation and Certification, Observations Concerning Certification of Forensic Science Practitioners* at 3 (2013).

[23] Nat's Res. Council, Nat'l Acad. of Scis., *Strengthening Forensic Science in the United States: A PathForward*, (2009) at 209.

[24] http://thefsab.org/accredited.htm

[25] *Id.*

FSAB accreditation standards "are not recognized by a third party or accredited under ISO-17011."[26] As the NAS report noted in Recommendation 7, certification should take into account established and recognized standards, such as those published by ISO.[27] ISO-17024 (Conformity assessment – General requirements for bodies operating certification of persons) describes the necessary standards for organizations that certify individuals. In recommending that all certification bodies achieve ISO-17024 accreditation within 10 years, the White House Interagency Working Group on Accreditation and Certification asserted that accreditation under ISO-17024, "ensures the validity, reliability, and quality of the certification programs."[28] Given all current information available to the Commission, it is unlikely the ABFO would be able to achieve ISO-17024 accreditation for its certification program anytime in the near future.

VI. RECOMMENDATIONS

The Commission recommends that bitemark comparison not be admitted in criminal cases in Texas unless and until the following are established:

1. *Criteria for identifying when a patterned injury constitutes a human bitemark.* This criteria should be expressed clearly and accompanied by empirical testing to demonstrate sufficient inter and intra-examiner reliability and validity when the criteria are applied.

2. *Criteria for identifying when a human bitemark was made by an adult versus a child.* This criteria should be expressed clearly and accompanied by empirical testing to demonstrate sufficient inter and intra-examiner reliability and validity when the criteria are applied

3. Rigorous and appropriately validated proficiency testing using the above criteria.

4. A collaborative plan for case review including a multidisciplinary team of forensic odontologists and attorneys.

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[26] White House Subcommittee on Forensic Science at 4.
[27] *Id.*
[28] Subcommittee on Forensic Science at 4.

Assuming the first two research areas can be addressed sufficiently, the Commission believes follow-up research should focus on the criteria that form the basis for the "exclude" and "cannot exclude" categories contemplated by new decision trees making their way through the ABFO and the Organization for Scientific Area Committees ("OSAC") processes. (*See* **Exhibit J.**) ABFO guidelines should also follow the example of other forensic disciplines by including peer/technical review of cases as well as the development of a model report that provides information to the trier of fact regarding the limitations of the forensic analysis.

The Commission understands these items are already high priorities for the ABFO leadership, and the organization will need to work with other stakeholders (academic institutions, etc.) in implementing the recommendations. To that end, the Commission encourages collaboration and participation between the ABFO, researchers and practitioners.

A. Special Word About Victims of Child Abuse

The Commission understands that victims in bitemark cases are often small children. There is no question that the health and safety of our most vulnerable population must be protected. For this reason, the Commission reiterates that its recommendations do not apply to civil cases involving Child Protective Services, but are limited to those cases in which an individual is accused of a crime and faces the loss of liberty if convicted. The Commission's recommendations for foundational research are focused on what it understands to be the most important issues in child abuse cases. If subsequent published data supports the ability of forensic odontologists to identify human bitemarks reliably and accurately based on defined criteria and to distinguish between the bitemarks of adults and children reliably and accurately, the Commission will revise its recommendations to reflect these developments.

During one of the Bitemark Panel meetings, Commissioners were told that recommending a moratorium on bitemark comparison would "hurt children." The Commission disagrees. First, if anyone should take responsibility for the current state of bitemark comparison, it is the very organization of practitioners that, due to its glacial pace, reticence to publish critical data, and willingness to allow overstatements of science to go unchecked for decades, is facing a barrage of well-founded criticism. As many Texas prosecutors have indicated, no conviction for child abuse or other violent crime should rest solely on bitemark comparison evidence. While the Commission understands and appreciates the important and helpful role forensic science plays in providing justice to victims, we must be vigilant to ensure the science used in criminal cases stands on a solid foundation of research and data, both for the benefit of victims and the accused.

VII. DEVELOPMENTS SINCE FEBRUARY 12, 2016 MEETING

The ABFO held its annual meeting at the AAFS meeting in Las Vegas the week of February 22, 2106. During that meeting, Dr. Adam Freeman was elected President of the organization, and he released a letter to the stakeholder community describing organizational progress shortly after the meeting. (*See* **Exhibit H**.) Some non- exhaustive highlights of developments since the Commission's last meeting are:

1. The old decision tree including the terms "Biter" and "Probably Biter" has been removed from the ABFO website and guidelines. New guidelines were adopted which do not permit for biter identity, and additional guideline revisions are in progress.

2. A research team including Drs. Pretty, Freeman, Wright and Wood has begun working on the Commission's first recommendation regarding foundational research set forth above. An update on that research isexpected within six months.

3. Significant efforts are underway to improve the ABFO proficiency testing and should be adopted in February 2017.

4. An ABFO subcommittee has been established to assist with case reviews to guard against miscarriages of justice. Individual odontologists in and outside of Texas have expressed willingness to assist with these cases.

5. The Bitemark Committee has been charged with the task of developing a mandatory blinded second opinion methodology.

6. The ABFO implemented a bylaws change to allow for changes of standards and guidelines as new information becomes available, and not only at the organization's annual meeting. Dr. Freeman has publicly expressed his commitment to making the ABFO a more nimble and responsive organization. (*See* **Exhibit H**.)

The Commission looks forward to working with the ABFO, the Complainant and other interested stakeholders regarding these and other developments in the weeks and months ahead. This report may be updated to reflect the results of additional research and/or case reviews. Any questions regarding the contents of this report may be directed to the Commission's General Counsel, Lynn Garcia at lynn.garcia@fsc.texas.gov.

EXHIBIT A

October 18, 2015

Harvey Kessler, DDS, MS
Texas Forensic Science Commission
1700 North Congress Ave, Suite 445
Austin, Texas 78701

Dear Dr. Kessler,

The American Board of Forensic Odontology would like to once again thank you for involving us in this Review Panel. We are currently hard at work researching and writing detailed responses to those questions communicated to us in the September 8, 2015 letter. We will have these to your committee in advance of the November 16 meeting.

The American Board of Forensic Odontology does NOT have a list of any Bitemark comparison cases done anywhere in the United States. Although Diplomates may list their casework to verify that they have met our requirements when they recertify, this information has never been saved after it is reviewed. Also, it has never been mandatory that a Diplomate list all their case work, rather just enough to meet the recertification requirements. Thus, the ABFO does not have any data as it relates to any bitemark court testimonies done anywhere in the country at any time. However, the ABFO stands ready to assist your commission and when you are ready will request of our membership that any Diplomate that has been involved in a Texas bitemark comparison case, contact your panel directly at the Texas Forensic Science Commission.

I personally continue to read in the media about "no less than 24 people have been wrongly convicted or indicted on the basis of bitemark evidence". This quote seems to be self-replicating within the media, with no cases ever cited. The Innocence Project letter dated July 22, 2015 used this statistic also and cited two media reports as it source. Knowledge of these "24" individual cases could be beneficial to all involved in this process.

In your letter dated October 7, 2015 a request was made for a memorandum from the ABFO as it related to Dr. Senn's response during the September 16, 2015 Panel meeting in Dallas, Texas. This same request was made directly to Dr. Senn, and it my understanding that he is currently working on such, and will be directly communicating with your committee. I do not see the need to duplicate his efforts, and we will continue to work on the responses to the initial questions from the September 8, 2015 letter.

The American Board of Forensic Odontology has many individuals with diverse experience, perspectives and interest in forensic bitemark analysis. I would first like to recommend any or all of the five of the ABFO Forensic Odontologist that live and work in Texas.

<u>Dr. David Senn, DDS, DABFO</u>
Clinical Assistant Professor at U of T HSC - San Antonio Dental School,
Director of C.E.R.F., the Center for Education and Research in Forensics
A Past President of the American Board of Forensic Odontology
NIST OSAC Forensic Odontology Subcommittee - Vice Chair

<u>Dr. Paula Brumit, DDS, DABFO</u>
Vice President American Board of Forensic Odontology
NIST OSAC Forensic Odontology Subcommittee – affiliate member

<u>Dr Roger Metcalf, DDS, DABFO</u>
Chair of Bitemark Committee of the American Board of Forensic Odontology
Director of the Human ID Lab and Chief Forensic Odontologist for Tarrant County
President of the American Society of Forensic Odontology
NIST OSAC Forensic Odontology Subcommittee - Executive Secretary

<u>Dr Robert Williams, DDS, DABFO</u>
Chief Forensic Odontologist Dallas, Travis and Webb County ME Offices
Research Associate, Center for Human Identification, Dept of Forensic Anthropology, University of North Texas

.<u>Dr Bruce Schader, DDS, DABFO</u>
Executive Director American Society of Forensic Odontology

In addition, the following individuals from other areas of the United States all would be excellent additions to your commission.

Mark Bernstein, DDS. DABFO - University of Louisville School of Dentistry,
Diplomate of Oral and Maxillofacial Pathology
Diplomate of the American Board of Forensic Odontology

Robert Barsley, DDS, JD, DABFO
A Past President of the American Academy of Forensic Science
A Past President of the American Board of Forensic Odontology
Professor LSU HSC School of Dentistry Director of Oral Health Resources, Community and Hospital Dentistry, LSU Health Sciences Center School of Dentistry
NIST OSAC Forensic Odontology Subcommittee - Chair

Robert Dorion, DDS, DABFO
Vice President 2014-15 of the American Academy of Forensic Science
A Past Board of Directors member American Academy of Forensic Science
A Past President of the American Board of Forensic Odontology
Course Director Forensic Dentistry Program McGill University School of Dentistry
Edited the only stand-alone book on Bitemark Evidence

Robert Wood, DDS, MSC, PhD, FRCD(c), DABFO
Associate Professor, Faculty of Dentistry, University of Toronto
Chief Forensic Dentist, Ontario Forensic Pathology Services, Office of the Chief Coroner, Ontario, Canada

It is my understanding that the ABFO will have several individuals present at the November 16, 2015 scheduled meeting. All these individuals would be happy to participate in the discussions that day. They would appreciate it if they could have notice of the planned discussions besides the Freeman/Pretty Study so that they could prepare for them.

Sincerely,

Gary Berman DDS DABFO
President – American Board of Forensic Odontology

November 10, 2015

Texas Forensic Science Commission
1700 North Congress Ave, Suite 445
Austin, Texas 78701

Dear Dr. Kessler,

In your September 8, 2015 letter to the American Board of Forensic Odontology, you requested ABFO assistance with any data, scientific studies, or peer-reviewed articles available to the ABFO which pertain to the four questions presented in the recently filed complaint from the Innocence Project.

A panel of diplomates from the ABFO compiled the following information in regard to those questions. Please be reminded that the included articles and citations do not necessarily represent the opinions or positions held by the ABFO. Furthermore the ABFO cannot guarantee the continuing veracity or validity of these articles and/or studies, some of which were published many years ago.

Due primarily to the time constraints involved in the process of gathering the materials, we ask that you please excuse the different formats for parts of some answers.

Sincerely,

Gary Berman DDS, DABFO
President – American Board of Forensic Odontology

Question 1: Is human dentition unique?

In general, the answer to the broad question is yes:

In Senn & Stimson's book, Chapter 9 – Tabor and Schrader provide excellent discussion of the statistical and mathematical models for the statistical improbability of having two individuals with the same combination of teeth missing and present/restore and unrestored.

There are many other features than comprise the dentition: arch shape and circumference, arch width, vertical height. These features were not included in the statistical analysis above.

A cursory review of orthodontic literature results in a plethora of variation. For example just recently from the AJO-DO:

- Extreme variations in the shape of mandibular premolars**, sample 29,2006**
- Longitudinal alteration of the occlusal plane and development of different dentoskeletal frames during growth, sample 102, 2008
- Longitudinal evaluation of dental arch asymmetry in Class II subdivision malocclusion with 3-dimensional digital models, sample 706, 2014
- Morphologic, functional, and occlusal characterization of mandibular lateral displacement malocclusion, sample 116, 2010
- Submorphotypes of the maxillary first molar and their effects on alignment and rotation, sample 175, 2014
- Tooth-wear patterns in subjects with Class II Division 1 malocclusion and normal occlusion, sample 310, 2010
- Tooth-wear patterns in adolescents with normal occlusion and Class II Division 2 malocclusion, sample 165, 2010
- Variation in maxillary and mandibular molar and incisor vertical dimension in 12-year-old subjects with excess, normal, and short lower anterior face height, sample 344, 1994

In Mary Bush's affidavit, she notes under #16 that "It is important to note that for purposes of our research, the dentition refers to the biting surface of the front teeth. The dentition does not refer to the universe of identifying information that may be drawn from the entire mouth, which in a typical adult involves 32 teeth with five sides per tooth. …….thus our research undermines the assumption of uniqueness of the human dentition recorded in the skin; it does not purport to investigate or disprove that human teeth, in the aggregate are indistinguishably similar."

From D. Sweet and IA Pretty: A look at forensic dentistry – Part 2: Teeth as weapons of violence- identification of bitemark perpetrators: “The sizes, shapes and pattern of the biting edges of the anterior teeth that are arranged in the upper and lower dental arcades are thought to be specific to that individual. This is mainly caused by the sequence of eruption of anterior and posterior teeth. Canines must force their way into the dental arch, which often result in bodily movement, rotation, and displacement of other teeth. The resulting configuration of the dentition produces an identifiable pattern that may be compared with similar patterns found on bitten objects to determine the likelihood that a specific individual has left their calling card. (later) In situations where sufficient detail is available, it may be possible to identify the biter to the exclusion of all others”

<u>--More specifically, the implied question is "are the biting surfaces of the dentition unique":</u>

Franco et al, “The uniqueness of the human dentition as forensic evidence: a systematic review on the technological methodology”, 2014

- Twelve articles selected published between 1982 and 2013
- Based on this review, the uniqueness of human dentition was not scientifically proven.
- Cited lack of 1. Power analysis for the stratification and size calculation of the studied sample. 2. Intra and inter examiner calibrations. 3 advanced 3D data registration, 4. Automated landmarking, 5. Validated 3D shape comparison software and 6. Statistical methods and quantifications for data comparison.

Kieser, et al, "the Uniqueness of the Human Anterior Dentition: A Geometric Morphometric Analysis” Journal Forensic Science, May 2007, Vol 52, No3

- Looked at 50 post orthodontic models ages 17-20
- Results tabulated for 33 maxillary and 48 mandibular arches
- Study showed a clear difference in the anterior "dental arcade" both in shape and form.
- The main variation is related to general changes in the depth and width of the arcades. These differences are greater than those due to the relative position of teeth or their individual morphology.
- However, when individuals with very similar arcade shape were superimposed, differences in tooth orientation were still evident.
- Only examined occlusal surfaces and sample was small.
- From the abstract: “Procrustes superimposition between the two individuals located most closely (0.0444) and the two most separated (0.1567) along the

first axis of relative warp analyses show that individuals are not only differentiated by the relative position of their teeth but also by their arch shape. In conclusion, it appears that the incisal surfaces of the anterior dentition are in fact unique."

- From the second from last paragraph in the discussion, ""Hence, it can be said that in the present sample, specifically selected to have lower levels of individuality than the general population, there are no two individuals with identical tooth morphology."

Johnson et al, "Replication of known dental characteristics in porcine skin: emerging technologies for the imaging specialist", http://epublications.marquette.edu/cgi/viewcontent.cgi?article=1043&context=dentistry_fac ; NIJ 2010-DN-BX-K176 2014

- Initial investigations substantiated results of Kieser et al where uniqueness was found of the anterior teeth in both arches. Geometric morphometric analysis of similar dentitions as a result of orthodontic treatment, focused on morphology and spatial locations of anterior dentitions in both arches that demonstrated subtle differences. As reported in Rawson's initial study as well, certain characteristics such as shape, number, mesio-lingual rotations and restorations were found to be interrelated.
- This study used additional data by measuring angles formed by intersecting extensions of a line drawn on the incisal edge of the 4 anterior teeth in each arch. Markers were placed directly opposite of each other on the mesial and distal outline of the teeth in a recognizable patterned injury. Intersecting line angles as measured across the incisal edge of the teeth, intersected with adjacent incisal lines of other anterior teeth at measurable angles.
- Prior published studies demonstrated at least 7 characteristics of the human dentition that can be quantified. This study developed a data set quantifying 8 dental characteristics in two and three-dimensions.
- The initial quantification of width, damage, angles of rotation, missing teeth, diastema characteristics (spaces) and arch length were augmented by also the displacement of the anterior teeth (labial or lingual) from the normal physiologic dental arch form. A three-dimension study of width and incisal position of the anterior teeth on the horizontal (Z) plane supplemented the data.
- A method of establishing tooth rotation provided an additional method of analysis. Utilizing the intersecting angles formed by the incisal lines, enabled the measurement of 6 angles of rotation and the intersecting angle formed by the extension of those incisal lines remains constant.

Question 2: If human dentition is unique, is human skin capable of accurately recording and maintaining unique features of human dentition?

Skin in general is not a reliable impression material when compared to the typical dental impression materials which are accurate to 100ths of a mm when crowns and appliances are fabricated. However, skin is in some instances capable of replicating patterns created by teeth and in some cases shows unique features belonging to the dentition that created it. The research in this area demonstrates that there is a broad range of biomechanical effects on bitemark patterns created in skin under laboratory conditions. Currently there are only two studies using live human subjects. It has been extremely difficult to get Institutional Review Board permission for live human testing. Therefore most studies have used other substrates for testing of skin properties, most notably live porcine skin and human cadaver skin. There are problems with both of these models. The most important feature in any of these studies for the purpose of bitemark research is that the tissue is vital at the time the injury is inflicted. There is a need for more research in this area to answer this question more definitively.

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Replication of Known Dental Characteristics in **Porcine Skin:**
Emerging Technologies for the Imaging Specialist
NIJ 2010-DN-BX-K176
Award period October 1, 2010 – September 30, 2013
Johnson, LT1; Radmer, TW1; Jeutter, DC3; Corliss, GF3; Stafford, GL1; Wirtz, TS1; Groffy, RL4; Thulin, JD2; Ahn, KW2; Visotky, AD2
This research serves as a template, refining the ability to scientifically calculate that an unknown bite mark replicated in skin can correlated with probability to a member of the population data base. This study demonstrates that it is sometimes possible to replicate patterns of human teeth in porcine skin and determine scientifically, that a given injury pattern (bite mark) belongs to a very small proportion of our population data set, e.g. 5%, or even 1%. Predictably, building on this template, with a sufficiently large database of samples reflecting the diverse world population, a sophisticated imaging software application requiring operators inserting parameters for measurement and additional methods of applying forces for research need further investigation. This is applied science for injury pattern analysis and is only foundational research.

1974 Millington PF. J Forensic Sci Soc; 14(3):239-40 Histological studies of skin carrying bitemarks

1975 Whittaker DK. Int Dent J; 25(3):166-71 Some laboratory studies on the accuracy of bitemark comparisons. Author studied bites in wax and on pig skin. Found that those on pig skin were less reliable than those on wax in terms of biter identification.

2009 Bush MA, Miller RG, Bush PJ, Dorion RBJ. Biomechanical Factors in Human Dermal Bitemarks in a Cadaver Model J Forensic Sci, 2009; 54(1):167-76.

2010. Bush MA, Thorsrud K, Miller RG, Dorion RBJ, Bush PJ. The Response of Skin to Applied Stress: Investigation of Bitemark Distortion in a Cadaver Model. J Forensic Sci, January 2010, Vol. 55, No. 1

2010 S.L. Avon, et al., Error rates in bite mark analysis in an in vivo animal model, Forensic Sci. Int. (2010), doi:10.1016/j.forsciint.2010.04.016 Showed error rates of examiners using a live pig model

2011 Bush MA, Bush PJ, Sheets HD. A study of multiple bitemarks inflicted in human skin by a single dentition using geometric morphometric analysis. Forensic Science International (2011), doi:10.1016/j.forsciint.2011.03.028

AAFS Atlanta February, 2012
F30 A Study of Bitemark Characteristics in Live Human Subjects
Kenneth P. Hermsen, DDS*, Creighton University, School of Dentistry,
2500 California Plaza, Omaha, NE 68178; Eric S. Wilson, DDS*, PO Box
50, Cole Camp, MO 65325

Eilers, Senn et al- study with mechanical bites on living unanesthetized human skin-preliminary study, unpublished 2013

Effects of skin elasticity on bite mark distortion
Lewis C, Marroquin LA
Forensic Sc Int 2015 Sep 21:257:293-296.doi: 10.1016/j.forsclint.2015.07.048 [epub ahead of print PMID 16451773

Clinical and histopathological examination of experimental bite marks in-vivo
Avon SL, Mayhall JT, Wood RE
J Forensic Odontostomatol 2006 SDec:24(2):53-62
PMID 17175837 (Free Article)

Naru AS.
Forensic Sci Rev. 1997 Dec;9(2):123-39.Review
PMID: 2407108

The Skin as a repository and masker of evidence
Perper JA, Menges DJ.
Am J Forensic Med Pathol. 1990 Mar;11(1):56-62.Review
PMID: 2407108

The use of videotape to demonstrate the dynamics of bitemarks
West, MH, Frair J
J Forensic Sci. 1989 Jan;34(1):88-95
PMID 2918292

Transillumination in bitemark evidence
Dorion RB
J Forensic Sci. 1987 May:32(3):690-7
PMID 3598518

Discussion of “Photographic techniques of concern in metric bite mark analysis”
Ebert JL, Campbell HR Jr.
J Forensic Sci. 1985 Jul;30(3):599-602. No abstract available
PMID 4031799

Bite mark lesions in human Skin
Jakobsen JR, Keiser-Nielsen S.
Forensic Sci Int. 1981 Jul-Aug;18(1):41-56. No abstract available
PMID 7250868

Two bitemarks on assailant. Primary link to homicide conviction
Irons F, Steuterman MC, Brinkhous W
Am J Forensic Med Pathol. 1983 Jun;4(2):177-80
PMID 6859006

Effects of skin elasticity on bite mark distortion
Lewis C, Marroquin LA
Forensic Sci Int. 2015 Sep 21:257:293-296/j.forsclint.2015.07.048 [Epub ahead of print]
PMID 26451773

Bite Mark Lesions in Human Skin
Jan R Jakobsen and Saren Keiser-Nielsen
Forensic Science International, 18 (1981) 41-55 Elsevier Sequoia S.A., Lausanne 41

The Skin as a repository and masker of evidence.
Perper JA, Menges DJ.
Am J Forensic Med Pathol. 1990 Mar:11(1):56-62.Review.
PMID 2407108

A Method for Mathematically Documenting Bitemarks
CODEN: JFSOAD
ASTM License Agreement
McGivney, J. Barsley, R
ISSN:0022-1198

<u>Question 3: Are forensic dentists able to associate a human dentition with a bitemark in a reliable manner (i.e generating reproducible results between experts or with a single expert over time)?</u>

The research shows that the association of human dentition to a bitemark is strongly dependent on the quality of evidence and the specificity of an individual such as unusual arch alignment patterns and/or missing or rotated teeth. Bitemark evidence, of high evidentiary value, shows uniformity between experts in their results. Further, working in a construct with 1) only defined, high quality evidence and, 2) where linkage is limited to exclude or cannot exclude, will only strengthen reliability.

Avon, 2007 p326 from from Dorion RBJ. Bitemark Evidence: A Color Atlas and Text, 2nd edition,. CRC Press, Boca Raton, Fl., 2011.

Avon SL. An In Vivo Model For The Study Of The Accuracy Of Human Bite Mark Analysis: Development Of The System And Testing The Experts [dissertation]. Univ. of Toronto, Ontario. 2007.

Bernitz H, vanHeerden FP, Solheim T, Owen JH. A Technique to Capture, Analyze, and Quantify Anterior Teeth Rotations for Application in Court Cases Involving Tooth Marks. J. Forensic Sci. 2006:51:3:624-629.

Bitemark 2000 p571-584 from Dorion RBJ, Bitemark Evidence, editor, Marcel Dekker, (CRC Press), New York, NY, 2005.

Bush MA, Bush PJ, Sheets HD. A Study Of Multiple Bitemarks Inflicted In Human Skin By A Single Dentition using Geometric Morphometric Analysis. Forensic Science International. 2011:211:1–8.

De las Heras SM, Tafur D. Comparison Of Simulated Dermal Bitemarks Possessing Three-Dimensional Attributes To Suspected Biters Using A Proprietary Three-Dimensional Comparison. Forensic Sci International. 2009:1:1-3:33-37.

Dorion, Bitemark, 2000 p.323-324 from Dorion RBJ. Bitemark Evidence: A Color Atlas and Text, 2nd edition,. CRC Press, Boca Raton, Fl., 2011.

Dorion,B.J., Bitemark Evidence, G12 presented at the AAFS Orlando 2015 meeting

Freeman, Adam J., DDS, and Iain A. Pretty, DDS, PhD
G14 Construct Validity of Bitemark Assessments Using the ABFO Bitemark Decision Tree – Presented at the AAFS Odont Section 2015.

Johnson LT, Radmer TW, Jeutter DC, Stafford GL, Thulin J, Wirtz T, Corliss G, Ahn KW, Visotky A, Groffy RL. Replication of Known Dental Characteristics in

Porcine Skin: Emerging Technologies for the Imaging Specialist. NIJ 2010-DN-BX-K176 Award. Marquette University e-Publications. 2014.

Layton, JJ. Identification from a Bite Mark in Cheese. Journal of the Forensic Science Society, 1966:**6:**2:76-80.

Naru A, Dykes E. Digital Image Cross-Correlation Technique For Bite Mark Investigations. Science & Justice 1997:37:4:251-258.

Sheets HD, Bush MA. Mathematical Matching Of A Dentition To Bitemarks: Use And Evaluation Of Affine Methods. Forensic Science International. 2011:207:111–118.

Sheets HD, Bush PJ, Bush MA. Bitemarks: Distortion and covariation of the maxillary and mandibular dentition as impressed in human skin. 2012:223:1-3:202–207.

Sognnaes RF, Rawson RC, Gratt BM, Nguyen VBT. Computer Comparisons of Bitemark Patterns in Identical Twins. JADA. 1982:105:9:449-451.

Tuceryan M, Li F, Blitzer HL, Parks ET, Platt JA. A Framework for Estimating Probability of a Match in Forensic Bite Mark Identification**.** J Forensic Sci. 2011:56:1:

Whittakera DK, Brickleyb MR, Evansb L, A Comparison Of The Ability Of Experts And Nonexperts To Differentiate Between Adult And Child Human Bite Marks Using Receiver Operating Characteristic (ROC) Analysis. Forensic Science International 1998:92:11–20.

Bite Mark Analysis: Additional Investigations of Accuracy and Reliability

George A. Gould, DDS, 6101 Puerto Drive, Rancho Murieta, CA 95683; Nicole T. Pham, DDS*, and David R. Senn, DDS; University of Texas Health Science Center at San Antonio, Dental School, 7703 Floyd Curl Drive, Mail Code 7919, San Antonio, TX 78219-3900*

The goals of this project are 1) to determine if odontologists of varying experience can select the correct biter from a group of suspects, 2) to evaluate and compare bite mark analysis on human skin in a limited but more extensive population, and 3) to assess the range of opinion in bite mark interpretation by examiners in the current study.

This study is the next logical step of a pilot study presented at the 2004 AAFS meeting by Gould and Cardoza. This study will impact the forensic community by providing information to support or question the concept that bite mark analysis can offer objective, reliable and credible sciencebased opinion. The study further examines the importance of using quality evidence, skillful interpretation, and trained forensic odontologists.

Background: Bite mark evidence has been accepted by the North American forensic community and legally admissible in courts in the

United States of America. It has played an important part in the successful prosecution in numerous criminal cases. Nevertheless, there are critics who have questioned the scientific validity of bite mark analysis. This constructive skepticism about the process and how forensic experts derive bite mark opinions is healthy and welcome. It is also perceived as a tool in helping to excel deliberately and to strengthen the process of bite mark analysis.

Introduction: Bite marks are indicative of violence whether made by the perpetrator during an assault or the victim in self-defense. To recognize a human bite mark is an important criterion in an initial investigative phase in deceased or living human victims. Therefore, it is critical to understand and follow the protocol for data collection and preservation of bite mark evidence. If these steps are followed, quality evidence may be available to maximize accurate evidentiary analysis.

Are evidentiary opinions based on the same evidence similar among forensic odontologists? This experiment is designed to provide insight to the stated question. The accurate interpretation of bite mark evidence is essential. The implications for the lives and liberty of the accused are an enormous responsibility not to be taken lightly by competent and experienced investigators. This study explores the relationship between quality evidence and accurate interpretation of bite marks in reaching forensic evidentiary opinion. If quality bite mark evidence is properly analyzed, can trained odontologists assist triers of fact to make appropriate decisions and judgements.

What is the literature on validation studies of bitemark analysis such as blind trials, concordance rate between and among examiners, correlation with DNA studies, witnesses and/or video recordings of incident?

Dorion, R. B. J., (2011) Bitemark Evidence. CRC Press: Boca Raton
Chpt 29, Case Law, Barsley, RE; Testing the Expert, 538-539.
1983 case, Louisiana v Stokes, trial judge requires prosecution odontologist to use teeth impressions of five different persons (one the defendant) for comparison with photographs taken of the bite-marks on the victim. This might be considered a "blind trial".

Chpt 10, Bitemarks as Biological Evidence, Sweet, D; DNA Analysis, 136-144. Discusses whether suspect might be implicated by DNA evidence or excluded by such evidence. Several case examples presented.

Chpt 18, Human Bitemarks; Dorion, RBJ; DNA, 272. Discussion of bitemark case where DNA was found at site that matched suspect but suspect was not the biter. Author states "DNA is but a fragment of the puzzle--not its sole solution."

What empiric studies of bitemark analysis error rates exist in the literature?

1975 -Whittaker, DK; Some laboratory studies on the accuracy of bitemark identification, *Int Dent J*, 25:166-171.

Abstract: Bite marks in wax and in pig skin were compared with study models of the subject making the bite. Photographs, impressions and measurements of the bites were used. Bites in wax could be readily identified especially if measurements were made on photographs but identification from bites in non-vital pig skin was more unreliable. It is suggested that similar difficulties may be encountered in the assessment of bites in human skin.

1998 - Whittaker, DK, Brinkley, MR, Evans, L; A Comparison of the Ability of Experts and Non-experts to Differentiate Between Adult and Child Human Bite Marks Using Receiver Operating Characteristic (ROC) Analysis, *Forensic Science International*, 92(1):11-20.

Abstract: Fifty color prints of human bite marks were sent to 109 observers who were asked to decide using a six point rating scale, whether the marks had been produced by the teeth of an adult or a child. The observers consisted of accredited senior forensic dentists, accredited junior forensic dentists, general dental practitioners, final year dental students, police officers, and social workers. The results were compared against a "gold standard" which was the actual verdict from the case.

2001 – Arheart, KL, Pretty, IA; Results of the 4th ABFO Bitemark Workshop—1999, *Forensic Science International*, 124:104-11.

Abstract: Thirty-two certified Diplomates of the American Board of Forensic odontology (ABFO) participated in a study of the accuracy of bitemark analysis.

2006 – Bowers, CM; Problem-based analysis of bitemark misidentifications: The role of DNA. *Forensic Science International*, 159:S104-S109.

Abstract: Article discusses bitemark methodology and it suggests that it is sorely lacking in rigorous scientific testing. Contra to this fact, the bitemark legal case law is surprisingly strong and is used as a substitute for reliability testing of bite mark identification.

2010 – Avon, SL, Victor, C, Mayhall, JT, Wood,RE; Error rates in bite mark analysis in an in vivo animal model, *Forensic Science International*, 201:45–55.

Abstract: Article discusses the reliability of comparative forensic disciplines is description of both scientific approach used and calculation of error rates in determining the reliability of an expert opinion.

2007 – Pretty, IA; Development and validation of a human bitemark severity and significance scale, *Forensic Sci*, 52:687-91.

Abstract: Numerous efforts have been made to develop a consistent manner to describe bite injuries. A novel index, relating severity to forensic significance, was developed. A text version and accompanying visual index were produced and distributed (via the web) to three groups: odontologists, forensic pathologists, and police officers. A total of 35 bitemarks were assessed and rated using the new index. The index shows promise as a universal means of describing bite injuries between professionals concerned with their detection and analysis.

What is the literature on quantitative measures, measurement imprecision and uncertainty of bite-mark analysis including but not limited to individual tooth measurements and total pattern measurements? What is the literature on reproducibility between examiners, between institutions and by the same examiner over time in blinded and double blinded trials?

1960 - Fearnhead RW; Facilities for forensic odontology, *Med Sci Law*, 1:273-77.
Abstract: Describes the use of hand drawn acetate overlays. Draws the conclusion that "evidence which involves the identification of a person by tooth-marks left as bruises in flesh should never be admitted". Describes simple experiment. One of the first papers to question the use of bitemark evidence based upon the reliability of the technique.

1966 - Layton, JJ; Identification from a bitemark in cheese, *J Forensic Sci Soc*, 6:76-80.
Abstract: A bitemark in cheese found at a crime scene. Control bitemark made in similar cheese by the suspect and twenty points of similarity are discussed. Suspect admitted guilt. States that BMs can never be as positive as fingerprints.

1968 - Furness J; A new method for the identification of teeth marks in cases of assault and homicide, *Br Dent J*, 124(6):261-7.
Abstract: Paper describes the inking of the occlusal surfaces of the teeth which are then photographed and placed on white board. Lines of comparison are drawn with photographs of the injury. Technique is still used today for court exhibits depicting bitemark comparisons.

1971 - DeVore DT; Bitemarks for identification? A preliminary report, *Med Sci Law*, 11(3):144-5.
Abstract: Author used ink models to place marks on living volunteers and cadavers. Photographs of the marks were taken in several body positions. Skin from the cadavers bearing the ink was excised. Paper concludes that there is a large margin of error in using bitemark photographs and unsecured excised skin. States that the exact position of the body when bitten must be known and replicated. A useful study. Little attention has been paid to this paper that encourages caution when examining bite injuries

1973 - Stoddart TJ; Bitemarks in perishable substances. A method of producing permanent models, *Br Dent J*, 135(6):285-7.
Abstract: A method for producing accurate models of bitten materials, silicone impression material is recommended. Technique described is still applicable today.

1973 - Harvey et al; Bite-marks the clinical picture; physical features etc., *Int J leg Med*, 1973;(8):3-15.

Abstract: First paper to show stress/strain curve for skin. Remarkable biting experiment on live volunteer with tissue specimens taken. Paper focuses on 'suckling' as a factor.

1974 - Marshall W; Bitemarks in apples - forensic aspects ,*Criminol*, 9(32):21-34.
Abstract: Paper describes the stability and usefulness of bites in a variety of different types of apple.

1974 - Jonason CO, Frykholm KO, Frykholm A; Three dimensional measurement of tooth impression of criminological investigation, *Int J Forensic Dent*, 2(6):70-8.
Abstract: Use of a stereomicroscope to measure the three dimensional aspects of bitemarks. Later repeated using scanning electron microscopy.

1974 - Barbanel JC, Evans JH; Bitemarks in skin - mechanical factors, *J Forensic Sci Soc,* 14(3):235-8.
Abstract: Describes the mechanical factors used to produce a bite, including tongue pressure and suction. States that the properties of particular skin area bitten may affect the appearance of a bitemark. Clear and concise coverage of the topic that has not been addressed since.

1974 - MacFarlane TW., MacDonald DG, Sutherland DA; Statistical problems in dental identification, *J Forensic Sci Soc*, 14(3):247-52.
Abstract: Discusses the issue of the individuality of the human dentition and describes an experiment to determine this. Authors conclude that their preliminary data supports the notion that human teeth are unique to an individual level. Study looked at incidence of certain dental traits in the anterior dentition. N=200.

1975 - Solheim T, Leidal TI; Scanning electron microscopy in the investigation of bitemarks in foodstuffs, *Forensic Sci*, 6(3):205-15.
Abstract: In this study students with no obvious irregularities on their anterior teeth were asked to bite various foodstuffs. Using SEM the marks were analysed and the authors concluded that as many individual characteristics were visible the technique was useful in forensic investigations. An interesting technique, although infrequently used in case work.

1975 -Whittaker DK; Some laboratory studies on the accuracy of bitemark comparisons, *Int Dent J*, 25(3):166-71.
Abstract: Studied bites in wax and on pig skin. Found that those on pig skin were less reliable than those on wax in terms of biter identification. Highest accuracy found was 76%. Extrapolates that bites on human skin may be similarly unreliable; offers a warning that more research is required. Highly cited paper - often regarded as one of the first attempts to validate the science of bitemark analysis. Warning went unheeded

1975 -Whittaker DK, Watkins KE, Wiltshire J; An experimental assessment of the reliability of bitemark analysis, *Int J Forensic Dent*, 3:2-7.

Abstract: Same paper as described above - republished with some editorial differences and apparently two new authors.

1979 - Rawson RD, Bell A, Kinard BS, Kinard JG; Radiographic interpretation of contrast-media-enhanced bite marks, *J Forens Sci*, 24(4):898-901.
Abstract: Describes a techniques of radiographing soft -tissue that has been removed from cadavers. Study used postmortem bites.

1981 - Sognnaes, RF, Rawson, RD, et al.; Computer Comparison of Radiographic Bite-Mark Patterns in Identical-Twins, *J Forensic Sci Soc*, 21(2):144-144.
Abstract: Not available.

1982 - Sognnaes RF, Rawson RD, Gratt BM, Nguyen NB; Computer comparison of bitemark patterns in identical twins, *JADA*, 105(3):449-51.
Abstract: Using computer technology and radiographic bitemark analysis the authors conclude that occlusal arch form and individual tooth positions, even in identical twins are in fact unique. This paper is frequently cited as evidence of dental "uniqueness". Highly cited paper, frequently used as part of the dental uniqueness argument.

1983 - Ligthelm AJ, de Wet FA; Registration of bitemarks: a preliminary report, *J Forens Odontstomatol*, 1(1):19-26.
Abstract: Used bites on sheep to investigate methods of recording bitemarks. Utilized SEM to compare back to the human volunteers who bit the sheep.

1984 - Krauss TC; Photographic techniques of concern in metric bite mark analysis, *J Forens Sci*, 29(2):633-8.
Abstract: Author advises the use of a rigid ruler for scale, proper camera positioning in relation to the scale, and a method to evaluate the distortion in a two-dimensional print that records a three-dimensional object is suggested. Disregarding these.

1984 - Rawson RD; Statistical evidence for the individuality of the human dentition, *J Forens Sci*, 29(1):245-53.
Abstract: A general population sample of bite marks in wax was used to determine how unique bites are. Authors conclude that the analysis confirms the unique nature of human bites. Seminal paper, but incorrectly assumed that tooth position is uniformly distributed and not correlated. Used the product rule to calculate probability. Refuted by Bush et al, 2011.

1984 - Fellingham SA, Kotze TJ, Nash JM; Probabilities of Dental Characteristics, *J Forensic Odonto-Stomatology*, 2(2):45-52.
Abstract: Combination review and study of statistical probability of dental configurations. Found 4% match rate in two out of three populations studied.

1986 - Rawson RD, Vale GL; Analysis of photographic distortion in bitemarks: a report of the bitemark guidelines committee, *J Forens Sci*, 31(4):1261-8.
Abstract: States that some degree of distortion is found in all bitemarks. A method of analyzing the distortion is presented. Recommend a 90o angle for bitemark photography.

1986 - Rawson RD, Vale GL, Sperber ND, Herschaft EE, Yfantis A; Reliability of the Scoring System of the American Board of Forensic Odontology for Human Bite Marks, *J Forens Sci*, 31(4):1235-60.
Abstract: The various methods of determining the validity of the scoring guide are presented with statistical data generated from scores reported by recognized forensic science experts. States that this paper represents the first truly scientific approach to bitemark analysis. Emphasize the need for peer review. The paper was ultimately disregarded as overly complex and the system never gained credibility with forensic dentists.

1988 - Hyzer WG, Krauss TC; The Bite Mark Standard Reference Scale--ABFO No. 2, *J Forensic Sci*, 33(2):498-506.
Abstract: The ABFO scale is now universally adopted by not only forensic dentists but also many other forensic professionals. This paper describes the design and constructional features of the scale and offers guidelines for its effective application to bite mark photography. Paper describes an important tool in BM investigations.

1988 - Vale GL, Rawson RD; Discussion of "Reliability of the scoring system of the ABFO for human bitemarks", *J Forensic Sci*, 33(1):20.
Abstract: A "back-track" from the scoring system, advising caution when using the index and recommending more research. Brought to an end the point system - no further work was carried out.

1990 -West MH, Barsley RE, Frair J, Seal MD; The use of human skin in the fabrication of a bite mark template: two case reports, *J Forensic Sci*, 35(6):1477-85.
Abstract: In this article skin was used as a template for the reproduction of a bite. In one case the victim's skin was used; in the other, the skin of a anatomically similar person was used. The use of inked dental casts, photography, and transparent overlays significantly reduced the errors common to analysis of bite marks in these highly curved areas. Novel technique although not well accepted.

1991 - Dailey JC; A practical technique for the fabrication of transparent bite mark overlays, *J Forensic Sci*, 36(2):565-70.
Abstract: A quick, inexpensive, and accurate technique for generating transparent overlays, using office photocopy machines, for use in bite mark case analysis is presented. Photocopy technique was the 1st attempt to produce an objective overlay with precision.

1994 - Wood RE, Miller PA, Blenkinsop BR; Image editing and computer assisted bitemark analysis: a case report, *J Forensic Odont*, 12(2):30-6.
Abstract: Three different approaches for comparison with the bitemark photograph were utilized: comparison with radiographs of amalgam-filled impressions of dental casts, a transparent overlay technique and comparison with photographs of a simulated bitemark inked onto the hand of a volunteer.

1995 - Nambiar P, Bridges TE, Brown KA; Quantitative forensic evaluation of bite marks with the aid of a shape analysis computer program: Part 1; The development of "SCIP" and the similarity index, *J Forensic Odont*, 13(2):18-25
Abstract: In this study, an interactive shape analysis computer program ("SCIP"-Shape Comparison Interactive Program) has been employed in an attempt to derive experimentally a quantitative comparison, in the form of a Similarity Index (S.I.), between the "offender's" teeth and the bite marks produced on a standard flat wax form.

1995 - Nambiar P, Bridges TE, Brown KA; Quantitative forensic evaluation of bite marks with the aid of a shape analysis computer program: Part 2; "SCIP" and bite marks in skin and foodstuffs, *J Forensic Odont*, 13(2):26-32.
Abstract: In this study, "SCIP" was employed in an attempt to quantify the comparison, in the form of the Similarity Index (S.I.), between the "offender's" teeth and the bite marks produced on foodstuffs and on human skin, under experimental conditions.

1996 - Naru AS, Dykes E; The use of a digital imaging technique to aid bite mark analysis, *Science & Justice*, 36(1):47-50.
Abstract: Describes the use of a computer based overlay technique and uses a case example to illustrate the method.

1997 - Naru AS, Dykes E; Digital image cross-correlation technique for bite mark investigations, *Science & Justice*, 37(4):251-8.
Abstract: Describes the production of a complex computer program for assessing bitemarks. Describes a series of experiments to validate the system.

1997 -Williams RG, Porter BE; Forensic dentistry. Documentation of bite-mark evidence using multiple computer-assisted techniques, *J Oklahoma Dent Assoc*, 88(2):29-30.
Abstract: Describes a computer technique - however describes using a pencil to highlight the incisal edges prior to scanning - subjective?

1998 - Sweet D, Parhar M, Wood RE; Computer-based production of bite mark comparison overlays, *J Forensic Sci*, 43(5):1050-5.
Abstract: This paper describes this technique to enable the odontologist to produce high-quality, accurate comparison overlays without subjective input.

1998 - Sweet D, Bowers CM; Accuracy of bite mark overlays: a comparison of five common methods to produce exemplars from a suspect's dentition, *J Forensic Sci*, 43(2):362-7.
Abstract: Five common overlay production methods were compared using digital images of dental study casts as a reference standard.

1998 -Whittaker DK, Brickley MR, Evans L; A comparison of the ability of experts and non-experts to differentiate between adult and child human bite marks using receiver operating characteristic (ROC) analysis, *Forensic Sci Int*, 92(1):11-20.
Abstract: Fifty colour prints of human bite marks were sent to 109 observers who were asked to decide using a six point rating scale, whether the marks had been produced by the teeth of an adult or a child. Non-experts had similar performance to experts.

1999 - McGivney, J, Barsley, RE; A method for mathematically documenting bitemarks, *J Forensic Sci*, 44(1): 185-186
Abstract: Proposed method paper.

2001 - Arheart, KL, Pretty, IA; Results of the 4th ABFO Bitemark Workshop-1999, *Forensic Science International*, 124(2-3):104-111.
Abstract: Reports results of an ABFO blind study workshop using ROC analysis. Paper has contradictory language stating that forensic pattern analysis is subjective and not an exact science, but also that bitemark examination is an accurate technique. The results as described can be interpreted in several ways.

2001 - Kouble, RF, Craig, GT; Comparisons between direct and indirect techniques for bite mark analysis, *J Dent Research*, 80(4):1179.
Abstract: Method paper.

2001 - Pretty IA, Sweet D; The scientific basis for human bitemark analyses – a critical review, *Science & Justice*, 41(2): 85-92.
Abstract: Much cited review paper.

2001 - Pretty, IA, Sweet, D; Digital bite mark overlays - An analysis of effectiveness, *J Forensic Sci,* 46(6):1385-1391.
Abstract: One of the few papers addressing error rates. Used a pigskin model and reported sensitivity and specificity values against a known gold standard. Best practices were employed with overlays provided to the examiners.

2001 - Rothwell, BR, Thien, AV; Analysis of distortion in preserved bite mark skin, *J Forensic Sci*, 46(3): 573-576.
Abstract: In addition to other methods for conservation of bite mark evidence, preservation of actual skin from deceased victims is often suggested. This study was undertaken to analyze the dimensional stability of such specimens. Utilizing a prefabricated template, marks approximating "bites" were made in postmortem skin of

Miniature Hanford pigs, producing imprints with distinct margins and indentations. Tissue samples were stored in 10% formalin after affixing an acrylic support ring with cyanoacrylate adhesive and sutures. Measurements of the six tooth mark analogues and cross-arch dimensions were taken at intervals of up to 38 days. Data from these measurements indicate a wide range of amount and type of distortion in preserved tissue. Although some samples were dimensionally stable, there was both contraction and expansion of bite mark specimens, even within individual skin samples. It appears that standard techniques for storage and preservation of bite mark samples will not produce reliable dimensional accuracy.

2001 - Sheasby DR, McDonald DG; A forensic classification of distortion in human bitemarks, *For Sci Int*, 122(1):75-8.
Abstract: Important cautionary paper. Acknowledges that distortion is probably present in all bitemarks.

2002 - Kittelson JM, Kieser JA, Buckingham DM, Herbison GP; Weighing evidence: Quantitative measures of the importance of bitemark evidence, *J For Odont*, 20(2):31-7.
Abstract: Concludes that likelihood ratios are not useful in bitemark analysis

2003 - Pretty IA; A web-based survey of odontologist's opinion concerning bitemark analysis, *J Forens Sci*, 48(5):1117-20.
Abstract: 91% of respondents believed the dentition unique, 78% believed uniqueness transferred to skin.

2004 - Kouble, RF, Craig, CT; A comparison between direct and indirect methods available for human bite mark analysis, *J Forensic Sci*, 49(1):111-118.
Abstract: Repeat of material presented in 2001.

2005 - McNamee, AH, Sweet, D et al; A comparative reliability analysis of computer-generated bitemark overlays, *J Forensic Sci*, 50(2):400-405.
Abstract: Another study on overlays.

2006 - Al-Talabani et al; Digital analysis of experimental human bitemarks: Application of two new methods, *J Forensic Sci*, 51(6):1372-5.
Abstarct: In the only empirical study of it's kind, 50 living volunteers were bitten. Study concludes that it was difficult to distinguish biters due to gross similarity of the dentitions.

2007 - Pretty, IA; Development and validation of a human bitemark severity and significance scale, *J Forensic Sci*, 52(3):687-691.
Abstract: First serious attempt to develop and evidentiary value scale by means of a survey of 30 examiners looking at 35 bitemarks. Landmark effort, although the resulting scale has not been universally adopted.

2007 - Blackwell SA et al; 3-D imaging and quantitative comparison of human dentitions and simulated bitemarks, *Int J Leg Med*, 121:9-17.
Abstract: Found 15% false positive rate in wax bites.

2007 - Kieser et al; The uniqueness of the human anterior dentition: a geometric morphometric analysis, *J Forensic Sci*, 52(3).
Abstract: Used shape analysis methods to study a small (33 mx 49 mn) population. Claimed dental uniqueness based on small differences. Did not report measurement error. Flawed inference from insufficient data.

2009 - Bowers, CM, Pretty, IA; Expert Disagreement in Bitemark Casework, *J Forensic Sci*, 54(4):915-918.
Abstract: Assessment of outcome of 49 cases using the 2007 severity scale. Concludes that expert disagreement is related to quality of evidence.

2009 - Bush MA, Miller RG, Bush PJ, Dorion RBJ; Biomechanical Factors in Human Dermal Bitemarks in a Cadaver Model, *J Forensic Sci*, 54(1):167-76.
Abstract: First serious consideration of skin properties. 23 bites were made with the same dentition in cadaver skin, none were measurably the same. Postural distortion was also studied and found to be significant. Bitemarks were not reproducible. Landmark paper using cadaver model.

2010. Bush MA, Thorsrud K, Miller RG, Dorion RBJ, Bush PJ. The Response of Skin to Applied Stress: Investigation of Bitemark Distortion in a Cadaver Model. *J Forensic Sci*, Vol. 55(1): .
Abstract: Force per unit area was varied during controlled bites on cadaver skin using an instrumented biting machine. Bite appearance was not predictable, nor did laceration reliably occur. A principal variable is tissue type.

2009 - Martin-de-las-Heras, S, Tafur, D; Comparison of simulated human dermal bitemarks possessing three-dimensional attributes to suspected biters using a proprietary three-dimensional comparison, *Forensic Science International* 190(1-3):33-37.
Abstract: Dental models of nine adults and four children with mal-alignments were used to bite wax and pigskin in a self-validation study. Flawed study because of sample selection bias.

2009 - Miller RG, Bush PJ, Dorion RBJ, Bush MA; Uniqueness of the Dentition as Impressed in Human Skin: A Cadaver Model, *J Forensic Sci*, 54(4):909-14.
Abstract: 100 models were compared to bitemarks made with 10 dentitions with different alignments. Results showed difficulty distinguishing the biter from individuals with similarly aligned dentitions and in some cases, an incorrect biter appeared better

correlated to the bite. Cautionary paper empirically demonstrating unreliability of bitemark analysis.

2010 - Avon, SL et al; Error rates in bite mark analysis in an in vivo animal model, Forensic Sci Int doi:10.1016/j.forsciint.2010.04.016.
Abstract: Showed error rates of examiners using a live pig model. Inexperienced examiners performed as well as board-certified examiners. Suggested that results might support the contention that bite mark analysis is entirely subjective.

2011 - Bush MA, Bush PJ, Sheets HD; Statistical Evidence for the Similarity of the Human Dentition, *J Forensic Sci*, 56(1):118-23.
Abstract: Refutation of Rawson's 1984 study that claimed dental uniqueness. Two dental populations of 172 and 344 were examined for match rates. Statistics were used that took into account dental correlation and non-independent nature of the human dentition. Matches were found in the populations studied. Study suggests that the dentition is not unique as measured.

2011 - Bush MA, Bush PJ, Sheets HD; Similarity and Match Rates of the Human Dentition in 3-Dimensions: Relevance to Bitemark Analysis, *International Journal of Legal Medicine* published online 4 September 2010.
Abstract: Match rates determined in a population of 500 dentitions using 3D models and shape analysis. Significant numbers of matching dentitions were found. The effect of 2D vs 3D measurement on match rate was also explored (match rate lowered when 3D included). This and prior studies showed that dental match rate is population-dependent.

2011 - Bush MA, Sheets HD; Mathematical matching of a dentition to bitemarks: Use and evaluation of affine methods, *Forensic Science International* (2010), doi:10.1016/j.forsciint.2010.09.013.
Abstract: Mathematical investigation into distortion correction using bitemarks in cadavers. Affine methods cannot be applied because of skin anisotropy. Refutation of Stols and Bernitz 2010 approach and mathematical confirmation of Bush 2010 empirical distortion study

2011 - Bush MA, Bush PJ, Sheets HD; A study of multiple bitemarks inflicted in human skin by a single dentition using geometric morphometric analysis, *Forensic Science International* (2011), doi:10.1016/j.forsciint.2011.03.028.
Abstract: Comparison of 89 bitemarks to dentition shape. Concludes that false positives are readily possible due to distortion of dental shape in skin.

2011 - Santoro V, Lozito P, De Donno A, Introna F; Experimental Study of Bite Mark Injuries by Digital Analysis, *J Forensic Sci*, 56(1).
Abstarct: Digital morphometric comparison of 20 dentitions and 20 bites in pigskin and plastic.

2011 - Martin-de-las-Heras, S, Tafur D; Validity of a dichotomous expert response in bitemark analysis using 3-D technology, *Science & Justice*, 51:24–27.
Abstract: Study explores decision-making process. However, this and a previous study (Heras 09) used the same set of 13 dentitions, selected because they were distinct from each other. It is no surprise that it was possible to match biter with dentition.

2011 - Sheets HD, Bush PJ, Brzozowski C, Nawrocki LA, Ho P, Bush MA; Dental shape match rates in selected and orthodontically treated populations in New York State: A 2-dimensional study, *J Forensic Sci*, 56(3):621-6.
Abstract: Study of dental match rates using shape analysis methods in a general population of 410 (match rate 1.46%) and an orthodontically treated population of 110 (match rate 42%). Orthodontic treatment had a dramatic effect on match rate.

2011 - Tuceryan M, Li F, Blitzer HL, Parks ET, Platt JA; A Framework for Estimating Probability of a Match in Forensic Bite Mark Identification, *J Forensic Sci*, 56(S1).
Abstract: Bitemarks were simulated by impressing 15 lipstick coated dental models on a rubber doll. Metric analysis was attempted.

Question 4: Are there any scientific studies indicating what percentage of the population or sub-group of a population may have produced similar bitemarks (i.e statistical data regarding likelihood of a random match)?

There are a few scientific studies that have attempted to determine if the size, position, morphology and relationships of individual teeth within the human dentition are unique from person to person. Of the full text articles cited that address this subject some conclude that the human dentition is unique and others conclude it is not. As in any study or experimental design to examine a postulate, there have been criticisms of most of these studies.

As a background, the ABFO terminology guidelines include two types of characteristics that are applied to the human dentition and bitemarks:

1. Class characteristics: A feature, trait or pattern that distinguishes a bitemark (*teeth*) from other patterned injuries (*teeth*). Thus it identifies the group from which it originates: human, animal, fish, other species or inanimate objects as a weapon (tool).
2. Individual characteristics: A feature, trait or pattern that represents an individual variation rather than an expected finding within a defined group. These have been further subdivided into two types:
    a. *Arch characteristic:* a feature or trait that represents tooth arrangement within a bitemark (*teeth).* For example, rotated teeth, buccal or lingual version, mesio-distal drifting, and varying horizontal alignment of teeth.

b. *Dental characteristic:* a feature or trait within a bitemark (*teeth*) that represents an individual tooth variation. For example, unusual wear pattern, notching, angulations, fractures.

It is these individual characteristics of the teeth that may provide the uniqueness of the human dentition.

However, in any given case it may not be important whether or not the entire population of the world has unique dentitions. The true value of bitemark analysis lies in the ability to exclude individuals as possible biters. With the new proposed ABFO Bitemark Decision Tree Guidelines, regardless whether ~~if~~ suspects in a given case have dissimilar dentitions or similar dentitions the linkage to the bitemark can only be "exclude, cannot exclude or inconclusive". Naming a "biter" to the exclusion of all others is not sanctioned by the ABFO therefore the uniqueness of the human dentition may not be a question that needs a definitive answer.

Citations

Johnson, L.T., Radmer, T.W., Wirtz, T.S., Pajewski, N.M., Cadle, D.E., Brozek, J., Blinka, D.D. Quantification of the individual characteristics of the human dentition (2015) Journal of Forensic Identification, 65 (4), pp. 716-732

Franco, A., Willems, G., Souza, P.H.C., Bekkering, G.E., Thevissen, P. (2014) The uniqueness of the human dentition as forensic evidence: a systematic review on the technological methodology. International Journal of Legal Medicine, 7 p. Article in Press.

Johnson, L.T., Radmer T.W., Jeutter,D., Stafford, G.L., Thulin, J., Wirtz, T., Corliss, G., Ahn, K.W., Visotky, A. Groffy, R.L. (2014) Replication of known dental characteristics in porcine skin: Emerging technologies of the imaging specialist. Marquette University e-publication pp1 - 105

Martin-De-Las-Heras, S., Tafur, D., Bravo, M. A quantitative method for comparing human dentition with tooth marks using three-dimensional technology and geometric morphometric analysis (2014) Acta Odontologica Scandinavica, 72 (5), pp. 331-336.

Sheets HD, Bush PJ, Bush MA (2013) Patterns of variation and match rates of the anterior biting dentition: characteristics of a database of 3-D scanned dentitions. J Forensic Sci 58:60–68

Bush MA, Bush PJ, Sheets HD (2011) Statistical evidence for the similarity of the human dentition. J Forensic Sci 56:118–123

Bush MA, Bush PJ, Sheets HD (2011) Similarity and match rates of the human dentition in three dimensions: relevance to bitemark analysis. Int J Legal Med 125:779–784

Sheets HD, Bush PJ, Brzozowski C, Nawrocki LA, Ho P, Bush MA (2011) Dental shape match rates in selected and orthodontically treated population in New York state: a two-dimensional study. J Forensic Sci 56:621–626

Tuceryan M, Li F, Blitzer H, Parks ET, Platt JA (2011) A framework for estimating probability of a match in forensic bite mark identification. J Forensic Sci 56:83–89

Martin-de las-Heras S, Tafur D (2009) Comparison of simulated human dermal bitemarks possessing three-dimensional attributes to suspect biters using a proprietary three-dimensional comparison. Forensic Sci Int 190:33–37

Blackwell SA, Taylor RV, Gordon I, Ogleby CL, Tanijiri T, Yoshino M, Donald MR, Clement JG (2007) 3-D imaging and quantitative comparison of human dentitions and simulated bite marks. Int J Legal Med 121:9–17

Kieser JA, Bernal V, Waddell JN, Dip Tech M, Raju S (2007) The uniqueness of the human anterior dentition: a geometric morphometric analysis. J Forensic Sci 52:671–677

Pretty IA, & Sweet D. (2001). The scientific basis for human bitemark analyses--a critical review. *Science & Justice : Journal Of The Forensic Science Society*, *41*(2), 85-92

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Nambiar P, Bridges TE, Brown KA (1995) Quantitative forensic evaluation of bite marks with the aid of a shape analysis computer program: part 2; “SCIP” and bite marks in skin and foodstuffs. J Forensic Odontostomatol 13:26–32

Rawson RD, Ommen RK, Kinard G, Johnson J, Yfantis A (1984) Statistical evidence for the individuality of the human dentition. J Forensic Sci 29:245–253

Sognnaes RF, Rawson RD, Gratt BM, Nguyen NBT (1982) Computer comparison of bitemark patterns in identical twins. J Am Dent Assoc 105:449–451

T. W. Macfarlane, D. G. Macdonald, and D. A. Sutherland (1974) Statistical Problems in Dental Identification. J Forensic Sci 4:247-252

Keyes FA (1925) Teeth marks on the skin as evidence in establishing identity. Dental Cosmos 67: 1165-1167

EXHIBIT B

Construct validity of Bitemark assessments using the ABFO decision tree

Adam Freeman
Iain Pretty*

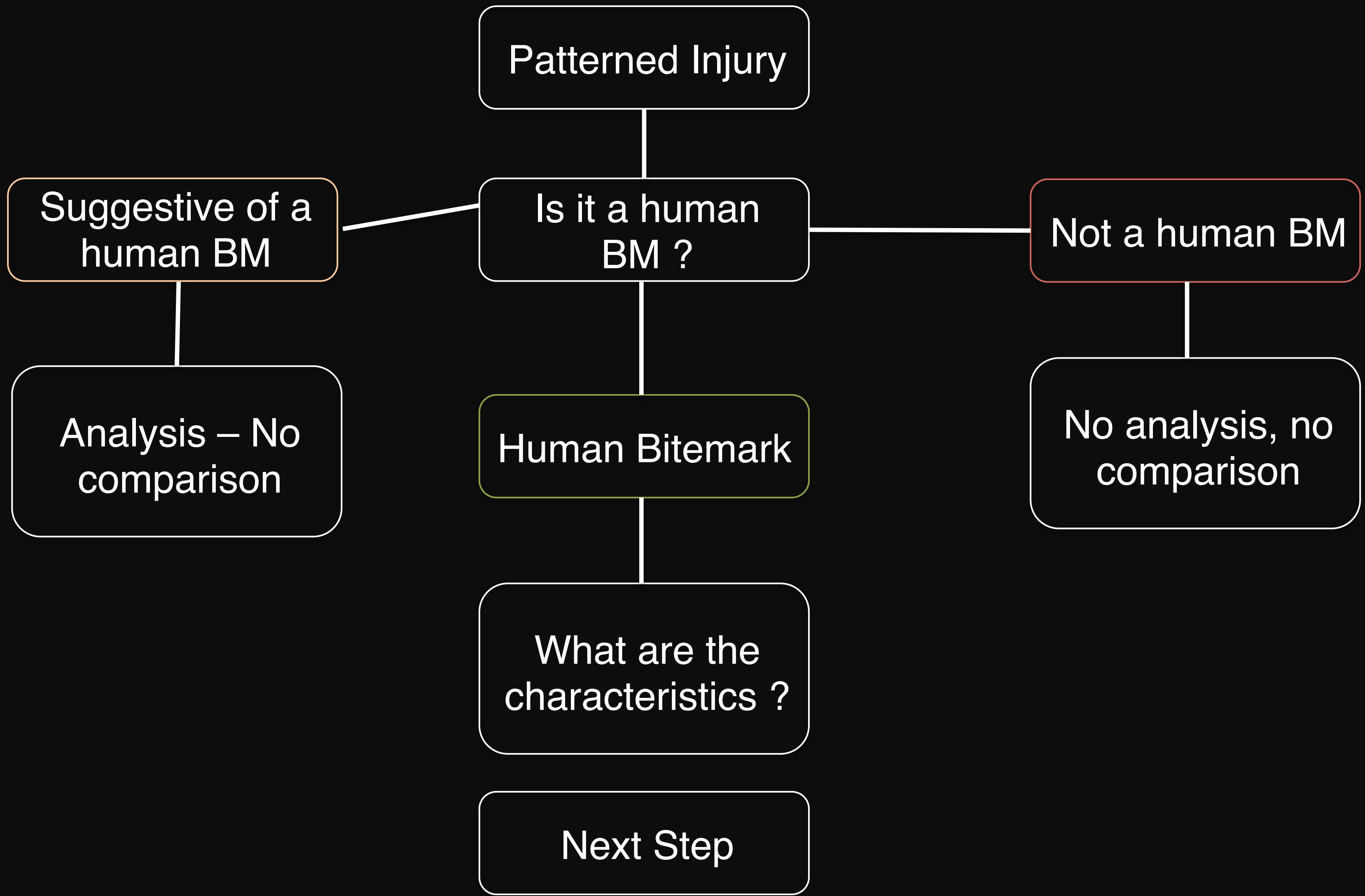
Overview of presentation

- Background
- Scientific approach
- Methods
- Results
- Impact and suggestions

Background

The decision tree is a means of formalizing the approach to bitemark analysis by taking the assessor through a series of stages and decisions that aim to ensure that the decisions made are consistent with the level of forensic evidence available.

Background – Schematic of tree



Background

This study examined Step 1 – the evaluation of the injury, is the injury a bitemark and if so, what are the bitemark's characteristics?

Today presenting data on the assessment of the injury as a bitemark only

Scientific approach

Several methods being applied to BM research:

- Mechanistic approach
- Decision making approach

In the absence of truth we are using construct validity – through reliability testing - if its not reliable its not valid.

Methods

250 cases submitted by DABFO – included an orientation shot and a close up with scale

Selected 100 cases to represent a wide spread of anatomical location, presentation, evidence quality

Presented to DABFO on an online system with anonymity of decisions

Asked if there was sufficient evidence to render any opinion, and if so, what is it?

Methods

Data collected

Demographics reported

Kappa used to measure agreement

Descriptive statistics to assess the spread of decisions and understand the reasons for disagreement

Results

38 Diplomates completed the whole study, 44 completed partially.

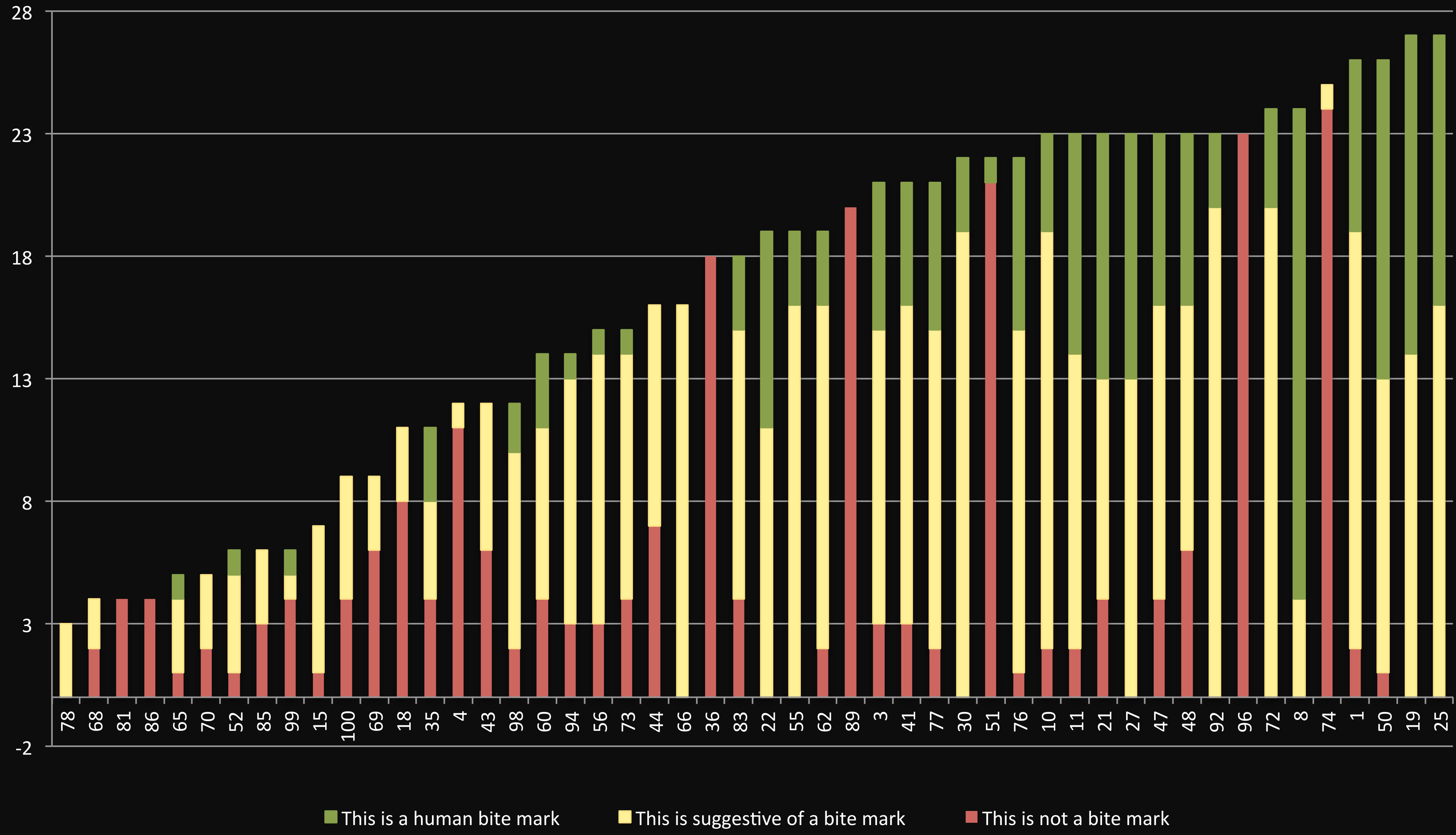
Represents a total of 3924 decisions on bitemark cases

Range of experience measured in three ways:

- How many cases in past 5 years – 18.58
- How many years have you been active – 19.87
- How many times have you testified in the past five years? – 2.05

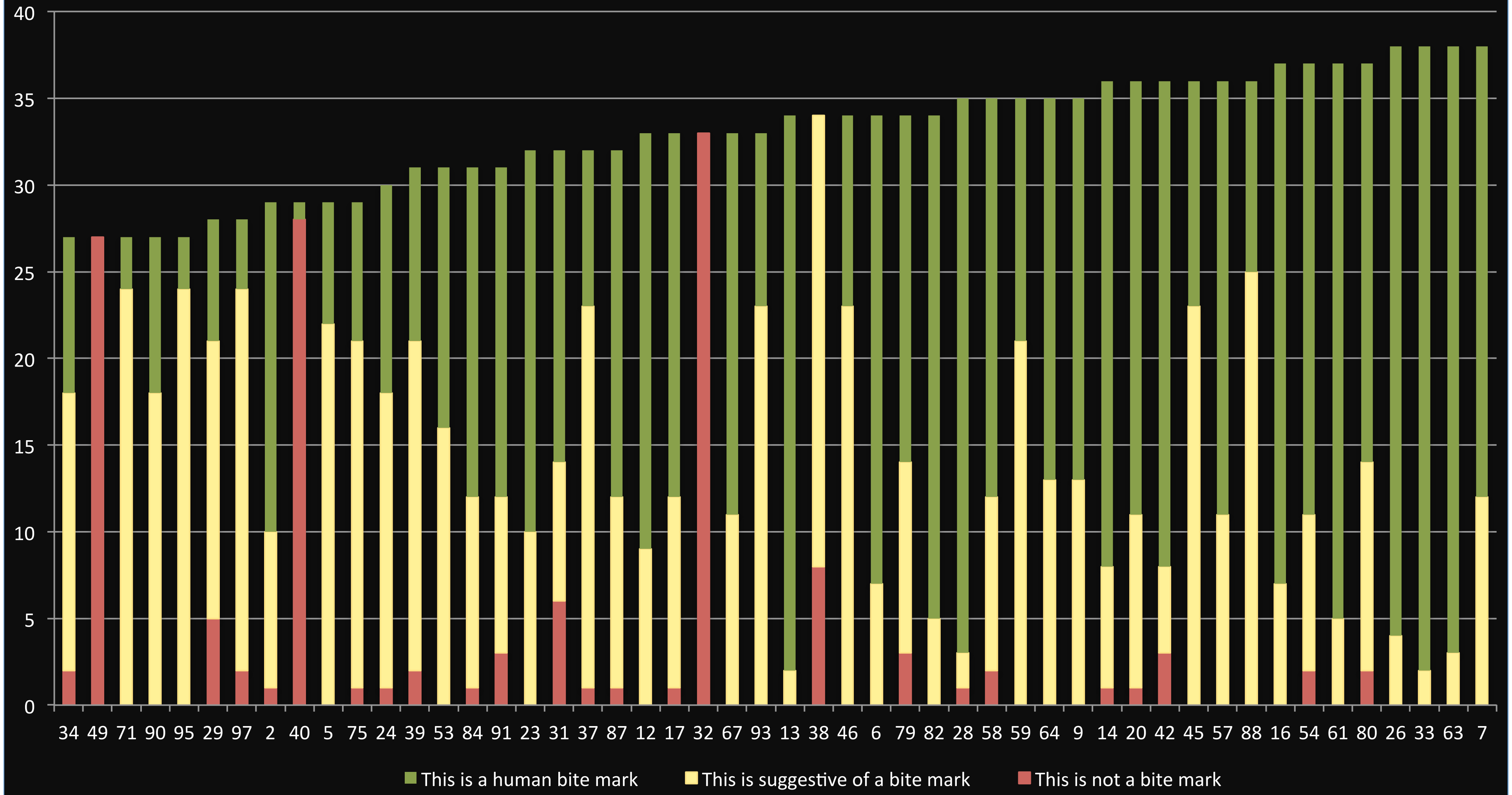
Results – decision spread

Look at the spread of decisions for individual cases.



Results – decision spread

Look at the spread of decisions for individual cases.



Impact and suggestions

All research has strengths and weaknesses

- Good number of decisions
- A lot of work – not all diplomates completed
- Some argued that not realistic approach

The study suggests level of reliability of injury assessment for bitemarks is *not currently satisfactory* from the population of assessors studied

The impact of *three choices* from the decision model has decreased reliability– removal of “suggestive” combined with greater detail on the identification of bitemarks within the decision model should be considered. The use of a simpler, dichotomous decision, should lead to increased reliability – although the decision direction of the “suggestives” is unknown.

Impact and suggestions

We need to undertake further examination of those cases where there *was higher levels of agreement* to determine how the decision tree can capture these elements to improve reliability, both for bites and non-bites.

The first step of BM analysis is determining if the presented injury is a bitemark – the current data suggest that agreement levels observed require significant improvement and means of achieving this have been proposed. A further assessment following the introduction of these changes will be required.

Thank you

We would like to thank those Diplomates who submitted their cases for inclusion in the study and for those who took the time to complete the exercise.

Thank Dr Peter Loomis, and the ABFO, for supporting this work through design, implementation and reporting of findings.

EXHIBIT C

Submission to Texas Forensic Commission

Bitemark Analysis on Human Skin

Iain A Pretty

BDS, MSc, MPH, PhD,
FDSRCS(Ed), FRCSFS

1. Introduction

1.1 I have prepared this submission to be of assistance to the Commission in its consideration of bitemark evidence. The opinions expressed within the submission are my own, and do not reflect the position of the Odontology Section of the American Academy of Forensic Sciences of which I am currently Chair.

1.2 I am presenting this statement to assist the Commission. Rather than simply providing a list of literature, most of which has little to do with the fundamental hypotheses underlying bitemark analysis that I understand to be the Commission's focus, I have provided a narrative review of those papers and studies that I feel address the pertinent issues. The statement includes an assessment of the science but also my personal reflections on my experiences over the past 15 years.

1.3 The NAS Report[1] found that the literature they reviewed, and the expert testimony they received (in particular that from Dr. David Senn) did not support the use of bitemarks. They stated that "… there is no science on the reproducibility of [bitemark analysis] … high percentage of false positive matches" Senn's presentation[2] to the NAS group featured slides entitled "Major Problems" these included "The uniqueness of the human dentition has not been scientifically established", "The ability of the dentition … to transfer a unique pattern has not been scientifically established". These are the two, central, underlying principles of bitemark analysis and one of their key proponents has stated there is no scientific basis for them. See page 175 of the report, reference Senn 128. Unlike all other pattern matching disciplines, such as fingerprints, tool marks and ballistics, bite mark analysis attempts to interpret data from an ever-changing, pliable and unpredictable substrate (skin). As the NAS Report noted: "[B]ite marks on the skin will change over time and can be distorted by the elasticity of the skin, the unevenness of the surface bite, and swelling and healing. These features may severely limit the validity of forensic odontology."[1] Objective standards for bite mark analysis have not been developed because "[t]he effect of distortion on different comparison techniques is not fully understood and therefore has not been quantified."[1]The NAS report was published in 2009 – has there been a seismic shift in the scientific evidenced published since then to support the identification of biters from marks on skin? No, indeed research published since 2009 *continues to cast doubt* on the process.

1.4 I am one of the few forensic dentists to have undertaken a formal postgraduate degree in the subject. I trained between 1998 and 2000

[1] Strengthening Forensic Science in the United States: A Path Forward (2009)
[2] Dr David Senn - Presentation to NAS – attached to the appendix file as Senn NAS Presentation

in Vancouver under the supervision of Dr. David Sweet earning a Masters degree.

1.5 During this time bitemarks were de rigueur; they were an unquestioned part of dental forensic practice and while there was some research activity the majority of presentations and papers reported "success" stories in their application to criminal cases. The more sensational the case the more likely it to be presented at the American Academy. The literature was replete with case reports and papers describing modifications of techniques and processes; that these techniques had not been scientifically validated or demonstrated reliable was not discussed. I cannot recall of a cautionary presentation or one that questioned the biological plausibility of matching marks on skin to a human dentition by a forensic odontologist. There was no mention of wrongful convictions.

1.6 The advent of digital imaging and the widespread use of Photoshop lending a veneer of science to a process that had previously involved the use of office photocopiers or dentists using fiber pens on sheets of acetate. By using a formal "tool" and resizing images using software we all believed that we were advancing a science in which we had confidence.

1.7 The reality was, however, that despite these technological advances, the underpinning science of what we were finessing was not, and in my view is still not, proven. We were tinkering at the edges, doing what was easy and achievable and ignoring the difficult questions regarding the basis of the bitemark process and its validity.

1.8 As *Daubert* became accepted by increasing numbers of States and the subsequent decisions in *General Electric Co vs. Joiner* and *Kumho Tire Co. vs. Carmicheal* I, and others, looked at the standard that was being asked of experts and I began to consider whether these factors applied to bitemarks:

1.9

1. Empirical testing: whether the theory or technique is falsifiable, refutable, and/or testable.
2. Whether it has been subjected to peer review and publication.
3. The known or potential error rate.
4. The existence and maintenance of standards and controls concerning its operation.
5. The degree to which the theory and technique is generally accepted by a relevant scientific community.

1.7 This prompted my dissertation thesis – Digital Bitemark Overlays – an analysis of effectiveness, subsequently published in the *Journal of*

Forensic Sciences[3] and attached as Appendix A to this statement. In this work I sought to define an error rate for the application of overlays to bitemarks made in porcine skin. The accuracy within this study was 83.2% - i.e. in 2 cases out of 10 ABFO Diplomates[4] indicated the incorrect overlay in relation to the bitemark. The reliability between the examiners was moderate – a Kappa of 0.47[5]. These results first alerted me to the potential problems with bitemarks.

2. History

2.1 These findings prompted me to examine the literature in detail. I scoured the historical publications in relation to bitemarks, secured the studies, some written in obscure or defunct Journals, and assembled these into four volumes. For each paper I prepared a small summary and assembled these into a detailed bibliography. This was later updated by Peter and Mary Bush and a copy is attached as Appendix B to this statement.

2.2 This was a considerable undertaking and this resource has been used by the ABFO and others to present the "science" of bitemarks. Indeed in their submission to the Commission the ABFO use a large number of these commentaries in relation to their list of papers, although the source is unattributed. However I sometimes wonder if those who have distributed this work more widely have actually read any of the papers? The story is not one of conclusive proof for bitemarks but rather a collection of cautionary studies, commentaries and case reports. While under the title of questions papers have been cited – close examination reveals that while they address the question – they do not provide supportive evidence.

2.3 What I realized when I read these works was that the position in the early 2000 was not based on science – indeed as early as 1960 Fearnhead[6] stated that *"evidence which involves the identification of a person by tooth-marks left as bruises in flesh should never be admitted".* This work is attached as Appendix C. As I progressed through these papers I failed to find the science that supported the two main predicates of bitemark analysis:

a) That the human dentition is unique
b) That this uniqueness is replicated on human skin

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[3] Pretty IA, Sweet D. Digital bite mark overlays—an analysis of effectiveness. *J Forensic Sci* 2001; 46(6):1385–1391.
[4] A Diplomate of the ABFO has passed an examination and undertaken a minimum number of cases.
[5] Interestingly other groups of examiners; general dental practitioners and ASFO members (those with an interest in odontology) faired the same – there was no difference in their performance when compared to the Diplomates
[6] 1960 Fearnhead RW. Med Sci Law; 1:273-77 Facilities for forensic odontology.

2.4 All four volumes of the bitemark bibliography have been scanned and I can make any paper contained within them available to the Commission as they consider the evidence submitted.

2.5 My concerns were now raised that perhaps this technique did not meet the *Daubert* requirements as I failed to find the crucial elements within the literature to answer the five questions.

3. Error rates

3.1 These are perhaps the most important elements of *Daubert* – surely a trier of fact needs to be aware of the reliability of a scientific test, or its application by an individual expert. The scientific field of medical diagnostics provides the means by which we can assess bitemark evidence – are we reliable and valid? What is the predictive value of a positive bitemark identification and what are the metrics for sensitivity and specificity?

3.2 Some definitions are perhaps worthwhile considering, especially as such terminology may be used throughout the presentations of evidence to the Commission:

Reliability - Given the same materials and techniques how often is the same answer obtained by a single examiner (intra) or many examiners (inter). A test, or forensic examination must be reliable if it is to be considered valid

Validity – Is the test or examination measuring what it claims to measure? This often known an construct validity and is accompanied by convergent validity (does a measure relate to other measures) and discriminant validity (are unrelated measures properly identified)

Sensitivity – also known as true positive, the number of injuries correctly identified as bitemarks

Specificity – also known as true negative, the number of injuries correctly identified as not being caused by teeth

3.3 There are studies in the scientific literature that have examined error rates in relation to bitemarks. The first was reported by David Whittaker, a forensic dentist based at the University of Cardiff, in 1975[7]. What is surprising is that this work, has been largely ignored, and yet it provides sound data based on a solid methodology using techniques that are still used today. In his introduction he states that *"..the reliability of the method has been questioned by some authorities*

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[7] 1975 Whittaker DK. Int Dent J; 25(3):166-71 Some laboratory studies on the accuracy of bitemark comparisons.

who are of the opinion that further research is necessary before opinions on these matters can be regarded as "expert" testimony."

3.4 The paper is attached as Appendix D to this statement. Whittaker used a porcine model and a number of bitemarks (24) and examiners (2). Comparisons between models of potential biters and the injuries were undertaken at various time intervals after infliction of the bite.

3.5 The initial error rate was 37% but when examining photographs taken 1 hour after the bitemark was inflicted the rate increased to 75% and after 24 hours to a staggering 84%. Whittaker, an experienced and well respected odontologist concluded that "… experts ... should be aware that … there are problems not only in determining the incidence of identical or near identical occlusions but also in interpreting bitemarks …" He finished his paper by stating the further research is required to substantiate the reliability of the technique.

3.6 It is somewhat unbelievable that it is not until 1998 that a further paper is published that assess the reliability of the bitemark process. Instead the literature is filled with protocols for evidence recovery[8], an attempt at a scoring system by the ABFO[9] that was later abandoned[10] (despite the claims that this was the first "truly scientific" assessment of bitemarks), bitemarks being photographed 5 months after infliction[11] and endless case reports.

3.7 1998 saw a further publication by Whittaker – this time assessing the ability of forensic dentists to determine a child bite from an adult bite. An important question and one posed on a frequent basis by those investigating child abuse where a sibling is often suggested as a biter. The paper[12], is attached as Appendix E to this report.

3.8 Unlike the previous study, Whittaker used "real" forensic cases in this work. This has both advantages and disadvantages and they are worth describing at this stage as they also apply to the Pretty/Freeman study described later. By using real cases there can be little criticism of the authenticity of the bites – as seen when porcine or cadaver skin is used. However, one is uncertain of the truth – the reference standard.

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[8] 1990 Barsley RE, West MH, Fair JA. Am J Forensic Med Pathol; 11(4):300-8 Forensic photography

[9] 1986 Rawson RD, Vale GL, Sperber ND, Herschaft EE, Yfantis A. J Forens Sci; 31(4):1235-60

[10] 1988 Vale GL, Rawson RD. J Forensic Sci; 33(1):20 Discussion of "Reliability of the scoring system of the ABFO for human bitemarks"

[11] 1994 David, T. J. and M. N. Sobel (1994). "Recapturing a 5-Month-Old Bite Mark by Means of Reflective Ultraviolet Photography." Journal of Forensic Sciences **39**(6): 1560-1567

[12] 1998 Whittaker DK, Brickley MR, Evans L. Forensic Sci Int; 92(1):11-20 A comparison of the ability of experts and non-experts to differentiate between adult and child human bite marks using receiver operating characteristic (ROC) analysis

When undertaking diagnostic research one compares a novel method to a reference standard or truth. Given the apparently unreliable nature of bitemark comparisons from his earlier work, and the number of contemporary wrongful convictions, Whittaker's reliance on the Court verdict as the reference standard is worrying.

3.9 Nonetheless the study reported the findings using a ROC (receiver operator characteristics) methodology – in simple terms a combination of specificity and sensitivity. Senior forensic dentists had an AUC (area under the curve) of 0.693. A simplistic interpretation is that 30% of the marks were incorrectly identified. This methodology – taking a simple question and determining outcome was employed in the Pretty/Freeman study that will be discussed later.

3.10 2001 saw the publication of my work with David Sweet, described earlier in 1.7 and later that year I published, with Kris Arheart a highly controversial paper assessing the results of the ABFO Workshop number 4. This paper is attached as Appendix F to this statement[13].

3.11 It is worth noting the history of this work. I was asked by the ABFO Executive to assess the data from the Workshop and to publish it in a Journal. Dr Arheart was also asked to collaborate and together we undertook the work and shared it with the ABFO Board of Directors prior to publication. We received the data from the ABFO and had their full approval to publish. The aftermath of this process was my first experience of the ABFOs approach to those who questioned its firmly held beliefs. While the paper was written in careful terms, it was interpreted by many as showing that the *science was unreliable*. The ROC data suggested (0.86) that the accuracy was rated as "useful for some purposes" and was the first to show that reliability was higher when the forensic evidence was of the highest quality – something that the Pretty/Freeman study also showed later.

3.12 I have been challenged on numerous occasions about this paper, accused of releasing the data to others who undertook less favorable interpretations, that I was not qualified to assess the data and even that I had no permission to publish. All of this is untrue but it was a pattern of behavior from certain elements of the ABFO that I was to experience again, following release of the Pretty/Freeman data. In essence, the ABFO were happy to commission the data, authorized its publication but, when the results were shown in less favorable terms, they chose to attack the science and more importantly, and less ethically, the scientists who undertook the work.

[13] 2001 Arheart, K. L. and I. A. Pretty (2001). "Results of the 4th ABFO Bitemark Workshop- 1999." Forensic Science International **124**(2-3): 104-111.

3.13 This paper shows that the technique was not at a level acceptable for forensic purposes, showed high levels of disagreement and should have prompted a robust response in the form of further research. It did not, instead it has been lost in the historical literature with most ABFO members not having reading the paper (I have asked them on numerous occasions) but having a lasting impression that this was a piece of flawed and unethical publishing on my part. This impression has enabled them to disregard the findings.

3.14 The 2009 – 2010 papers of the Bush group examined reliability of bitemark impressions in cadaver skin. These papers are described within the bibliography and as one of the authors is presenting to the Commission I will not comment further on this work, leaving it instead to the authors themselves who can do a far better job than I. I would simply state that I described the importance of these papers, and their impact on the state of the science in my 2010 review paper[14] – one that called for a paradigm shift in our approach to bitemark evidence. A call that was the result of my now increasing concern with the continued use of this evidence in criminal matters leading to a positive identification of a biter.

3.15 2010 also saw the publication of the work of Avon and Wood[15], attached to this statement as Appendix G. Avon used a porcine model to produce 18 full "bitemark cases" and supplied a series of examiners with 3 sets of dental casts to consider. The results showed an error rate for Diplomates of 35.3%. Avon distinguished a "critical" error rate where an "innocent" party had been indicated as the biter – this rate was 6%. It should be noted that this study, as per the discussion in 3.8 has the benefit of absolute truth (the authors knew which study models had caused the bitemarks) but lacks the authenticity of "real" cases. If one looks at the bitemarks produced in this study it is clear that they are of extremely high forensic value.

3.16 The final paper to be considered is that of LT Johnson's group – attached as Appendix H to this statement. The results of this study are difficult to interpret – there is no percentage agreement or accuracy data provided. Instead we are left with the conclusions stated as "in 20% of cases the … model finds the target within the closest 5% of the population". We are left wondering what happened in the other 80% of cases. We should also note that this work, despite being funded by the NIJ, has not been published in a peer reviewed journal.

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[14] 2010 I.A. Pretty, D. Sweet, A paradigm shift in the analysis of bitemarks, Forensic Sci. Int. (2010), doi:10.1016/ j.forsciint.2010.04.004.

[15] 2010 S.L. Avon, et al., Error rates in bite mark analysis in an in vivo animal model, Forensic Sci. Int. (2010), doi:10.1016/ j.forsciint.2010.04.016.

3.17 No further reliability studies or those reporting error rates have been conducted until the Pretty/Freeman study. This will be discussed in a separate section.

4. Individuality of the human dentition

4.1 There is a range of studies assessing this issue [16] [17]. It is my personal view that the argument is moot. I have no doubt that if you measure anything with sufficient resolution you will be able to identify uniqueness. Indeed many of the papers examining this issue have looked at incredibly fine measures of the position of teeth. Such measurements are inappropriate due to the accepted (by all) distortion present in bitemarks[18].

4.2 Instead – the greater argument is that are any of these features rendered on skin, and if so in a reliable way? The cadaver studies of the Bush's [19] suggest that the same dentition will leave different impressions during multiple bites.

4.3 The ABFO have sought to mitigate this issue, not by conducting empirical research, but via the concept of open and closed populations. The underlying principle is that, within a closed population, one can make more substantive comments on the likelihood of an individual being the biter than one in an open population. This premise is fundamentally flawed as the examining odontologist cannot be sure of the nature of the population as it is not a fact that they are able to verify nor should they be acting as an investigator. Instead, such information is provided, typically, by agents for the prosecution and therefore such information becomes an irrefutable source of contextual bias. While scenarios as strange as locked prison cells will be argued this is a fundamental flaw in the ABFO's approach to their decision making process.

5. Law Reviews

5.1 Often ignored, law reviews present a wealth of information not only the law of evidence, expert witnesses and case precedent but often include well conducted reviews of the underlying literature, frequently with excellent critical analysis.

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[16] 1974 MacFarlane TW, MacDonald DG, Sutherland DA. J Forensic Sci Soc; 14(3):247-52 Statistical problems in dental identification
[17] 1984 Rawson RD. J Forens Sci; 29(1):245-53 Statistical evidence for the individuality of the human dentition
[18] 1986 Rawson RD, Vale GL. J Forens Sci; 31(4):1261-8 Analysis of photographic distortion in bitemarks: a report of the bitemark guidelines committee.
[19] 2009 Miller RG, Bush PJ, Dorion RBJ, Bush MA. Uniqueness of the Dentition as Impressed in Human Skin: A Cadaver Model. J Forensic Sci, 2009;54(4):909-14.

5.2 Without exception the law review have expressed incredulity that bitemark evidence continues to be accepted in US Courts. Zarkowski[20] is a good example of the sentiment expressed in these reports "… bitemarks evolved from a weak beginning….never progressed through a testing phase to measure accuracy and reliability".

5.3 I would encourage the Commission to consider the reviews of Zarkowski (attached as Appendix I) and that of Erica Beecher-Monas[21] (attached as Appendix J).

6. Pretty / Freeman Study

6.1 I would like to finally turn to the most contemporary piece of research to consider error rates in bitemark analysis. I would also like to place the work in context and describe its development.

6.2 During the AAFS Annual Meeting in Seattle, 2014 I attended a dinner with Drs Freeman, Senn, Wright and others. During dinner we described the need for the ABFO to participate in a validation study of the bitemark process and its newly developed Decision Tree. It was agreed that we would assess the first two stages of the newly proposed decision tree for bitemark analysis. I agreed to support the work, but did ask for a guarantee that, irrespective of the results, the work could be published. This was readily agreed.

6.3 Work started on the project and ABFO Diplomates were encouraged by the then President, Peter Loomis, to submit cases for potential inclusion. I received over 250 cases.

6.4 We also designed a website that could be used to present the cases and collect the data. As the lead author of the new draft of the ABFO decision tree Dr. David Senn was consulted at each stage of the process and he made various changes to the format, text and questions. Other senior diplomates were also consulted including Dr Dorion, Dr Loomis, and Dr. Wright were consulted with at differing stages of the process. Not until agreement was reached was the survey sent to all Diplomates to complete.

6.5 I collected the data and an independent statistician, Dr Michaela Goodwin, undertook the statistical analysis.

6.6 Having prepared the presentation for the AAFS Orlando 2015 meeting prior to my departure to the US Dr Freeman and I invited Drs Senn,

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[20] 1988 Zarkowski P. J Law & Ethi Dent; 1(1):47-57 Bite mark evidence: its worth in the eyes of the expert.

[21] Reality Bites: The Illusion of Science in Bite-Mark Evidence - Cardozo Law Review, Vol. 30, 2009 Wayne State University Law School Research Paper No. 08-44

Loomis and Wright to review the results and the presentation. All expressed surprise and concern about the outcome of the study but the consensus in the room was this is what the science has said, and this is what should be presented.

6.7 It is important to point out that, while we assessed two elements of the decision tree, the lack of agreement at the first stage negated the presentation of the findings of the second. Therefore the results no longer represented a decision tree assessment, but more simply the ability for Diplomates to determine, using three conclusion levels (four if one considered the “insufficient evidence option) if an injury was a bitemark or not.

6.8 Dr Freeman, then chair of the ABFO Bitemark Committee invited me present the results to the Committee (three days prior to the public presentation) which I did. At this stage it was apparent that there had been a change of opinion within at least some of the senior Diplomates. David Senn asked for a subset analysis of senior examiners to be produced to see if this improved the results. It didn’t.

6.9 I was then challenged by Senn regarding the use of Kappa statistics on multiple option studies. I explained to him that this was a valid approach but, given his concerns, and the fact that the data really spoke for themselves and needed no additional analysis, that I would remove them from the presentation. Over the following days I modified the presentation (although not the data) to provide a more favorable interpretation of the findings. I did this because I believed that by working with the ABFO we could have the best chance of repeating the study and undertaking more research. Like others, I was in genuine equipoise in relation to the issue – I wanted to get to the answer.

6.10 While I wish to present the data in a dispassionate way, I do believe that in order for this Commission to appreciate the nature of the debate within the forensic community, I need to address some issues that occurred during and since the Orlando 2015 meeting..

6.10 As the meeting progressed through to the time of presentation both myself and Dr Freeman became aware of a range of comments made by ABFO Diplomates in closed meetings. These comments concerned the study data but were not scientific objections, instead they were personal attacks. One such attack was that Dr Freeman had acted inappropriately as the Odontology Section program chair by accepting an abstract before all the data were available to review. This is usual and normal practice and indeed we were able to demonstrate that this courtesy had been extended to the very individual voicing the accusation on numerous occasions in the past.

6.11 The data were presented as per the presentation attached as Appendix K to this statement. I would ask the Commission to consider the graphs on pages 10 and 11.

6.12 These data **clearly show the lack of agreement** based on a three way decision model. The inclusion of suggestive has been cited as the reason for such poor agreement. Even if suggestive is removed, and the decisions from this element discarded there are numerous cases where the most experienced odontologists state that the injury was a bitemark and other state that it is not. This is not a complex test – we are asking if this injury is a bitemark or not.

6.13 One injury included in the study was provided by a Diplomate who has injured himself with a box cutter – 8 Diplomates indicated that this was a **definite bitemark**.

6.14 I suggested to the ABFO that we examine those cases where good agreement was found – those injuries had the highest level of detail and understand how we might limit bitemarks to injuries of this type and work on a new definition and new study be undertaken and that we would publish the results of both studies.

7 Conclusion

7.1 I have presented those papers and data that I feel will be of use to the Commission in their deliberations.

7.2 I believe that the current scientific position *does not support* the use of bitemarks to positively identify individuals in criminal matters. I think that the use of the terms “open” and closed “populations” are wholly inappropriate in such cases.

7.3 While I am convinced at times by the ability to *exclude individuals* in cases where there are gross discrepancies in shape form or number of teeth – there is an urgent need to develop the necessary evidence to support this common sense approach. It currently does not exist.

Statement of Truth

I believe that the facts stated in this report are true.

EXHIBIT C
APPENDIX A

Iain A. Pretty,[1] B.D.S. (Hons), M.Sc., and David Sweet,[2] D.M.D., Ph.D.

Digital Bite Mark Overlays—An Analysis of Effectiveness

REFERENCE: Pretty IA, Sweet D. Digital bite mark overlays—an analysis of effectiveness. J Forensic Sci 2001;46(6):1385–1391.

ABSTRACT: U.S. courts have stated that witnesses must be able to identify published works that define operational parameters of any tests or procedures that form the basis of scientific conclusions. Such works do not exist within the field of bite mark analysis. As the most commonly employed analytical technique in bite injury assessment, this study defines quantifiable variables for transparent digital overlays. A series of ten simulated, postmortem bites were created on pigskin and, with accompanying overlays, assembled into cases. Using two separate studies with four examiner groups, the study defined values of intra- and inter-examiner reliability, accuracy, sensitivity, specificity, and error rates for transparent overlays. Methods and statistical treatments from medical decision-making and diagnostic test evaluation were employed. Forced decision models and receiver operating characteristic analyses were utilized. Sensitivity and specificity values are described, and the results are consistent with other dental diagnostic systems. It was concluded that the weak inter-examiner reliability values explain the divergence of odontologists' opinions regarding bite mark identifications often stated in court. The effect of training and experience of the examiners was found to have little effect on the effective use of overlays within this study. The authors conclude that further research is required so that the results of the current study can be placed into context, but this represents a significant first step in establishing the scientific basis for this aspect of forensic dentistry.

KEYWORDS: forensic science, forensic dentistry, reliability, validity, examiner agreement, bite marks

It is not unusual to see dentists testifying in court. Forensic odontologists assist criminal proceedings by identifying the deceased victims of crime and by analyzing bite marks to identify the biter (1). Contemporary legal history is littered with cases where it has been possible to identify a bite on a victim to the person who has caused the bite. In many cases, this type of evidence may be crucial to the successful outcome of the trial (2). Bite mark evidence has been almost universally accepted in the courts, but the fundamental validity and scientific basis for its use is frequently challenged (2,3).

Rapid advances in forensic science have caused concern to the judicial system. Recent rulings, such as *Daubert* and *Kumho* in the United States, have placed a greater emphasis on the validity and reliability of opinion testimony based on supposed scientific principles. Judges have stated that witnesses must be able to identify published works that define the operational parameters of any tests or procedures that form the basis of scientific conclusions (2). Such works do not exist within the field of bite mark analysis (1).

The purpose of this study was to determine values of intra- and inter-examiner reliability, sensitivity, and specificity on both a dichotomous scale and the recommended American Board of Forensic Odontology conclusions scale (4). Methods from medical diagnostic assessments were employed to analyze the data. The impact of the examiners' training and experience was measured.

Materials and Methods

Selection of Examiners

To address the impact of training and experience on bite mark overlay use, the following groups of examiners were selected:

- Diplomates of the American Board of Forensic Odontology (ABFO).
- Members of the American Society of Forensic Odontology (ASFO).
- General Dental Practitioners (GDP).

The ABFO Diplomates were the examiners with the highest level of training and experience. Two separate groups were studied. The first ABFO group provided data for intra-examiner reliability. The second ABFO group was involved in determining the inter-examiner reliability.

Members of the ASFO who were practicing dentists with an interest in forensic dentistry and had been involved in at least one bite mark case or had attended a training course on the subject were recruited. General dental practitioners were recruited from a forensic dental study group concerned with responses to mass disasters. These dentists had no practical bite mark experience other than attending three lectures on the subject.

Ten simulated bite mark cases were presented to each of ten examiners. Each bite mark case included two suspects resulting in a total of 20 decisions for each examiner and 200 decisions for each examiner group. Overall, this represented 40 examiners (two ABFO groups, one ASFO group, and one GDP group) and 800 identification decisions.

Selection of Suspect Dentitions

Twenty-two sets (upper and lower) of high quality dental casts were selected to ensure that the bite marks represented a range of difficulty. This difficulty ranged from straight, even teeth to displaced, crowded teeth. Each of the ten bite mark cases had two sets of casts associated with it. One set of casts was used to produce the bite and the other was used as a foil (nonbiter). The casts that pro-

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duced the bite in each case were determined randomly. Case 3 and Case 4 had three sets of dental casts associated with them to create a situation in which neither suspect was the biter. In these cases, the third cast was used to produce the bite. Models were labeled "Suspect A" and "Suspect B" for each of the ten cases; the unseen biters were labeled "Suspect C" (See Table 1).

Production of Overlays

Sweet et al. describe the most accurate form of producing digital overlays that is currently available, and this method was used (5,6). Table 2 illustrates the equipment employed. This technique was used to produce 1:1 (life-sized) overlays of the anterior teeth of Suspect A and Suspect B for each case (See Fig. 1). Note that overlays were not produced for Suspect C in Cases 3 and 4.

Simulation of Bites on Animal Model

The use of animal skin analogues to produce simulated bite marks is well established within forensic dentistry (7). It was decided to create in situ postmortem bites on pigskin since this is widely accepted as an accurate analogue of human skin (8). Previous studies have used postmortem pigskin (7), antemortem dog skin (9), and postmortem sheepskin (10).

Two piglets (7 to 8 weeks old), freshly slaughtered, and weighing approximately 15 kg each, were obtained from a local abattoir. Anatomical locations were selected on each piglet that represented areas of minimal skin curvature and distortion. The lower abdomen and ears were found to be ideal sites. The dental casts from each randomly selected biter were clamped to the skin for 10 m to create a bite mark. Following the release of the clamp the bite mark was subjectively examined to ensure that sufficient detail was recorded.

The injury was photographed following the ABFO guidelines for evidence collection (4). Color and black-and-white photographs were exposed with the ABFO No. 2 scale in place. The best reproduction of each bite mark was selected and photographs were printed at 1:1 (life-sized). Subsequently, the photographs were scanned into a computer and stored in JPEG format at 1440 dpi. These images were printed with an inkjet printer at 1440 dpi on photographic paper. Prints were made for each examiner. An example of one of the bitemark photographs is shown in Fig. 2.

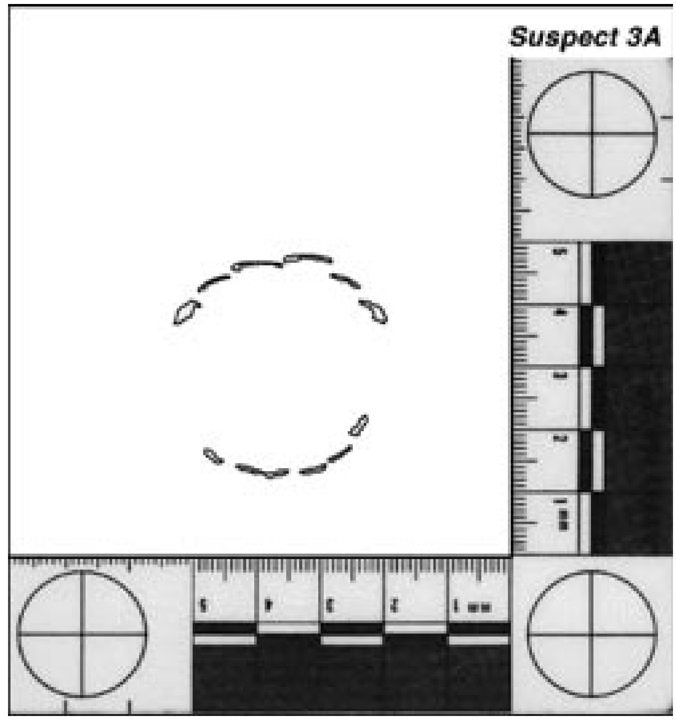

FIG. 1—*Digital overlay for Case 3, Suspect A showing 12 anterior teeth.*

TABLE 1—*Distribution of biters among the ten simulated cases.*

Case Number	Suspect A	Suspect B	Suspect C
1	Biter	Non Biter	
2	Non Biter	Biter	
3	Non Biter	Non Biter	Biter
4	Non Biter	Non Biter	Biter
5	Non Biter	Biter	
6	Biter	Non Biter	
7	Biter	Non Biter	
8	Non Biter	Biter	
9	Biter	Non Biter	
10	Non Biter	Biter	

TABLE 2—*Equipment for production of digital overlays.*

Item	Model	Manufacturer	Location
Scanner	HP ScanJet 4c	Hewlett Packard Co.	Palo Alto, CA
Scanning software	HP DeskScan	Hewlett Packard Co.	Palo Alto, CA
Scale	ABFO No. 2	Lightning Powder Co., Inc.	Salem, OR
Computer	PowerMac G3	Apple Computer Inc.	Cupertino, CA
Imaging software	Photoshop v5.0.2	Adobe Systems Inc.	Mountain View, CA
Laser printer	LaserWriter 4/600PS	Apple Computer Inc.	Cupertino, CA
Transparency film	Catalogue no. 9055	3M Visual Systems Division	Austin, TX

Study 1: Intra-Examiner Reliability

An anonymous group consisting of ten diplomates of the ABFO was selected. Each participant received ten simulated bite mark cases, which contained one color and one black-and-white photograph of the bite, two computer-generated overlays labeled Suspect A and Suspect B, occlusal views of the suspects' dentition, instructions, and an answer sheet. The examiners were asked to determine whether each suspect was the biter or not for the appropriate case. The examiners were asked to indicate "Positive" for the biter and "Excluded" for the nonbiter. No other option was available.

Ten diplomates returned answer sheets for the first assessment (100%). However, only seven returned the study materials. Since three Diplomates retained the materials, the second assessment to study intra-examiner reliability, which was carried out three months later involved only seven of the Diplomates. These diplomates were sent the same materials again and asked to repeat the exercise.

The results were entered into tables and treated statistically. Each of the examiners' responses was compared between the two different assessments and kappa was applied to correct for chance. PEPI statistical software was used to analyze the raw data (11).

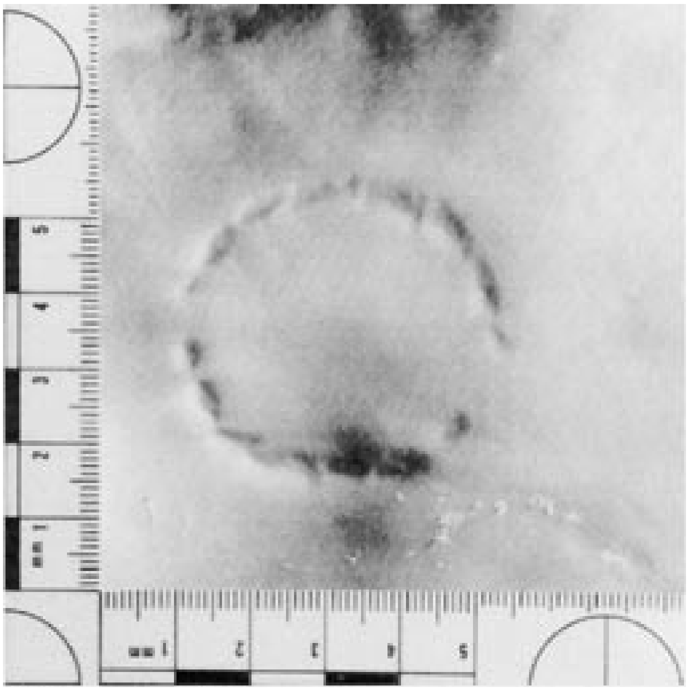

FIG. 2—*Example of case photograph from a simulated bite mark on pigskin.*

Study 2: Inter-Examiner Reliability

Three groups consisting of ten diplomates of the ABFO, ten members of the ASFO, and ten general dental practitioners were selected. Each participant received ten bite mark cases, which contained one color and one black-and-white photograph of a simulated bite mark, two computer-generated overlays labeled Suspect A and Suspect B, occlusal views of each suspect's dentition, instructions, and an answer sheet. The instructions and answer sheet were revised from Study 1 to make available the five levels of certainty described by the American Board of Forensic Odontology (4) and a "Don't Know" option within the forced decision model (FDM). Thirty examiners (100%) returned responses. Receiver-operating characteristics (ROC) were used to analyze the multiple-threshold data. Results were entered into tables and analyzed using the PEPI statistical application (11).

Results

Intra-Examiner Reliability

Seven examiners returned completed answer sheets on both occasions (70%) and the intra-examiner reliability was calculated for each (See Table 3). Kappa values were calculated to measure agreement between each of the examinations and to control for chance agreement (12). The kappa values varied from 0.30 to 1.00, or from fair to almost perfect agreement (13). Mean kappa was 0.72, indicating substantial agreement. Percent agreement (non-chance corrected) ranged from 65 to 100% with a mean value of 87.2%.

The mean accuracy for the seven examiners' first and second attempts was 85.7% and 83.5% respectively, with no statistically significant difference between the attempts ($p = 0.6286$). When examining kappa values for comparisons with the gold standard, a mean of 0.70 resulted from the first examination. This decreased slightly to 0.65 for the second examination. Both scores rate as substantial agreement and no significant differences were detected between the attempts ($p = 0.5568$).

The mean values for sensitivity (79.8%) and specificity (90.0%) for the first examination were calculated and compared with the mean sensitivity (73.2%) and specificity (89.3%) values for the second examination. No statistically significant difference was detected between these values (sensitivity $p = 0.5218$, specificity $p = 0.5792$).

Inter-Examiner Reliability

Thirty examiners (ten ABFO, ten ASFO, and ten GDP) returned completed answer sheets. The multiple-threshold ROC data reveal two main results: (a) the individual sensitivity and specificity of each conclusion threshold, and (b) the area under the curve (AUC) as a measure of overall effectiveness (See Table 4). Youden's Index, a measure of agreement using sensitivity and specificity, was also calculated for each of the five possible conclusion levels (See Table 5). The closer Youden's Index is to 1.0 the greater the level of agreement.

ABFO Diplomates—Forced Decision Model

Ten diplomates of the ABFO returned completed answer sheets (100%). Out of 200 decisions, 28 (14%) were "Don't Knows." However, 24 (12%) of these "Don't Knows" were attributable to two examiners (Examiner 2 = 16, Examiner 10 = 8). Excluding these examiners, the uncertain decisions are reduced to only 4 (2%). Sensitivity was calculated for each examiner and ranged

TABLE 3—*Study 1 summary data illustrating percentage agreement between examinations conducted three months apart.*

Examiner	Kappa	S.E.	Percent Agreement
1	0.30	0.222	65
2	0.38	0.219	70
3	1.00	0.224	100
4	1.00	0.224	100
5	0.52	0.224	80
6	0.88	0.222	95
7	1.00	0.224	100
Mean	0.72		87.2%

TABLE 4—*Mean values from ROC analyses.*

Mean Values	ABFO (%)	ASFO (%)	GDP (%)
Area Under the Curve	80.5 ± 11.8	81.0 ± 8.8	80.8 ± 8.0
Sensitivity			
Reasonable Medical Certainty	27.5	23.8	12.5
Probable	57.5	53.8	60.0
Possible	81.3	72.5	76.3
Exclusion	88.8	77.5	60.0
Inconclusive	100.0	100.0	100.0
Specificity			
Reasonable Medical Certainty	98.3	98.5	99.2
Probable	94.9	94.3	93.4
Possible	55.3	74.4	64.2
Exclusion	47.7	68.7	55.9
Inconclusive	0.0	0.0	0.0

TABLE 5—*Summary of ROC results for the three groups studied.*

Level of Conclusion	Sensitivity (%)	Specificity (%)	Youden's Index
ABFO diplomates			
Reasonable Medical Certainty	27.5 ± 24.1	98.3 ± 5.2	0.26
Probable	57.5 ± 26.5	94.9 ± 11.0	0.52
Possible	81.3 ± 22.2	55.3 ± 30.0	0.40
Exclusion	88.8 ± 19.1	47.7 ± 24.0	0.36
Inconclusive	100.0 ± 0.0	0.0 ± 0.0	0.00
ASFO Members			
Reasonable Medical Certainty	23.8 ± 17.1	98.5 ± 4.9	0.24
Probable	53.8 ± 17.7	94.3 ± 8.4	0.48
Possible	72.5 ± 12.9	74.4 ± 11.2	0.47
Exclusion	77.5 ± 14.1	68.7 ± 14.7	0.46
Inconclusive	100.0 ± 0.0	0.0 ± 0.0	0.00
GDP Novices			
Reasonable Medical Certainty	12.5 ± 11.8	99.2 ± 2.3	0.13
Probable	60.0 ± 18.4	93.4 ± 5.3	0.55
Possible	76.3 ± 10.9	64.2 ± 11.9	0.37
Exclusion	83.6 ± 10.3	55.9 ± 11.3	0.37
Inconclusive	100.0 ± 0.0	0.0 ± 0.0	0.00

from 28.6 to 100% with a mean sensitivity of 73.7 ± 22.0%. Specificity for this group ranged from 54.5 to 100% with a mean specificity of 84.1 ± 14.9%. There was no significant difference between the sensitivity and specificity scores ($p = 0.2721$).

Accuracy, determined as percent agreement with the gold standard, ranged from 65.0 to 100% with a mean value of 83.2%. Agreement determined by Cohen's Kappa ranged from 0.22 (fair agreement) to 1.00 (almost perfect agreement). Mean kappa was 0.58 (moderate agreement). Mean false positive rate (FPR) was 15.9%, ranging from 0 to 45.5%. Mean false negative rate (FNR) was 25.0%, ranging from 0 to 71.4%. Positive predictive value (PPV) ranged from 55.5 to 100% with a group mean of 77.7%. Negative predictive value (NPV) ranged from 66.6 to 100% with a group mean of 83.2%.

ROC Analysis—The mean sensitivity, specificity, and Youden's Index for each of the conclusion levels is shown in Table 5. The AUC for the ABFOs ranged from 62.0 to 97.7% (mean 80.5 ± 11.8%).

Reliability—Using Cohen's Kappa, each of the examiners was paired and compared using a crosswise system based on their FDM decisions. From these data it was determined that ten pairs (22%) had slight agreement, 11 pairs (24%) had fair agreement, 13 pairs (29%) had moderate agreement, three pairs (7%) had substantial agreement and eight pairs (18%) had almost perfect agreement. Mean kappa from the crosswise analysis was 0.47 ± 0.31 (moderate agreement).

ASFO Members—Forced Decision Model

Ten members of the ASFO returned completed answer sheets (100%). Out of 200 decisions, 18 (9%) were "Don't Knows." Sensitivity was calculated for each examiner and ranged from 28.6 to 85.7% with a mean sensitivity of 60.9 ± 22.9%. Specificity for this group ranged from 34.6 to 100% with a mean specificity of 82.4 ± 19.7%. There was no significant difference between the sensitivity and specificity scores ($p = 0.378$). Accuracy, determined as percent agreement with the gold standard, ranged from 55.0 to 94.1% with a mean value of 75.8%. Agreement, determined by Cohen's Kappa, ranged from 0.16 (slight agreement) to 0.88 (almost perfect agreement). Mean kappa was 0.50 (moderate agreement).

Mean FPR was 11.9%, ranging from 0 to 27.3%. Mean FNR was 39.3%, ranging from 14.3 to 74.4%. PPV ranged from 59.9 to 100% with a group mean of 79.7%. NPV ranged from 58.4 to 91% with a group mean of 78.1%.

ROC Analysis—The mean sensitivity and specificity for each of the conclusion levels is shown in Table 5. The AUC for the ASFO members ranged from 62.5 to 89.6% (mean 81.0 ± 8.8%).

Reliability—Using Cohen's Kappa, it was determined that three pairs (7%) had poor agreement, five pairs (11%) had slight agreement, nine pairs (20%) had fair agreement, 16 pairs (36%) had moderate agreement, 11 (24%) pairs had substantial agreement and one pair (2%) had almost perfect agreement. Mean kappa from the crosswise analysis was 0.44 ± 0.22 (moderate agreement).

General Dental Practitioners (GDP)—Forced Decision Model

Ten GDPs returned completed answer sheets (100%). Out of 200 decisions, 15 (7.5%) were "Don't Knows." Sensitivity was calculated for each examiner and ranged from 62.5 to 100% with a mean sensitivity of 80.7 ± 13.5%. Specificity for this group ranged from 50 to 100% with a mean specificity of 77.9 ± 15.0%. There was no significant difference between the sensitivity and specificity scores ($p = 0.6001$). Accuracy, determined as percent agreement with the gold standard, ranged from 55.6 to 84.2% with a mean value of 74.7%. Agreement, determined by Cohen's Kappa, ranged from 0.14 (slight agreement) to 0.89 (almost perfect agreement). Mean kappa was 0.56 (moderate agreement).

Mean FPR was 22.0%, ranging from 0 to 50.0%. Mean FNR was 19.3%, ranging from 0 to 37.5%. PPV ranged from 46.0 to 100% with a group mean of 72.7%. NPV ranged from 70.1 to 100% with a group mean of 85.7%.

ROC Analysis—The mean sensitivity, specificity, and Youden's Index for each of the conclusion levels is shown in Table 5. The AUC for the GDPs ranged from 64.1 to 90.6% (mean 80.8 ± 8.0%).

Reliability—It was determined that three pairs (7%) had poor agreement, six pairs (13%) had slight agreement, eight pairs (18%) had fair agreement, 17 pairs (38%) had moderate agreement, ten pairs (22%) had substantial agreement and one pair (2%) had almost perfect agreement. Mean kappa from the crosswise analysis was 0.45 ± 0.23 (moderate agreement).

Comparison of the Three Examiner Groups—Table 5 shows data from the ROC results of the three groups. Table 6 shows a comparison of mean values obtained from the FDM study. There was no statistically significant difference between the distributions of "Don't Knows," kappa values, AUC, accuracy, sensitivity, or specificity between the three groups of examiners when tested with ANOVA.

Discussion

A key feature of modern forensic science is that scientific principles are no longer accepted based on opinion or anecdotal beliefs. This new doctrine has been enforced by legal judgments, such as

TABLE 6—*Mean values for the FDM and crosswise kappa analyses.*

Mean Values	ABFO	ASFO	GDP
Don't Knows	14.0%	9.0%	7.5%
Sensitivity	73.7 ± 22.0%	60.9 ± 22.9%	80.7 ± 13.5%
Specificity	84.1 ± 14.9%	82.4 ± 19.7%	77.9 ± 15.0%
Accuracy	83.2%	75.8%	74.7%
Kappa (Gold standard)	0.58	0.50	0.56
Kappa (Crosswise)*	0.47	0.44	0.45
False Positive Rate	15.9%	11.9%	22.0%
False negative Rate	25.0%	39.3%	19.3%

* Inter-examiner crosswise kappa comparisons.

those described in *Daubert* and *Kumho.* Claims are now to be checked against empirical evidence. The value of this evidence is based on the way it has been collected and presented (14). The purpose of this study was to establish empirical justification for the use of digital overlays in bite mark analysis.

The increased interest in evidence-based medicine and dentistry has revitalized techniques for the assessment of diagnostic effectiveness. The discipline of medical-decision making has employed these techniques in increasingly novel ways to challenge the basis upon which clinical practice is built. Using these techniques, this study has determined quantitative values for the analysis of overlay effectiveness.

During the initial planning stages of this project, considerable thought was given to the use of cases employing either real or simulated bites. The use of real forensic cases as study material has advantages. First, authenticity is assured. Materials used are the same as those handled by forensic dentists during routine casework. Second, many examples of bite marks exist both at the author's laboratory and in other centers. Therefore, the collation and duplication of such materials would be straightforward.

But, several disadvantages are also associated with the use of real cases. The most important of these is that of the gold standard. One of the criteria for assessing the effectiveness of a particular test is to ensure that it is compared against a suitable gold standard. The use of real case materials requires that the conclusions of the original examining odontologist are regarded as such a standard. Due to the lack of published studies, it is impossible to determine how accurate these original conclusions are likely to be. Indeed, it is the purpose of the current study to provide such data.

The use of simulated bite marks enabled greater control over the injury. Variables such as anatomical location, the teeth used to create the bite, the number of teeth in the bite, and the collection of the evidence were easily controlled and standardized. The use of simulations also permitted a consistent quality of materials to be produced, allowing parity between each of the study cases, and removing any potential biases introduced by case variability. However, simulations do have limitations. Significantly, the simulated bites were not on human skin.

Postmortem bites, as used in this study, do not display any of the ecchymosis or bruising patterns that are seen in antemortem or perimortem bite injuries and this could be considered a limitation. However, postmortem injuries do record the details of teeth well. The use of postmortem simulated bites is well accepted within forensic dental research (6,15).

Before discussing the effectiveness of the overlays, it is important to discuss the issue of examiner and test separation so that the results from the FDM and ROC analyses can be placed in the correct context. The performance of individual examiners and their decision-making processes were thought to be separate entities. Originally, it was decided to assess the use of overlays in the identification of biters. To this end, materials supplied to the examiners were limited to those that permitted the use of overlays only. But it was discovered that examiner performance and decision making are not separate. The use of bite mark overlays has been shown to be both examiner and case sensitive. And despite the objectivity of the overlay production technique, the subsequent application of that technique is highly subjective (16). In tests where subjectivity is high, there is always interplay between the operator and the test (17). The separation of operator and test in assessment of performance is impossible. With this caveat in mind, the discussion of the examiners' performance follows.

FDM Performance

The forced decision model allowed the use of simple statistical analysis. The use of terms such as false positive and true negative are easily understood. Hence, the power of this model is in its ease of use and explanation of results. However, there are drawbacks to the model. First, the American Board of Forensic Odontology recommends the use of particular levels of conclusion that are not replicated in the dichotomous decisions offered by the FDM. (There is a speculative argument, however, that the recommended levels of conclusion are simply extrapolated by courts and jurors to a positive or a negative judgment.) Second, the FDM is especially prone to influence by the personal threshold of the examiner.

This study resulted in 539 decisions from the FDM (excluding "Don't Know" decisions). The data that were most useful were the values of sensitivity, specificity, accuracy, and kappa agreement with the gold standard. It should be noted that no forensic dental study, either on the subject of bite marks or on other topics, describing these values was found in the literature. This makes it difficult to compare the values obtained for overlay effectiveness in the current study to other tests in forensic dentistry.

Sensitivity values for the three groups of examiners were not significantly different. The mean sensitivity from the three groups was 71.8%. The GDP novices had the smallest standard deviation among the groups (GDP>ABFO>ASFO) and achieved the highest sensitivity. Specificity values were not significantly different for the three groups. The mean specificity was 81.5%. The ABFO expert group achieved the highest score. In no group was there a significant difference between the sensitivity and specificity scores. These mean values are similar to values for sensitivity and specificity from other dental diagnostic tests.

The use of percentage agreement (accuracy) and kappa allowed a different perspective on the data obtained. In simple terms, how often were the examiners correct? Percentage agreement is a simple measure of this, and the mean across all three groups was 77.9%. The ABFO diplomates were the most accurate examiners scoring a group mean of 83.2%. However, the differences between the groups were small and not statistically significant.

It is interesting to note that two of the diplomates chose "Don't Know" responses for more than half of the cases, resulting in over 85% of the "Don't Know" decisions for this group. Significantly, both of these participants obtained 100% accuracy. This could indicate that they had very high personal thresholds to identify or exclude biters. Mathematically, their responses resulted in increasing the diplomates' mean accuracy. When these participants are removed from consideration, the mean accuracy of the diplomates group dropped to 78.5%. The results indicate that these two examiners are unlikely to render opinions in bite mark cases that are presented to them. However, if they were prepared to reach a conclusion, then it would most likely be highly accurate.

A more powerful technique for quantifying agreement with a gold standard is the chance-corrected kappa value. The mean for all three groups with this value was 0.54; the diplomates scored the highest kappa at 0.58. When Examiners 2 and 10 were removed, the mean kappa for diplomates dropped to 0.54, which placed the GDP kappa (0.56) as the highest. Regardless if these outlying examiners are included or excluded, the mean kappa score for all three groups falls into the "moderate agreement" category of the Landis rating scale (12,13).

No significant difference was detected between the three groups of examiners using any of the measured values. This indicates that training and experience have little effect on the application of overlays to bite mark identifications. However, caution must be applied in this conclusion since more detailed questionnaires would be required to identify correctly all of the variables surrounding experience and training.

ROC Analysis

The use of ROC enabled a range of conclusions, including "Don't Knows," to be incorporated into the analysis. Because this technique allowed the examiners to express their certainty within the established levels of conclusions, the operator sensitivity issues found in the FDM were minimized. ROC analysis provides a means by which the identification of biters using transparent overlays can be distinguished from the judgment of the operator. This separation is achieved by using a rating scale that is equivalent to varying the examiner's personal threshold while holding the properties of the bite mark constant. The area under the curve provides an objective parameter of the diagnostic accuracy of the test (the ability to determine biters) that is far superior to comparing single combinations of specificity and sensitivity because the influence of threshold is eliminated (18–20) (See Table 4). The AUC is a combination and generalization of the concepts of sensitivity and specificity into a single measure of accuracy (21). In this study, the AUC values from the three groups were very similar, with the ASFO members having the value closest to 100% (perfect diagnostic test). Six hundred decisions made up the AUC analysis. The mean AUC for the combined groups was 80.7%, which means that the biter was correctly determined approximately eight out of ten times.

It is difficult to place this result into context. A value of 50% assumes that a test is nondiagnostic. Thus, bite mark overlays are closer to the perfect diagnostic test than a purely random allocation of biters and nonbiters. Whittaker's study determined a mean AUC of 63% for the determination of whether bites were caused by adults or children (22). Comparison of these results with those of the current study indicate that the use of overlays in determining biters is more effective than the subjective determination of biter age group. But, this is not a particularly useful comparison and serves only to allow a point of reference. Further research into bite mark identification techniques is required to produce a range of AUC values from other methods and contexts. These data will then enable a comparison of techniques and move the discipline to a more evidence-based approach. The ease by which AUC can be calculated and compared promises to allow exciting additional research possibilities in the future. Studies could be carried out using the same base materials as in this study (i.e., bite mark photographs) but adding other items of dental evidence from suspects, including wax test bites or dental casts. Following calculation of the area under the curve, it would be possible to determine the relative impact of each item on the identification of biters from bite marks.

Conclusions

The continued use of computer-generated overlays in bite mark analysis appears to be justified, although further work is required to investigate the effect of examiner factors. In this study, no statistically significant differences were detected between the three examiner groups. This suggests that training and experience in forensic casework does not affect the success of overlays in correctly determining the biter. This work has satisfied the requirements of *Daubert* in relation to determining error rates and other quantifiable values.

This study has examined the scientific basis for bite mark comparisons. The significance of the results will be realized in courts of law. While the overall effectiveness of overlays has been established, the variation in individual performance of odontologists is of concern. This variation is of particular importance to those odontologists testifying in court who must be aware of their own values of accuracy and reliability. Poor performance as an expert witness during testimony can have very serious implications for the accused, the discipline, and society.

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EXHIBIT C
APPENDIX B

Annotated Bibliography of the Peer Reviewed Literature concerning Bitemark Analysis

Bush, M, Bush, P, Pretty IA.

This bibliography is comprehensive, but is known not to be complete. The authors feel, however, that the majority of significant publications are represented.

The primary and secondary literature is covered (peer-reviewed original papers and review articles). The tertiary literature is not covered (books).

Bibliography:

1. 1960 Fearnhead RW. Med Sci Law; 1:273-77 Facilities for forensic odontology. Describes the use of hand drawn acetate overlays. Draws the conclusion that "evidence which involves the identification of a person by tooth-marks left as bruises in flesh should never be admitted". Describes simple experiment. One of the first papers to question the use of bitemark evidence based upon the reliability of the technique.

2. 1963 Taylor DV. Brit Dent J; 114:389 The law and the dentist. Written by a dual qualified dentist and lawyer. Describes all aspects of forensic dentistry, including bitemarks. States "..unlikely to establish convincing proof in most cases".

3. 1966 Layton JJ. J Forensic Sci Soc; 6:76-80 Identification from a bitemark in cheese. A bitemark in cheese found at a crime scene. Control bitemark made in similar cheese by the suspect and twenty points of similarity are discussed. Suspect admitted guilt. States that BMs can never be as positive as fingerprints.

4. 1966 Harvey W, Butler O, Furness J, Laird R. J Forensic Sci Soc; 8(4):157-219 The Biggar murder. Dental, medical, police and legal aspects of a case "in some ways unique, difficult and puzzling". Extensive case report detailing a Scottish murder in which bitemark evidence played a key role in the conviction of the defendant.

5. 1968 Furness J. Br Dent J; 124(6):261-7 A new method for the identification of teeth marks in cases of assault and homicide. Paper describes the inking of the occlusal surfaces of the teeth which are then photographed and placed on white board. Lines of comparison are drawn with photographs of the injury. Technique is still used today for court exhibits depicting bitemark comparisons.

6. 1969 Furness J. J Forensic Sci Soc; 9:126-75 Teeth marks and their significance in cases of homicide. Paper claims to differentiate between marks made in self-defence, those made sadistically and "love-nips". Unconvincing. Numerous case examples given. There is somewhat of a debate on the psychology of biting and the inferences that can be made about an attacker from the injury.

7. 1970 Hodson JJ. Med Sci Law; 10(4):247-51 Forensic odontology and its role in the problems of the police and forensic pathologist. Paper outlines the value of forensic dentistry to the police. Recommends the type of dentists who should be called to assist. Summarizes with case reports including a bitemark case on two young children.

8. 1970 Levine LJ, Beaghler RL. NY State Dent J; 36(9):539-42 Forensic odontology - a routine case and commentary. This paper, written for the general practitioner, mentions bitemarks only in passing. The majority of the paper is devoted to an identification case.

9. 1970 Furness J. Probe; 11:221-22 Dental evidence in a case of rape. Case report describing a bite to the nose of an assailant.

10. 1971 DeVore DT. Med Sci Law; 11(3):144-5 Bitemarks for identification? A preliminary report. Author used ink models to place marks on living volunteers and cadavers. Photographs of the marks were taken in several body positions. Skin from the cadavers bearing the ink was excised. Paper concludes that there is a large margin of error in using bitemark photographs and unsecured excised skin. States that the exact position of the body when bitten must be known and replicated. A useful study. Little attention has been paid to this paper that encourages caution when examining bite injuries.

11. 1972 MacDonald DG, MacFarlane TW. Glasg Dent J; 3(1):16-9 Forensic odontology. Report of a case involving bitemarks. Case report of a bitemark on a living victim.

12. 1973 Stoddart TJ. Br Dent J; 135(6):285-7 Bitemarks in perishable substances. A method of producing permanent models. A method for producing accurate models of bitten materials, silicone impression material is recommended. Technique described is still applicable today.

13. 1973 Butler OH. Int J Forens Dent; 1(1):23-4 The value of bitemark evidence. Written by a police officer, this paper discusses the types and presentation of dental evidence.

14. 1973 Woolridge ED. Int J Forens Dent; 2(1):6-12 Significant problems of the forensic odontologist in the USA. Describes some of the legal issues that

surround forensic dentistry. This topic has been addressed in more contemporary articles.

15. 1973 Harvey et al. Int J leg Med; 1973;(8):3-15. Bite-marks the clinical picture; physical features etc. First paper to show stress/strain curve for skin. Remarkable biting experiment on live volunteer with tissue specimens taken. Paper focuses on ‘suckling’ as a factor.

16. 1973 Luntz, L. L. and P. Luntz. "Case in Forensic Odontology - Bite-Mark in a Multiple Homicide." Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics **36**(1): 72-78. Case report.

17. 1974 Marshall W. Criminol; 9(32):21-34 Bitemarks in apples - forensic aspects. Paper describes the stability and usefulness of bites in a variety of different types of apple.

18. 1973 Sims BG, Grant JH, Cameron JM. Med Sci Law; 13(3):207-10 Bitemarks in the 'battered baby' syndrome Describes the frequent occurrence of bite injuries in child abuse cases and presents three cases.

19. 1974 Simon A, Jordan H, Pforte K. Int J Forens Dent; 2:17-2 Successful identification of a bitemark in a sandwich. Case report describing a bitemark in a sandwich.

20. 1974 Jonason CO, Frykholm KO, Frykholm A. Int J Forensic Dent; 2(6):70-8 Three dimensional measurement of tooth impression of criminological investigation. Use of a stereomicroscope to measure the three dimensional aspects of bitemarks. Later repeated using scanning electron microscopy.

21. 1974 Clift A, Lamont CM. J Forens Sci Soc; 14(3):241-5 Saliva in forensic odontology. Describes the methods for collecting and analysing saliva for the determination of blood groups. Influential paper, although now superseded by DNA work.

22. 1974 Dinkel EH Jr. J Forens Sci; 19(3):535-47 Use of bitemark evidence as an investigative aid. Reviews the current (74) literature dealing with the handling and examination of bitemarks. Includes a discussion of the legal implications of the time. Case reports described. Comprehensive, and describes areas in which improvement must be made.

23. 1974 Barbanel JC, Evans JH. J Forensic Sci Soc; 14(3):235-8 Bitemarks in skin - mechanical factors. Describes the mechanical factors used to produce a bite, including tongue pressure and suction. States that the properties of particular skin area bitten may affect the appearance of a bitemark. Clear and concise coverage of the topic that has not been addressed since.

24. 1974 Millington PF. J Forensic Sci Soc; 14(3):239-40 Histological studies of skin carrying bitemarks. Histological examination of bites from both living and deceased individuals. States that complete recovery of a bite injury may take 2 or 3 weeks. States that the use of histology in determining the time of the injury may be helpful. The ageing of wounds, and in particular bitemarks, is still debated.

25. 1974 MacDonald DG. J Forensic Sci Soc; 14(3):229-33 Bitemark recognition and interpretation. Describes a method of classification of bitemarks based on their aetiology.

26. 1974 MacFarlane TW., MacDonald DG, Sutherland DA. J Forensic Sci Soc; 14(3):247-52 Statistical problems in dental identification. Discusses the issue of the individuality of the human dentition and describes an experiment to determine this. Authors conclude that their preliminary data supports the notion that human teeth are unique to an individual level. Study looked at incidence of certain dental traits in the anterior dentition. N=200.

27. 1974 Ruddick RF. Med Biolo Illus; 24(3):128-9 A technique for recording bitemarks for forensic studies Describes the use of alternative light sources for the enhancement of bitemark injuries. A subject of interest to many forensic dentists.

28. 1975 Sognnaes RF, Therrell R. J Cal Dent Assoc; 3(10):50-3 Bitemark lesions in human skin caused by an unequivocally identified 'suspect'. Describes an accidental bite caused by a child on her father.

29. 1975 Solheim T, Leidal TI. Forensic Sci; 6(3):205-15 Scanning electron microscopy in the investigation of bitemarks in foodstuffs. In this study students with no obvious irregularities on their anterior teeth were asked to bite various foodstuffs. Using SEM the marks were analysed and the authors concluded that as many individual characteristics were visible the technique was useful in forensic investigations. An interesting technique, although infrequently used in case work.

30. 1975 Whittaker DK. Int Dent J; 25(3):166-71 Some laboratory studies on the accuracy of bitemark comparisons. Author studied bites in wax and on pig skin. Found that those on pig skin were less reliable than those on wax in terms of biter identification. Highest accuracy found was 76%. Extrapolates that bites on human skin may be similarly unreliable; offers a warning that more research is required. Highly cited paper - often regarded as one of the first attempts to validate the science of bitemark analysis. Warning went unheeded.

31. 1975 Whittaker DK, Watkins KE, Wiltshire J. Int J Forensic Dent; 3:2-7 An experimental assessment of the reliability of bitemark analysis. Same paper as described above - republished with some editorial differences and apparently two new authors.

32. 1976 Bang G. Acta Odontol Scand; 34(1):1-11 Analysis of tooth marks in a homicide case. Observations by means of visual description, stereo-photography, scanning electron microscopy and stereometric graphic plotting. Author was asked to re-examine a bitemark case involving an injury to a breast. Using novel techniques, including SEM, the author found that the originally convicted individual was the likely biter.

33. 1976 Anderson WR, Hudson RP. Forens Sci; 7(1):71-4 Self inflicted bitemarks in battered child syndrome. Victim of child abuse victim had bitemarks on both arms. Authors demonstrated that the bite was from the victim. Importance of this phenomenon in evaluation of bite injuries is discussed. Used transparent overlays in analysis. Established that bites can be self-inflicted.

34. 1976 MacDonald DG, Laird WR Int J Forensic Dent; 3(10):26-30 Bitemarks in a murder case. Case report describing a murder involving a bite to the abdomen and breast. Authors describe the use of statistics to determine the number of individuals capable of producing the bite. Statistical evidence was presented in court. Use of statistics is interesting in this case. Arrived at a figure of 1 in 62 million. It must be noted that approximately half of the Scottish population were edentulous at this time.

35. 1976 Sognnaes RF. Int J Forensic Dent; 3(9):14-6 Dental science as evidence in court. Describes some applications of forensic dental techniques in court.

36. 1976 Mills PB. Int J Forensic Dent; 3:38-9 An unusual case of bitemark identification. Describes a bitemark on a bullet.

37. 1976 Vale GL, Sognnaes RF, Felando GN, Noguchi TT. J Forensic Sci; 21(3):642-52 Unusual three-dimensional bitemark evidence in a homicide case.
Describes a case of bitemark identification. Bite was on victim's nose. Authors concluded a positive match and this became the first case in Californian Law using bitemark evidence.

38. 1976 Goodbody RA, Turner CH, Turner JL. Med Sci Law; 16(1):44-8 The differentiation of toothed marks: report of a case of special interest. Discusses the differences between bite injuries and "toothed" injuries such as those made by a saw. Used acetate film to compare to a suspect's dentition.

39. 1977 Levine LJ Dent Clin N Amer; 21(1):145-158 Bitemark evidence. Review followed by numerous case reports.

40. 1977 Sognnaes RF. Int J Forensic Dent; 4(13):17-20 The case for better bite and bitemark preservations. Describes the excision of skin and the use of elastomeric impression materials for the preservation of bitemark evidence.

41. 1977 Kerr NW. Int J Forensic Dent; 4:20-23 Apple bitemark identification of a suspect. Simple case report of a bitemark in an apple found after a house break-in.

42. 1977 Sognnaes RF. J Cal Dent Assoc; 4:22-8 Battered child death involving enigmatic bitemark evidence. Cases report describing bitemark evidence in a child abuse case. Describes comparison technique and the legal outcome. Uses SEM.

43. 1977 Sognnaes RF. New Eng J Med; 296:79-85 Forensic stomatology. Three part series. Sognnaes reviews the forensic literature in a three part series as part of the Medical Progress section. Various methods of forensic evaluation of bitemarks are discussed.

44. 1978 Sognnaes RF. Dental Survey; 54(12):12-24 Forensic oral measurements. A review of the "state-of-the-art" of forensic dentistry.

45. 1979 Beckstead JW, Rawson RD, Giles W. JADA; 99(1):69-74 Review of bite mark evidence. A general review.

46. 1979 Morrison HL. J Forens Sci; 24(2):492-502 Psychiatric observations and interpretations of bite mark evidence in multiple murders. Interesting paper in which the author describes over 400 hours of contact time with a serial murder who bit many of his victims. Whilst not answering "why do people bite?" author raises interesting questions. The psychological aspects of bitemarks are yet to be firmly established.

47. 1979 Rawson RD, Bell A, Kinard BS, Kinard JG J Forens Sci; 24(4):898-901 Radiographic interpretation of contrast-media-enhanced bite marks. Describes a techniques of radiographing soft -tissue that has been removed from cadavers. Study used postmortem bites.

48. 1979 Aitken C, MacDonald DG. An application of discrete kernel methods to forensic odontology. Applied Statistics, 28:1;55-61. Probability study using MacFarlane's 1974 dataset of 200 subjects. No practical value.

49. 1980 Glass RT, Andrews EE, Jones K 3d. J Forens Sci; 25(3):638-45 Bitemark evidence: a case report using accepted and new techniques. Case report with bitemarks found on a murder victim. Authors describe the use of novel techniques including microbiologic and histologic/histochemical. Preparation and presentation of evidence are discussed.

50. 1980 Holt JK. J Forensic Sci Soc; 20(4):243-6 Identification from bitemarks. A collection of case reports describing different methods of augmenting bite photographs and production of 3D models of bite injuries.

51. 1981 Furness J. Am J Forensic Med Pathol; 2(1):49-52 A general review of bitemark evidence.

A personal recollection of a forensic dentist, describes case work and issues around bitemarks in English law. No papers cited.

52. 1981 Sperber ND, Lubin H. J Am Col Health Association.; 29(4):165-7 Bite mark evidence in crimes against persons. Paper describes bites for college and university health workers and security personnel. Techniques for photographing the injuries are presented.

53. 1981 Jakobsen JR, Keiser-Nielsen S. Forensic Sci Int; 18(1):41-55 Bitemark lesions in human skin. Case of severe bitemarks on the back of a male victim. The authors used a volunteer to repeat the bite injuries for comparison. Ethical issues surround the use of human volunteers in bitemark studies.

54. 1981 Sognnaes, R. F., R. D. Rawson, et al. (1981). "Computer Comparison of Radiographic Bite-Mark Patterns in Identical-Twins." Journal of the Forensic Science Society **21**(2): 144-144.

55. 1981 Suzuki, K., M. Hashimoto, et al. (1981). "Bite Mark Evidence - a Case-Report and Preliminary-Study." Journal of the Forensic Science Society **21**(2): 147-148. Case report.

56. 1982 Dorion RB. J Can Dent Assoc; 48(12):795-8 Bite mark evidence. General review.

57. 1982 Webster G. Forensic Sci Int; 20(1):45-52 A suggested classification of bitemarks in foodstuffs in forensic dental analysis. Author states that it is the labial surfaces rather than the biting edges that are responsible for bitemarks in food. Webster suggests an alternate terminology to bring uniformity in describing such evidence. Bitemarks in food are rare in criminal cases, although recently cheese has yielded DNA from a bite.

58. 1982 Sognnaes RF, Rawson RD, Gratt BM, Nguyen NB. JADA; 105(3):449-51 Computer comparison of bitemark patterns in identical twins. Using computer technology and radiographic bitemark analysis the authors conclude that occlusal arch form and individual tooth positions, even in identical twins are in fact unique. This paper is frequently cited as evidence of dental "uniqueness". Highly cited paper, frequently used as part of the dental uniqueness argument.

59. 1982 Rudland M. Med Sci Law; 22(1):47-50 The dimensional stability of bitemarks in apples after long-term storage in a fixative. Paper describes the method for preserving a variety of apple types. Used a pre-defined mark which was examined over a period of ten years, with little distortion noted.

60. 1983 Irons F, Steuterman MC, Brinkhous W. Am J Forensic Med Pathol; 4(2):177-80 Two bitemarks on assailant. Primary link to homicide conviction. Two bitemarks were found on a suspect in a homicide. The authors state that the injuries matched the victims' teeth and the suspect pled guilty to the offence.

61. 1983 McCullough DC. Am J Forensic Med Pathol; 4(4):355-8 Rapid comparison of bitemarks by xerography. Case report of bite in cheese, the detective used a photocopier to record the evidence.

62. 1983 Ligthelm AJ, de Wet FA. J Forens Odontstomatol; 1(1):19-26 Registration of bitemarks: a preliminary report. Used bites on sheep to investigate methods of recording bitemarks. Utilized SEM to compare back to the human volunteers who bit the sheep.

63. 1983 Deming JE, Mittleman RE, Wetli CV J Forens Sci; 28(3): 572-6 Forensic science aspects of fatal sexual assaults on women. The authors review the case files of 41 female victims of proven fatal sexual assault. Describe bitemarks as not infrequent in such crimes.

64. 1983 Vale GL, Noguchi TT. J Forens Sci; 28(1):61-9 Anatomical distribution of human bitemarks in a series of 77 cases. Paper which examined the author's own cases to establish common bite locations. Seminal paper, establishes the nature of bites and likely crimes.

65. 1984 Rawson RD, Brooks S. Am J Forensic Med Pathol; 5(1):19-24 Classification of human breast morphology important to bitemark investigation. Describes the range of breast morphologies found and their likely impact on bitemark analysis.

66. 1984 Walter RA. Am J Forensic Med Pathol; 5(1):25-9 An examination of the psychological aspects of bitemarks. Paper attempts to examine some of the psychological threads which appear to be operative for the perpetrator of bite marks. Author makes outrageous claims. Walter later discredited.

67. 1984 Corbett ME, Spence D. Br Dent J; 157(8):270-1 A forensic investigation of teeth marks in soap. A bite mark in soap was used as evidence in the prosecution of a homicide of a 2 year old girl.

68. 1984 Elliot TR. Rogers AH. Haverkamp JR. Groothuis D. Forens Sci Int; 26(2):131-7 Analytical pyrolysis of Streptococcus salivarius as an aid to identification in bitemark investigation Authors describe "finger-printing" strains of Streptococcus salivarius. The results of the analysis of isolates from two individuals are presented, illustrating the differentiation of S. salivarius at strain level according to the origin of the isolate.

69. 1984 Brown KA. Elliot TR. Rogers AH. Thonard JC. Forensic Sci Int; 26(3):193-7 The survival of oral streptococci on human skin and its implication in bitemark investigation. Authors describe their experiments for recovering bacteria from saliva. Found that after 24 hours on skin viable bacteria could still be removed.

70. 1984 Dorion RB. J Can Dent Assoc; 50(2):129-30 Preservation and fixation of skin for ulterior scientific evaluation and courtroom presentation. Describes a method for removing and preserving human skin exhibiting bite injuries. Author uses acrylic which is placed on the skin, cyanoacrylate glue used to stick the acrylic ring to the skin and the tissue excised. Three year preservation achieved little or no post fixation shrinkage. No discussion of how the lack of shrinkage was assessed. Numerous photographs illustrate the procedure well.

71. 1984 Krauss TC J Forens Sci; 29(2):633-8 Photographic techniques of concern in metric bite mark analysis. Author advises the use of a rigid ruler for scale, proper camera positioning in relation to the scale, and a method to evaluate the distortion in a two-dimensional print that records a three-dimensional object is suggested. Disregarding these factors makes metric bite mark analysis inappropriate.

72. 1984 Rawson RD. J Forens Sci; 29(1):245-53 Statistical evidence for the individuality of the human dentition. A general population sample of bite marks in wax was used to determine how unique bites are. Authors conclude that the analysis confirms the unique nature of human bites. Seminal paper, but incorrectly assumed that tooth position is uniformly distributed and not correlated. Used the product rule to calculate probability. Refuted by Bush et al, 2011.

73. 1984 Rawson RD. J Forens Sci; 29(1):254-9 Incidence of bitemarks in a selected juvenile population: a preliminary report. A study of the frequency of bite marks among sheltered children. Found an incidence of 1 545 bite marks per 100 000 population. Analysis of the age, sex, and location of bite marks is presented.

74. 1984 Karazulas CP. J Forens Sci; 29(1):355-358 Presentation of bitemark evidence resulting in the acquittal of a man after serving seven years in prison for murder Author describes case in which he appeared for the defense with another odontologist testifying for the prosecution. 3 months of bitemark analysis.

75. 1984 Rao VJ, Souviron RR. J Forensic Sci; 19(1):326-30 Dusting and lifting the bite print: a new technique. Utilizing the powder and brush method employed in lifting fingerprints, one of the authors was able to lift tooth prints on the body surface of both living and dead victims. Possibly a useful technique but never revisited.

76. 1984 Fellingham SA, Kotze TJ, Nash JM. J Forensic Odonto-Stomatology 2:2, 45-52. Probabilities of Dental Characteristics. Combination review and study of statistical probability of dental configurations. Found 4% match rate in two out of three populations studied.

77. 1984 Sperber, N. D. (1984). "A Bite Mark Being the Only Item of Physical Evidence That Led to the Conviction of a Suspect in a Southern Californian Mutilation Homicide Case." Journal of the Forensic Science Society **24**(4): 304-305.

78. 1984 Sperber, N. D. (1984). "Procedures in Recording Bite Mark Evidence in Sexual Assault and Child-Abuse Cases." Journal of the Forensic Science Society **24**(4): 305-305.

79. 1985 Krauss TC, Warlen SC. J Forens Sci; 30(1):262-8 The forensic science use of reflective ultraviolet photography. The procedure for reflective ultraviolet photography in bite mark cases is presented. Technique is described as simple and inexpensive.

80. 1985 Havel DA Journal of Biological Photography. 53(2):59-62 The role of photography in the presentation of bitemark evidence. Paper explains the various photographic techniques that can be used with bitemark evidence.

81. 1985 Walter RD. Am J Forensic Med Pathol; 6(3):219-21 Anger biting - the hidden impulse. Examines principle of anger related biting, describes memory loss of biting incidents and offers a framework to resolving anger biting by decompressing the emotional content. Needs a serious assessment.

82. 1985 Drinnan AJ, Melton MJ. Int Dent J; 35(4):316-21 Court presentation of bitemark evidence. Instructs readers on court presentation techniques and gives details on how to avoid common pitfalls. Opens with the acceptance that an individual's bite is unique. Quote twin study as support for this and supported by Rawson et al. Discusses the polarization of expert opinions. Describes Frye.

83. 1985 Sobel, M. N. and J. A. Perper (1985). "Self-Inflicted Bite Mark on the Breast of a Suicide Victim." American Journal of Forensic Medicine and Pathology **6**(4): 336-339. Case report.

84. 1985 Bernstein ML. J Forens Sci; 30(3):958-64 Two bitemark cases with inadequate scale references. Both cases illustrate that a technical infraction in processing and recording bite marks, though serious, need not automatically disqualify the analysis.

85. 1986 Sperber N. Forensic Sci Int; 30(2-3):187-93 Identification of children and adults through federal and state dental identification systems: recognition of human bitemarks. Mainly a discussion of human dental identification - the paper contains a small section on human bitemarks to complete the forensic dental review.

86. 1986 David TJ. J Forens Sci; 31(3):1126-34 Adjunctive use of scanning electron microscopy in bitemark analysis: a 3D study. Case report in which adjunctive use of scanning electron microscopy (SEM) demonstrated the presence of

unusual three-dimensional characteristics in a bite mark. Technical problems with images.

87. 1986 Rawson RD, Vale GL. J Forens Sci; 31(4):1261-8 Analysis of photographic distortion in bitemarks: a report of the bitemark guidelines committee. States that some degree of distortion is found in all bitemarks. A method of analyzing the distortion is presented. Recommend a 90o angle for bitemark photography.

88. 1986 Rawson RD, Vale GL, Sperber ND, Herschaft EE, Yfantis A. J Forens Sci; 31(4):1235-60 Reliability of the Scoring System of the American Board of Forensic Odontology for Human Bite Marks. The various methods of determining the validity of the scoring guide are presented with statistical data generated from scores reported by recognized forensic science experts. States that this paper represents the first truly scientific approach to bitemark analysis. Emphasize the need for peer review. The paper was ultimately disregarded as overly complex and the system never gained credibility with forensic dentists.

89. 1986 ABFO Inc. JADA; 112:383-6 Guidelines for bitemark analysis. This paper, written by the members of the Bite Mark Committee, presents guidelines for the proper investigation of bite injuries. The article cites Hale's 78 paper as an instigator in the process of establishing protocols. These guidelines include a discussion of the controversial bitemark scoring system. Despite being described as "dynamic" these guidelines were not updated.

90. 1986 Bernstein, M. L. (1986). "Testing the Bite Mark." Journal of the American Dental Association **112**(6): 806-806. Letter to the editor.

91. 1986 Wagner GN. Pediatric Dentistry 1986;8: Special issue 1. 96-100 Bitemark identification in child abuse cases. General review of causes and occurrence of BM in children.

92. 1987 Warnick AJ, Biedrzycki L, Russanow G. J Forensic Sci; 32(3):788-92 Not all bite marks are associated with abuse, sexual activities, or homicides: a case study of a self-inflicted bitemark. A case of self-inflicted bite mark during an episode of myocardial ischemia is presented. Paper alerts odontologists to the non-criminal bite.

93. 1987 Ligthelm AJ, Coetzee WJ, van Niekerk PJ. J Forensic Odont;97
5(1):1-8 The identification of bite marks using the reflex microscope. Used bitemarks in cheese, apples and chewing gum. The use of the reflex microscope is described. Not used in casework.

94. 1987 Farrell, W. L., R. D. Rawson, et al. (1987). "Computerized Axial-Tomography as an Aid in Bite Mark Analysis - a Case-Report." Journal of Forensic Sciences **32**(1): 266-272. Case report.

95. 1987 Dorion RB. J Forens Sci; 32(3):690-7 Transillumination in bite mark evidence. Author describes the value of using transillumination in the examination of bitemarks. Author describes the technique's use when bites are poorly defined, barely visible, or obscured by other superimposed bite marks or traumatic injury patterns. Controversy surrounds the removal of tissue from victims of crime. Does the increase in evidentiary value justify this mutilation?

96. 1988 Zarkowski P. J Law & Ethi Dent; 1(1):47-57 Bite mark evidence: its worth in the eyes of the expert. Excellent review of the legal status of bitemarks. States " [BMs] evolved from a weak beginning….never progressed through a testing phase to measure accuracy and reliability" Recommends cautious use.

97. 1988 Hyzer WG, Krauss TC. J Forensic Sci; 33(2):498-506 The Bite Mark Standard Reference Scale--ABFO No. 2. The ABFO scale is now universally adopted by not only forensic dentists but also many other forensic professionals. This paper describes the design and constructional features of the scale and offers guidelines for its effective application to bite mark photography. Paper describes an important tool in BM investigations.

98. 1988 Benson, B. W., J. A. Cottone, et al. (1988). "Bite Mark Impressions - a Review of Techniques and Materials." Journal of Forensic Sciences **33**(5): 1238-1243. Method paper.

99. 1988 Vale GL, Rawson RD. J Forensic Sci; 33(1):20 Discussion of "Reliability of the scoring system of the ABFO for human bitemarks" A "back-track" from the scoring system, advising caution when using the index and recommending more research. Brought to an end the point system - no further work was carried out.

100. 1988 Summers, R. and D. A. Lewin (1988). "Photographic Procedures Relating to Bite Mark Evidence." Journal of the Forensic Science Society **28**(3): 211-212. Method paper.

101. 1989 Gundelach A. J Forensic Odont;7(2):11-6 Lawyers' reasoning and scientific proof: a cautionary tale in forensic odontology. Describes a legal case and states that a cautious approach to bitemark evidence should be taken. Yet another paper which advises caution when using bitemark evidence. Little attention paid to such articles.

102. 1989 Grey, T. C. (1989). "Defibrillator Injury Suggesting Bite Mark." American Journal of Forensic Medicine and Pathology **10**(2): 144-145. Case report.

103. 1989 Dailey, J. C., A. F. Shernoff, et al. (1989). "An Improved Technique for Bite Mark Impressions." Journal of Prosthetic Dentistry **61**(2): 153-155. Method of taking impression using low viscosity impression and custom tray materials.

104. 1990 Whittaker DK Dental Update; 17(9):386-90 Principles of forensic dentistry: 2. Non-accidental injury, bitemarks and archaeology. The paper reviews the role of the forensic dentist with respect to non-accidental injury to children, analysis of bite marks, and archaeological investigations. Another review on this subject.

105. 1990 West MH, Barsley RE. Mississippi D Ass J; 46(4):7, 11-2 First bite mark convictions in Mississippi. Case reports of bitemark cases in this State.

106. 1990 West MH, Barsley RE, Frair J, Seal MD. J Forensic Sci; 35(6):1477-85 The use of human skin in the fabrication of a bite mark template: two case reports. In this article skin was used as a template for the reproduction of a bite. In one case the victim's skin was used; in the other, the skin of a anatomically similar person was used. The use of inked dental casts, photography, and transparent overlays significantly reduced the errors common to analysis of bite marks in these highly curved areas. Novel technique although not well accepted.

107. 1990 Pierce LJ, Strickland DJ, Smith ES Am J Forensic Med Pathol; 11(2):171-7 The case of Ohio v. Robinson. An 1870 bite mark case. This trial represents an early and perhaps the first attempt to admit bite-mark evidence in a court of law in the United States. First case - historical value only.

108. 1990 Barsley RE, West MH, Fair JA. Am J Forensic Med Pathol; 11(4):300-8 Forensic photography. Ultraviolet imaging of wounds on skin. This article discusses the photographic techniques involved in reflective and fluorescent UVL. Documentation of skin wounds via still photography and dynamic video photographic techniques, which utilize various methods of UV illumination, are covered. The use of advanced photographic techniques has been questioned in courts.

109. 1990 R T Allison and D K Whittaker 1990 43: 600-603*J Clin Pathol* of Use of benzidine for histological demonstration of haemoglobin in human bite marks. Describes use of a prohibited carcinogen to stain for haemoglobin.

110. 1991 Dailey JC. J Forensic Sci; 36(2):565-70 A practical technique for the fabrication of transparent bite mark overlays. A quick, inexpensive, and accurate technique for generating transparent overlays, using office photocopy machines, for use in bite mark case analysis is presented. Photocopy technique was the 1st attempt to produce an objective overlay with precision.

111. 1992 Robinson E, Wentzel J. J Forensic Sci; 37(1):195-207 Toneline bite mark photography. A high-contrast film technique previously used primarily in the graphic arts field has been refined and applied to forensic odontology.

112. 1993 Mailis NP. J Forensic Odont; 11(1):31-3 Bitemarks in forensic dental practice: the Russian experience. Cases from Russia are described.

113. 1993 Figgener L. J Forensic Odont; 11(2):71-5 Points of contact between quality issues and forensic aspects. Issues related to jurisprudence.

114. 1994 Ligthelm AJ, van Niekerk PJ J Forensic Odont; 12(2):23-9 Comparative review of bitemark cases from Pretoria, South Africa. The purpose of this study was to record the experiences with bitemark cases presented to forensic odontologists at the University of Pretoria from 83-93 and to compare them with trends and findings elsewhere. Some details on anatomical locations may be useful.

115. 1994 Wood RE, Miller PA, Blenkinsop BR. J Forensic Odont; 12(2):30-6 Image editing and computer assisted bitemark analysis: a case report. Three different approaches for comparison with the bitemark photograph were utilized: comparison with radiographs of amalgam-filled impressions of dental casts, a transparent overlay technique and comparison with photographs of a simulated bitemark inked onto the hand of a volunteer.

116. 1994 Thompson IO, Phillips VM. J Forensic Odont; 12(2):37-40 A bitemark case with a twist. This is a case report in which the bite patterns of two suspects were compared to a bitemark on the breast of a murder victim. Each suspect had sufficient concordant features to have been found guilty of producing the bitemark. The irony in this case is that the bitemark was not inflicted by the murderer.

117. 1994 Aboshi H, Taylor JA, Takei T, Brown KA. J Forensic Odont; 12(2):41-4 Comparison of bitemarks in foodstuffs by computer imaging: a case report. Marks in cake discovered at a crime scene were examined and compared with the teeth of a suspect arsonist. The comparison was made by computer imaging analysis and a remarkable similarity in arch shape was observed.

118. 1994 Jessee SA Paediatric Dentistry; 16(5):336-9 Recognition of bite marks in child abuse cases. Health professionals must be attentive to any and all signs of child maltreatment. Bite marks are one of several visual expressions of active child abuse. Another paper describing this important issue.

119. 1994 Barry LA Bull Hist Dent; 42(1):21-7 Bite mark evidence collection in the United States. A legal historical review.

120. 1994 Nuckles DB, Herschaft EE, Whatmough LN. General Dentistry. 42(3):210-4 Forensic odontology in solving crimes: dental techniques and bite-mark evidence.
Usual review of technique and legal issues.

121. 1994 David, T. J. and M. N. Sobel (1994). "Recapturing a 5-Month-Old Bite Mark by Means of Reflective Ultraviolet Photography." Journal of Forensic Sciences **39**(6): 1560-1567. The Kunco case report. Astonishing claim of being able to positively identify a bite perpetrator based on a 5 month old bitemark. Appeal denied in 2011.

122. 1994 Golden, G. S. (1994). "Use of Alternative Light-Source Illumination in Bite Mark Photography." Journal of Forensic Sciences **39**(3): 815-823. Method paper.

123. 1995 Nambiar P, Bridges TE, Brown KA. J Forensic Odont; 13(2):18-25 Quantitative forensic evaluation of bite marks with the aid of a shape analysis computer program: Part 1; The development of "SCIP" and the similarity index. In this study, an interactive shape analysis computer program ("SCIP"-Shape Comparison Interactive Program) has been employed in an attempt to derive experimentally a quantitative comparison, in the form of a Similarity Index (S.I.), between the "offender's" teeth and the bite marks produced on a standard flat wax form.

124. 1995 Nambiar P, Bridges TE, Brown KA. J Forensic Odont; 13(2):26-32 Quantitative forensic evaluation of bite marks with the aid of a shape analysis computer program: Part 2; "SCIP" and bite marks in skin and foodstuffs. In this study, "SCIP" was employed in an attempt to quantify the comparison, in the form of the Similarity Index (S.I.), between the "offender's" teeth and the bite marks produced on foodstuffs and on human skin, under experimental conditions.

125. 1995 Free EW, Brown KA. J Forensic Odont; 13(2):33-5 A bitemark and a fracture? Case presents an interesting problem of interpretation of odontological evidence relevant to the identification of the offender, and raises issues concerning proper procedures for the utilisation of expertise in forensic odontology. First case in Dutch law.

126. 1995 Jakobsen J, Holmen L, Fredebo L, Sejrsen B. J Forensic Odont; (13)2:36-40 Scanning electron microscopy, a useful tool in forensic dental work. Another description of the use of SEM in bitemarks, presents four example cases.

127. 1995 Rothwell BR. JADA; 126(2):223-32 Bite marks in forensic dentistry: a review of legal, scientific issues. This review article explores the legal and scientific basis of bite mark evidence.

128. 1995 McKinstry, R. E. (1995). "Resin Dental Casts as an Aid in Bite Mark Identification." Journal of Forensic Sciences **40**(2): 300-302. Method paper.

129. 1996 Naru AS, Dykes E. Science & Justice. 36(1):47-50 The use of a digital imaging technique to aid bite mark analysis. Describes the use of a computer based overlay technique and uses a case example to illustrate the method.

130. 1996 Vale GL. J Cal Dent Assoc; 24(5):29-34 Dentistry, bite marks and the investigation of crime. Another review of the bitemark science - includes case examples.

131. 1996 West MH, Hayne S, Barsley RE. Wound patterns: detection, documentation and analysis. J Clinical Forensic Med (1996)3, 21-7. Discussion of how odontologists team with pathologists to interpret wounds in skin.

132. 1996 Aksu MN, Gobetti JP. Am J Forensic Med Pathol; 17(2):136-40 The past and present legal weight of bite marks as evidence. Legal review. This paper was followed by a letter from Ann Norrlander who criticised many of the points. Better legal reviews available.

133. 1997 Naru AS, Dykes E. Science & Justice; 37(4):251-8 Digital image cross-correlation technique for bite mark investigations. Describes the production of a complex computer program for assessing bitemarks. Describes a series of experiments to validate the system.

134. 1997 Williams RG, Porter BE. J Oklahoma Dent Assoc; 88(2):29-30 Forensic dentistry. Documentation of bite-mark evidence using multiple computer-assisted techniques. Describes a computer technique - however describes using a pencil to highlight the incisal edges prior to scanning - subjective?

135. 1997 Dailey, J. C. and C. M. Bowers. Aging of bitemarks: A literature review. Journal of Forensic Sciences **42**(5): 792-795. Cautionary analysis suggesting that aging of wounds is not reliable.

136. 1998 Sweet D, Parhar M, Wood RE. J Forensic Sci; 43(5):1050-5 Computer-based production of bite mark comparison overlays. This paper describes this technique to enable the odontologist to produce high-quality, accurate comparison overlays without subjective input.

137. 1998 Wright FD. J Forensic Sci; 43(4):881-7 Photography in bite mark and patterned injury documentation. Part 2: A case study. The evidence recovered at each photography session is discussed and photographs are presented for review. Suggestions concerning the need for more research are presented.

138. 1998 Sweet D, Bowers CM. J Forensic Sci; 43(2):362-7 Accuracy of bite mark overlays: a comparison of five common methods to produce exemplars from a suspect's dentition. Five common overlay production methods were compared using digital images of dental study casts as a reference standard.

139. 1998 Atkinson SA. Med, Sci & Law; 38(1):34-41 A qualitative and quantitative survey of forensic odontologists in England and Wales, Forty forensic odontologists in England and Wales, as

listed for the British Association for Forensic Odontology in Spring 94, were surveyed by post. Interesting paper with some useful statistics.

140. 1998 Whittaker DK, Brickley MR, Evans L. Forensic Sci Int; 92(1):11-20 A comparison of the ability of experts and non-experts to differentiate between adult and child human bite marks using receiver operating characteristic (ROC) analysis. Fifty colour prints of human bite marks were sent to 109 observers who were asked to decide using a six point rating scale, whether the marks had been produced by the teeth of an adult or a child. Non-experts had similar performance to experts.

141. 1999 McKenna CJ, Haron MI, Taylor JA. J Forensic Odont, 1999;17:40-43. Evaluation of a bitemark using clear acrylic replicas of the suspect's dentition – a case report.

142. 1999 McGivney, J. and R. Barsley (1999). "A method for mathematically documenting bitemarks." Journal of Forensic Sciences **44**(1): 185-186. Proposed method paper.

143. 1999 Sweet, D. and G. G. Shutler (1999). "Analysis of salivary DNA evidence from a bite mark on a body submerged in water." Journal of Forensic Sciences **44**(5): 1069-1072.

144. 2000 Rawson, R. B., G. H. Starich, et al. (2000). "Scanning electron microscopic analysis of skin resolution as an aid in identifying trauma in forensic investigations." Journal of Forensic Sciences **45**(5): 1023-1027. SEM study claiming that living skin records detail as small as 3μm.

145. 2000 Pretty, I. A. and D. Sweet (2000). "Anatomical location of bitemarks and associated findings in 101 cases from the United States." Journal of Forensic Sciences **45**(4): 812-814. Analysis of bitemark anatomical location in US cases.

146. 2001 Sheasby DR, McDonald DG. For Sci Int 122:1:Oct 75-8. A forensic classification of distortion in human bitemarks. Important cautionary paper. Acknowledges that distortion is probably present in all bitemarks.

147. 2001 Pretty IA, Turnbull MD. Lack of dental uniqueness between two bite mark suspects. Urges caution due to similarity of dentitions.

148. 2001 Pretty IA, Sweet D. Science and Justice 2001;41(2): 85-92. The scientific basis for human bitemark analyses – a critical review. Much cited review paper.

149. 2001 Pretty, I. A. and D. Sweet (2001). "Digital bite mark overlays - An analysis of effectiveness." Journal of Forensic Sciences **46**(6): 1385-1391. One of the few papers addressing error rates. Used a pigskin model and reported sensitivity and specificity values against a known gold standard. Best practices were employed with overlays provided to the examiners.

150. 2001 Karazulus, C. P., T. M. Palmbach, et al. (2001). "Digital enhancement of sub-quality bitemark photographs." Journal of Forensic Sciences **46**(4): 954-958. Describes arbitrary image manipulation.

151. 2001 Kouble, R. F. and G. T. Craig (2001). "Comparisons between direct and indirect techniques for bite mark analysis." Journal of Dental Research **80**(4): 1179-1179. Method paper.

152. 2001 Rothwell, B. R. and A. V. Thien (2001). "Analysis of distortion in preserved bite mark skin." Journal of Forensic Sciences **46**(3): 573-576.

153. 2001 Sweet, D. and I. A. Pretty (2001). "A look at forensic dentistry - Part 2: Teeth as weapons of violence - identification of bitemark perpetrators." British Dental Journal **190**(8): 415-418. General review article.

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175. 2006 Murmann, D. C., P. C. Brumit, et al. (2006). "A comparison of animal jaws and bite mark patterns." Journal of Forensic Sciences **51**(4): 846-860. Metric survey of animal jaws.

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179. 2007 Kieser et al. The Uniqueness of the Human Anterior Dentition: A Geometric Morphometric Analysis J Forensic Sci, May 2007, Vol. 52, No. 3. Used shape analysis methods to study a small (33 mx 49 mn) population. Claimed dental uniqueness based on small differences. Did not report measurement error. Flawed inference from insufficient data.

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186. 2009 Bush MA, Miller RG, Bush PJ, Dorion RBJ. Biomechanical Factors in Human Dermal Bitemarks in a Cadaver Model J Forensic Sci, 2009; 54(1):167-76. First serious consideration of skin properties. 23 bites were made with the same dentition in cadaver skin, none were measurably the same. Postural distortion was also studied and found to be significant. Bitemarks were not reproducible. Landmark paper using cadaver model.

187. 2009 Miller RG, Bush PJ, Dorion RBJ, Bush MA. Uniqueness of the Dentition as Impressed in Human Skin: A Cadaver Model. J Forensic Sci, 2009;54(4):909-14. 100 models were compared to bitemarks made with 10 dentitions with different alignments. Results showed difficulty distinguishing the biter from individuals with similarly aligned dentitions and in some cases, an incorrect biter appeared better correlated to the bite. Cautionary paper empirically demonstrating unreliability of bitemark analysis.

188. 2010. Bush MA, Thorsrud K, Miller RG, Dorion RBJ, Bush PJ. The Response of Skin to Applied Stress: Investigation of Bitemark Distortion in a Cadaver Model. J Forensic Sci, January 2010, Vol. 55, No. 1. Force per unit area was varied during controlled bites on cadaver skin using an instrumented biting machine. Bite appearance was not predictable, nor did laceration reliably occur. A principal variable is tissue type.

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190. 2010 I.A. Pretty, D. Sweet, A paradigm shift in the analysis of bitemarks, Forensic Sci. Int. (2010), doi:10.1016/j.forsciint.2010.04.004. Uses three of the Bush group papers to suggest that the paradigm shift is already occurring. Also lists cases in which exonerations occurred.

191. 2010 S.L. Avon, et al., Error rates in bite mark analysis in an in vivo animal model, Forensic Sci. Int. (2010), doi:10.1016/j.forsciint.2010.04.016. Showed error rates of examiners using a live pig model. Inexperienced examiners performed as well as board-certified examiners. Suggested that results might support the contention that bite mark analysis is entirely subjective.

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193. 2010 Wright, F. D. and G. S. Golden (2010). “The use of full spectrum digital photography for evidence collection and preservation in cases involving forensic odontology.” Forensic Science International **201**(1-3): 59-67. Photography method description.

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198. 2011 Santoro V, Lozito P, De Donno A, Introna F. Experimental Study of Bite Mark Injuries by Digital Analysis. J Forensic Sci, January 2011, Vol. 56, No. 1. Digital morphometric comparison of 20 dentitions and 20 bites in pigskin and plastic.

199. 2011 Tuceryan M, Li F, Blitzer HL, Parks ET, Platt JA. A Framework for Estimating Probability of a Match in Forensic Bite Mark Identification. J Forensic Sci, January 2011, Vol. 56, No. S1. Bitemarks were simulated by impressing 15 lipstick coated dental models on a rubber doll. Metric analysis was attempted.

200. 2011 Bush MA, Bush PJ, Sheets HD. Statistical Evidence for the Similarity of the Human Dentition. J Forensic Sci, 2011;56(1):118-23.
Refutation of Rawsons 1984 study that claimed dental uniqueness. Two dental populations of 172 and 344 were examined for match rates. Statistics were used that took into account dental correlation and non-independent nature of the human dentition. Matches were found in the populations studied. Study suggests that the dentition is not unique as measured.

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202. 2011 Bush MA, Bush PJ, Sheets HD. Similarity and Match Rates of the Human Dentition In 3 Dimensions: Relevance to Bitemark Analysis. International Journal of Legal Medicine published online 4 September 2010.
Match rates determined in a population of 500 dentitions using 3D models and shape analysis. Significant numbers of matching dentitions were found. The effect of 2D vs 3D measurement on match rate was also explored (match rate lowered when 3D included). This and prior studies showed that dental match rate is population-dependent.

203. 2011 Bush MA, Sheets HD. Mathematical matching of a dentition to bitemarks: Use and evaluation of affine methods. Forensic Science International (2010), doi:10.1016/j.forsciint.2010.09.013. Mathematical investigation into distortion correction using bitemarks in cadavers. Affine methods cannot be applied because of skin anisotropy. Refutation of Stols and Bernitz 2010 approach and mathematical confirmation of Bush 2010 empirical distortion study.

204. 2011 Bush MA, Bush PJ, Sheets HD. A study of multiple bitemarks inflicted in human skin by a single dentition using geometric morphometric analysis. Forensic Science International (2011), doi:10.1016/j.forsciint.2011.03.028. Comparison of 89 bitemarks to dentition shape. Concludes that false positives are readily possible due to distortion of dental shape in skin.

EXHIBIT C
APPENDIX C

ACADEMY PROCEEDINGS, 1960

V. FACILITIES FOR FORENSIC ODONTOLOGY

R. W. FEARNHEAD *

THE title of this article is no small embarrassment to me, for at present in the British Isles there are virtually no facilities for forensic odontology. Furthermore, there is no one who can claim to be a forensic odontologist, although scattered about the world are a few dentists who have gained, *ad hoc*, some experience in the application of dental science to forensic problems. The first point that I wish to make, therefore, is really in the form of a plea for some form of organisation in this country, within which forensic odontology may flourish, for there is no doubt that the teeth and jaws can provide in many cases a most accurate means of identification.

The need for an organised development of this subject was recognised some years ago by the scientific commission of the Federation Dentaire Internationale and a small international committee was established by this organisation to study and advise on methods, research and the dissemination of knowledge of forensic odontology. The value of this committee is somewhat limited because in many countries there exists no organised system for the application of odontology to forensic problems. The Scandinavian countries are notable exceptions to this statement, where the application of dental science to problems of identification has already taken on some semblance of orderliness. For example, in Norway, small teams, each consisting of a medical, dental and a police officer, are available to deal with identification problems arising from major catastrophes such as air disasters, fires and so on. In such an event the dental and medical records of the suspected victims are collected immediately and are available to the forensic scientists when they

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commence their investigation. In the event of an individual being reported as missing, after one month the medical and dental records are collected in some central place as a routine procedure. These records are then available to the identification team of three for comparison with any human remains which from time to time may be brought to light.

Theoretically, information that can be obtained from an examination of teeth and jaws could form a most accurate method of identification, especially in Great Britain today, for under the National Health Scheme a very high percentage of the population have their dental characteristics recorded. However, matching dentitions with dental record charts forms only part of the information that can be obtained from a careful examination of the dentition. For example, the age of a person may be judged from the stage of development of the teeth, or by assessing the degree of those changes which can be related to the passage of time. In some cases characteristic features of either the dentition or the type of conservative treatment may give some indication of race or place of derivation.

It must be quite clear to the reader that an assessment of the value of such information as can be obtained from an examination of the teeth and jaws can only be made and placed in its correct perspective by a properly qualified expert. Frequently even an expert can only give an opinion, although at times he may be able to establish conclusive factual evidence which may have a bearing on the case under consideration. Obviously therefore before forensic medicine can benefit much from applied odontology, the postgraduate training of a nucleus of forensic odontologists is urgently needed. Such persons would need to be well versed in the methods of the basic sciences as well as medicine and dentistry, for only with such people can methods of forensic odontology be improved by well-conceived research programmes. Apart from a few isolated places research in forensic odontology is non-existent. Studies into growth rates of the teeth and jaws; age changes in tooth structure; and studies of the uptake of radioactive strontium by dental tissues, are a few examples of dental researches which are of fundamental importance to forensic science. The special requirements of forensic problems therefore ought to be actively represented in such research programmes by practising forensic odontologists. Unfortunately for the present, we are a long way from achieving this ideal.

Unreliable Evidence—An Experiment

The need for a transfusion of dental research into forensic science is only too apparent when one considers the doubtful reliability of the deliberations occasionally given by so-called expert witnesses. The type of witness referred to here is usually a self-styled expert, but remarkable as it may seem his statements are often accepted as conclusive by the courts. It is common knowledge that tooth-bites often leave an impression in the material bitten, for example bruises in flesh, marks on foodstuffs, etc. From time to time such impressions have been used to establish the complicity of a suspect in some misdemeanour by comparing impressions of teeth left at the scene of the crime with models prepared from the suspect's teeth. This method of identification at first sight appears to be similar to that of fingerprint matching, and, not unnaturally, is often credited with the same degree of accuracy. I believe, however, that evidence which involves the identification of a person by tooth-marks left as bruises in flesh should never be admitted, and evidence involving bite-marks in, for example, foodstuffs should be examined extremely critically. In order to make this point I performed a simple experiment in collaboration with my colleague Mr. A Boyde. We set out to establish the following:

(a) Under ideal conditions could an expert relate models of a dentition with well-defined freshly made bite-marks in suitable foodstuffs?

(b) Could models from the dentitions of two people ever appear to fit a bite-impression made by one person?

The experiment was conducted in the following way. Five people were selected by Mr. Boyde, who prepared plaster of paris models of their teeth and jaws. Each was then requested to take a bite from pieces of cheese, pieces of chocolate and from an apple. The specimen bites from each individual were put into separate trays together with the five sets of bite-marks. I was then asked to match the models with the bite-marks. Unknown to me, models of the teeth and jaws from a sixth person had been exchanged for one of the experimental group. After a short examination I was able to identify correctly each of the four models with their respective bite-marks. It was also possible to eliminate the set of plaster models which did not match. This we felt established that under favourable conditions freshly prepared plaster models could be matched with freshly made bite-marks with a reasonable degree of certainty.

Pursuing the matter further Mr. Boyde was able, without much difficulty, to find among a collection of plaster models, kept in the hospital as a record of patients' jaws, a dentition which fitted the bite-marks of one of our experimental group just as perfectly as the models of the jaws that made them (Fig. 1). Furthermore, we found

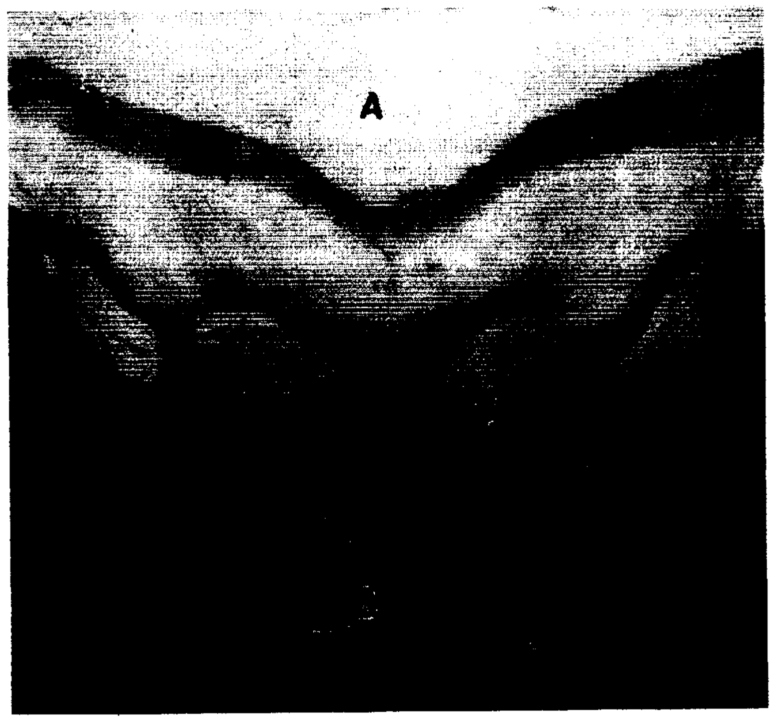

Fig. 1. Plaster models A of the upper incisor teeth of a female patient age 15 years, fitted with reasonable accuracy to the bite-marks made in an apple B by a male age 18 years.

that in the case of the cheese and the apple, after standing overnight, changes had occurred in the shape of the bite-marks and this, of course, prevented accurate register with the models. The plaster models were prepared for this experiment under optimal conditions, but it should be borne in mind that unless skilfully prepared by experienced people the plaster models themselves can be untruthful copies of the original.

I do not wish to overstate the importance of this experiment, but I do hope that it serves to illustrate the need for a more critical awareness by the legal profession and those concerned in forensic science of the danger of accepting, too readily, evidence which at first sight appears to be based on an exact science. This awareness can only come through the dissemination of knowledge from the sciences, which, in turn, can only be obtained through researches. In progress through research, dentistry has its humble part to play in common with the other branches of the forensic sciences.

In conclusion I hope that my words have served to emphasise the need to bring forensic odontology into its proper position within an organised forensic science. In order to do this, of course, experts need to be trained and research into the dental aspects of forensic problems initiated. If this were to be done I believe we could look forward to a valuable contribution to identification methods by forensic odontology.

EXHIBIT C
APPENDIX D

Some laboratory studies on the accuracy of bite mark comparison*

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Introduction

The study of artefacts left at the scene of a crime has always been an important means of proving or suggesting a suspect's presence. As techniques of analysis have improved not only fingerprints but also single hairs, cloth fibres, and many other items have assumed importance.

It was recognized as long ago as 1906 (Humble, 1933) that variations in the human dentition might allow bite marks left in food at the scene of a crime or on the bodies of victims of assault to be identified by comparing them with the dentition of a suspect. Since that time there have been numerous reports in the literature of successful prosecutions using this technique (Keyes, 1925; Nielsen, 1950; Furness, 1968; Suzuki *et al.*, 1970) but the reliability of the method has been questioned by some authorities who are of the opinion that further research is necessary before opinions on these matters can be regarded as 'expert' testimony.

Gustafson (1966) supported the contention that bite marks left in a good recording medium might enable identification to be made but was of the opinion that bite marks in skin would present a difficult problem. Taylor (1963) commented that bite marks may be helpful but technical difficulties make them useless in a high percentage of cases. Strom (1954) took a more cautious view and advised that bite marks should only normally be used to prove the innocence of a suspect and not his guilt. Although dental surgeons are by training and experience experts on dentitions an[d] occlusions they should be aware of a numbe[r] of problems which are encountered whe[n] seeking to compare bite marks with dentitio[n] of suspects.

Firstly, the incidence of identical occlusio[n] in a population sample is not accurate[ly] known. Secondly, few experimental studie[s] have been carried out to determine th[e] reliability of comparison techniques either [o]f bite marks in food or in skin. Berg and Schei[t] (1954) carried out an investigation on bit[es] made in a plastic material which were com[-] pared with photographs of the teeth produci[ng] the bites. Out of 100 subjects tested in th[is] manner none were positively identified and [the] authors concluded that an accurate impress[ion] of at least 5 teeth is necessary to ena[ble] identification to be made.

Fearnhead (1961) carried out experime[nts] on bites in various foods and commented [on] the changes occurring in the hours follow[ing] the bite. Even under ideal laboratory con[di]tions it was not possible to be certain wh[ich] dentition was responsible for the bites and th[e] author stressed the need for a more criti[cal] awareness of the problem and further resear[ch] into the reliability of this method.

A degree of success was claimed by Fr[ei]holm *et al.* (1970) who used sophisticat[ed] three-dimensional measurements and wer[e] able to demonstrate a statistical differen[ce] between cases where identity existed a[nd] where it did not. However, they used plastici[ne] as their recording medium and admitted tha[t] under actual conditions in a forensic examina[-] tion, identification would be more difficult.

The reliability of bites in skin as a means [of]

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*This paper has also been published in the *International Journal of Forensic Dentistry*.

identification does not appear to have been investigated and the following study is a comparison between marks made in a good recording medium and those made in skin.

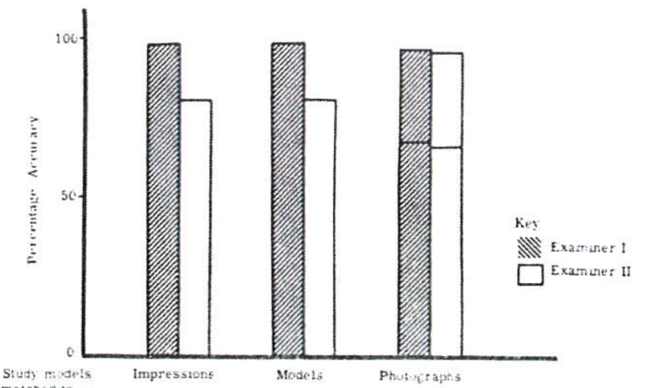
Materials and methods

Upper and lower alginate impressions were taken of 84 unselected adults between the ages of 20 and 24 years. Impressions were stored in a humidifier and poured in dental stone within 30 mins. Each set of models was varnished and coded so that the investigators could later compare bites and models in a blind manner. Each of the 84 subjects made a bite into wax under the following standard conditions. A treble thickness of toughened model wax was supported on a curved wire mesh base with a radius approximately that of the upper arm. Bites were made with an incisive action in such a way that impressions of the incisal edges and a portion of the labial and lingual surfaces of the upper and lower incisors and canines were recorded.

Each wax bite was immediately photographed alongside a scale using standardized lighting conditions. An impression of the wax bite was taken in silicone impression material supported on an Optosil base. Stone models of the bites were poured and photograph and model were coded in a similar manner to the original study models of the subject.

Bite marks in skin were produced in the following manner. Fresh pig skin from young animals removed immediately on death of the animal was obtained from an abbatoir and cut into strips 12 × 8 cm. and scrubbed with Hibitane in aqueous solution. This treatment had previously been shown not to result in distortion of the skin specimen. Skin was chosen from sites with minimum subcutaneous fat in order to approximate as closely as possible to the properties of human skin. The skin was placed over a rubber cylinder so that a radius approximating that of the upper arm was obtained. Twenty-four subjects were requested to bite slowly and deliberately into the skin surface which was immediately photographed against a scale. A silicone rubber impression was taken of the bite mark and stone models were cast. Photographs and impressions were repeated after 1 hr. and 24 hrs. During the first hour after biting the skin was kept moist by means of physiological saline. During the subsequent 23 hrs the skin

HISTOGRAM SHOWING RESULTS OF ANALYSIS OF WAX-BITE STUDY



1. Histogram of analysis of wax bite study. Tooth measurements from photographs increase the accuracy of comparison as shown in the columns above the horizontal lines.

Histogramme de l'analyse d'une étude sur une morsure dans la cire. Les mensurations dentaires d'après photos accroissent l'exactitude de la comparaison comme le montrent les colonnes sous les lignes horizontales.

Histogramm der Analyse von Bißabdrucken in Wachs. Die Zahnmessungen anhand der Fotos erhöhen Genauigkeit beim Vergleich wie aus den Säulen oberhalb der horizontalen Linien hervorgeht.

Histograma de análisis de un estudio de mordidas en cera. Las medidas de fotografías de dientes aumentan la precisión de la comparación como se demuestra en la columna superior con líneas horizontales.

specimen was kept in a refrigerator at −20 C and thawed before final examination was carried out.

By this means bites in both wax and skin were obtained along with impressions, stone casts and photographs. Coding of all specimens allowed comparisons to be made between these records and the dentitions of the subjects. Matching of the bites with the study models was carried out by two independent observers. Comparisons of study models with impressions, casts of impressions and photographs of the bites were made both by subjective comparison and by using measurements of arch curvatures, tooth widths and tooth angulations and spacing between adjacent teeth after the method described for use in cases of assault and homicide (Furness, 1968).

Results

The correlations between the two examiners in the wax bite study are shown in Fig. 1.

Both examiners were able to correctly match 98·8 per cent of impressions in wax with study models of the subjects and the same degree of accuracy was achieved when matching stone models of the wax bites against the original study models of the subjects. Incorrect matching was only found in one case where the incisal edges of the anterior teeth had not registered in the wax bite. Comparisons of wax bites and study models was made subjectively and by trying the fit of the study model in the wax bite.

When photographs of the wax bites wer compared with photographs of the stud models of the subjects' dentitions, using th method of Furness (1968), 96·5 per cer accuracy was achieved by one examiner an 95·5 per cent by the other. This result is n significantly different from the results obtaine using the wax bites themselves ($P = 0{\cdot}5$).

When photographs were used for visu comparison and no measurements were take the accuracy fell to 68 per cent for one exar iner and 67 per cent for the other. The resul for the two examiners were not statistical different ($P = 0{\cdot}5$), but the combined resu were statistically different from the compa sons of the wax bites or castings from the bi with the subjects' study models ($P = 0{\cdot}01$).

The results of the pig skin study are sho in Fig. 2. In all cases no significant differen were shown between the findings of the t

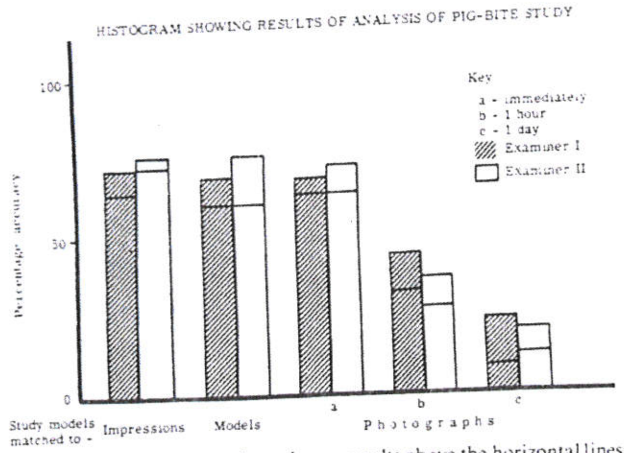


Fig. 2. Results of analysis of pig skin bites. In each case results above the horizontal lines are those measurements were used.

Résultats de l'analyse de morsures dans la peau de porc. Dans chaque cas, les résultats sous les horizontales sont ceux dont les mensurations ont été utilisés.

Ergebnis der Analyse von Bißmalen in Schweinehaut. In jedem Falle entsprachen die Ergebnisse ob der horizontalen Linien denen, bei denen Messungen angewandt wurden.

Resultados de análisis sobre mordidas en piel de cerdo. En este caso resulta superior la linea hori que donde se usaron las medidas.

aminers. Visual matching using subjective iteria was found to be less accurate than hen measurements were taken but there were statistical differences between comparisons f study models with impressions of the bites, dels of the bites or photographs taken mediately after the bites. The mean degree accuracy was 72 per cent when measurents were taken and 63·7 per cent when bjective comparison was carried out. These ues were significantly lower than the values tained for the wax bites ($P = 0{\cdot}01$) except hen photographs of the wax bites were used hout measurements.

The mean percentage of photographs which uld be matched with the study models of subjects 1 hr after biting had fallen to per cent and after 24 hrs to 16 per cent en measurements were used. If subjective ual comparisons only were made in the hr material, the degree of accuracy of nparisons fell to 9 per cent.

Discussion

he high correlation between independent miners of the bites made in wax is a measure the ability of this material to record an urate impression which is reliable for the rposes of this study. As in a previous study Berg and Scheidt (1954) only those wax cimens containing an accurate representaon of the whole of the incisal edges resulted positive identification, but unlike their dings it was found to be possible to match tes of only the central incisor teeth providing ficient of the labial and lingual surfaces were corded. Irregular alignment of teeth resulted, would be expected, in ease of identification. e high degree of accuracy with which bite arks in wax could be correlated with the clusion responsible for the bite marks dicates that forensic experts may comment on bites made in such materials with a sonable degree of confidence.

In both the wax bite and pig skin portions the study there were no statistical differences tween comparisons of study models with pressions of the bites and with photophs of the bites. These findings suggest that e use of photographs in forensic studies on e marks (Furness, 1968) is a satisfactory means of recording the characteristics of a bite mark.

In the pig skin study variability between examiners was higher than in the case of the wax bites, suggesting that a more subjective assessment has to be employed. Both examiners, however, were agreed that bites which were readily visible at the time of biting tended to remain so during the 24 hr period of the study but those which were not well defined faded rapidly. The inability of examiners to correctly identify bite marks in skin in 25 per cent of cases under ideal laboratory conditions and when examined immediately after biting suggests that under sometimes adverse conditions found in an actual forensic investigation it is unlikely that a greater degree of accuracy will be achieved.

The degree of distortion occurring in this non-vital tissue after biting was considerable and rendered impossible the matching of several bites. The problem of distortion is a serious one and Humble (1933) quoted a case in which the accused was discharged because fixation of a skin bite resulted in lack of fit of the subject's teeth to the bite. Humble recommended that photographs taken at the time of the bite would have prevented this difficulty from arising but the present experiments indicate that even under ideal conditions only 76 per cent correct identifications can be expected from photographs upon which measurements are made. Using a system of ink marks on human skin De Vore (1971) showed that distortion due to normal body movements and shrinkage due to excision and fixation rendered bite marks useless for positive identification unless the exact position and condition of the body were known at the time of biting.

For obvious reasons it is not possible to carry out a survey of bite marks on living human flesh. It is recognized that pig skin is not an ideal substitute for human skin for the purposes of these experiments, but its ready availability and similar histological structure (Montagna and Jeung, 1964) appear to make it the most suitable alternative. Results of these experiments are therefore not directly applicable to the problems encountered in actual bite mark cases but provide a preliminary assessment of the difficulties encountered in comparison techniques. Few attempts have previously been made to make any statistical assessment of the reliability of bite marks and the acceptance of the method in a court of law does not necessarily prove its validity. It may be that bite marks in human flesh are more readily matched with a suspect's teeth than are those in the skin of the pig but it appears likely that variations in quality of bite, variations in tissues bitten, and subsequent bruising and oedema would render bite mark comparisons an unsatisfactory means of identification in many cases.

The present experiments have shown that if a bite mark is obtained in a material with good recording properties (Taylor, 1963), then identification may be possible in up to 99 per cent of cases if good impressions or photographs of the bite can be obtained. In skin bites the highest percentage accuracy found was 76 per cent and if impressions cannot be taken this might fall as low as 20 per cent or even 9 per cent if photographs taken some time after the bite is made are used for comparison.

Conclusions

Expert witnesses involved in presentation of evidence on bite marks in a court of law should be aware that at the present state of our knowledge there are problems not only in determining the incidence of identical or near identical occlusions but also in interpreting bite marks made under standardized laboratory conditions. It seems probable that similar problems might be encountered in forensic analysis of bite marks in human skin and further studies to substantiate the reliability of the technique are clearly required.

Acknowledgement

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SUMMARY

Bite marks in wax and in pig skin were compared with study models of the subject making the bite. Photographs, impressions and measurements of the bites were used. Bites in wax could be readily identified especially if measurements were made on photographs but identification from bites in non-vital pig skin was more unreliable. It is suggested that similar difficulties may be encountered in the assessment of bites in human skin. Expert witnesses involved in presenting evidence on bite marks in a court of law should be aware of the difficulties of making valid comparison even under standardized laboratory conditions. Further studies to improve and substantiate the reliability of the technique are clearly required.

ÉTUDES DE LABORATOIRE SUR LA PRÉCISION COMPARÉES DES TRACES DE MORSURE

RÉSUMÉ

Les traces de morsure dans de la cire et la peau de porc ont été comparées avec les modèles d'étude des sujets effectuant la morsure. On a utilisé des photos, des empreintes et des mensurations. Les morsures dans la cire pouvaient être facilement identifiées spécialement si l'on effectuait des mensurations sur des photos mais l'identification d'après des morsures dans de la peau de porc dévitalisée était beaucoup moins sûre. On peut penser que l'on rencontrerait les mêmes difficultés pour l'identification de morsures dans de la chair humaine. Des experts appelés à témoigner en justice dans des preuves fondées sur des traces de morsure devraient être conscients des difficultés d'établir des comparaisons valables même dans le cadre des conditions standardisées du laboratoire. Des études ultérieures sont nécessaires pour améliorer et renforcer la sûreté de cette technique.

EXHIBIT C
APPENDIX E

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A comparison of the ability of experts and non-experts to differentiate between adult and child human bite marks using receiver operating characteristic (ROC) analysis

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Abstract

Fifty colour prints of human bite marks were sent to 109 observers who were asked to decide using a six point rating scale, whether the marks had been produced by the teeth of an adult or a child. The observers consisted of accredited senior forensic dentists, accredited junior forensic dentists, general dental practitioners, final year dental students, police officers and social workers. The results were compared against a ''gold standard'' which was the actual verdict from the case. Comparison of the results between the groups of observers and the standard was made using Receiver Operating Characteristics (ROC) methodology. The best decisions were made by senior/junior experts or final year dental students. General dental practitioners and police officers were least able to differentiate correctly between adult and child bite marks. The effect of training is important and its effects need to be assessed in more detail in future studies. © 1998 Elsevier Science Ireland Ltd.

Keywords: Bite marks; Adult; Child; Forensic dentistry

1. Introduction

The term ''bite mark'' is used rather loosely to describe a mark caused by the teeth

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alone, or the teeth in combination with other mouth parts. Bite marks can be found in flesh, foodstuffs and less frequently in a variety of other materials [1].

The procedure for comparison of bite marks on the skin of victims to the dentition of possible assailants is well established [2] and has been reported in historical cases [3,4], and in many cases to the present day. Since 1966 there have been more than 100 papers written on the subject, the majority of which are case reports or descriptions of technique. Bite mark evidence has recently become increasingly important in the investigation of non-accidental injuries to children [5].

Some well published court proceedings have highlighted disagreement between opposing experts not only as to methodology but in the fundamental question as to whether a defendant was responsible for the bite. Those with long experience in the courts will testify that dissent amongst so-called bite mark experts is commonplace [6]. Some odontologists are of the opinion that bite mark analysis should never be used to convict a suspect but only to eliminate him and some of the judiciary have recommended that bite mark evidence should not be acceptable in court.

Using an artificial model of post mortem bites in pig skin it has been shown [7] that even under standardised laboratory conditions, photographs of bites could only with difficulty be matched to the dentitions making them even when the exercise was carried out immediately. The possibility of errors of judgement have been emphasised [8] and it has been urged that more experimental work be carried out. The process has been criticised on a number of occasions in relation to its reliability [9] and the statistical problems associated with it [10,11]. Assessment of the probability of a bite having been made by a particular individual is a difficult subjective judgement requiring substantial experience and knowledge on the part of the expert. Clearly, this judgement is likely to be subjected to rigorous examination in court [1]. Bite mark investigation starts with examination to determine if the wound can be positively identified as a bite mark. If the wound can be orientated in such a way that it is possible to say which teeth in the mouth have caused each element of the mark, then it is appropriate to make a firm statement that the wound is a bite mark. Frequently however, an individual wound will show limited detail and it will be appropriate to identify it only as a possible bite mark.

There is sufficient disquiet in the ranks of practising forensic dentists to warrant further research being carried out and in this study we have tested the reliability of decision making in the interpretation of bite marks and compared established "experts" (forensic odontologists) with non-qualified lay personnel. This study has focused on the ability of these groups to differentiate between human bite marks by adults and children. This decision has important legal implications in terms of cases of non-accidental injury to children.

ROC analysis has not previously been applied to dental forensic decision making but is a well validated method of assessing treatment decisions. The study reported here examined the quality of the decision making abilities, in relation to the analysis and characteristics of bite marks as being of adult/child in origin. In particular, the aim of the study was to assess the degree to which it can be determined whether a bite mark was made by an adult or a child and the effect on the variability of the status of the observer.

2. Materials and methods

A total of 109 observers from England and Wales were included in the study from the following groups: Accredited Senior forensic dental experts (11), accredited Junior forensic dental experts (18), general practitioners with no experience in Forensic Dentistry (12), final year dental students (who had recently undertaken a short course in forensic dentistry including basic bite mark analysis (30), police officers with occasional involvement in child abuse cases (28), and social workers who see ''bites'' on their clients (10).

A series of 50 actual photographed bite mark cases (combined into a book) were distributed to each observer. The bite mark cases included a mix of non-accidental injuries inflicted by adults and accidental injuries inflicted by children. A self completed questionnaire pro forma (Appendix A) was devised in which the observer was asked to assign a level of certainty regarding whether the bite mark was made by an adult or a child. A pilot study was carried out in the University hospital with a random selection of staff and students, to test the clarity of the questionnaire. The books were then sent out to each observer with a letter explaining the purpose of the study and instructions on how to complete the questionnaire. Each observer was assured that participation would be anonymous and were asked to rate all of the cases to the best of their ability. The data were collected over a period of 6 months.

The results of the decisions made from each group of observers were compared against a ''gold standard,'' which was the actual case verdict from the court. It was acknowledged that the court verdict could always be questionable, although this is unlikely. In addition one of the authors (DW) specifically selected bite mark cases for inclusion where other evidence available strongly corroborated the courts' decision. The experts involved in the original court case may have had access to general information surrounding the circumstances of the case. The information given to the observers was limited to an actual photograph of the injury. This was to ensure that the decision made by the observers was based solely on their ability to identify the actual bite mark and was not influenced by any other information about the case.

When evaluating a decision-making system, it is important to measure both the sensitivity, (in this study, the degree to which observers correctly identified a bite mark as being inflicted by an adult in a non-accidental injury), and specificity (in this study, the degree to which an observer was able to limit the classification of bite marks as being inflicted by adults to those cases in which the bite marks were actually made by adults). In any decision making system there is the risk of cases being incorrectly identified. The measures may be quantified as the false positive rate (when the observer states a child made the bite but in fact it was inflicted by an adult).

It is possible to describe these functions numerically by:–

(i) $\rho(\mathrm{TP}) = \mathrm{Sensitivity} = (M_{Dd}/M_D)$

where:

τ(TP) =True positive rate
M_{Dd} =number of bite marks correctly identified as being caused by an adult in a non-accidental injury.
M_D =total number of bite marks which were made by adults.

(ii) Specificity$=(M_{Nn}/M_N)$

where:

M_{Nn} =number of bite marks correctly identified as being made by children (in a non-criminal incident).
M_N =total number of bite marks made by children (in non-criminal incidents).

(iii) $\rho(\mathrm{FP})=1-$Specificity

where:

ρ(FP) =False positive rate (The rate of bite marks incorrectly identified as being inflicted by adults when they were actually made by children).

Sensitivity and specificity are ‘‘black and white’’ measures that assume that the respondent is always definite about their decision. However, in a series of cases, the expert attempting to classify the bite mark injury will be more certain about classifying some bite marks as being made by adults than others. To actually make the decision the observer will set a ‘‘cut off point’’ or ‘‘threshold’’ of certainty. If the case exhibits enough characteristics of an adult bite to exceed the observer’s threshold, then the bite mark will be identified as being of adult origin. If this is not so then the case will be classified as being a child’s bite mark (representing a ‘‘non-case’’ of non-accidental injury). As an observer alters the degree of certainty at which he/she identifies an injury as being inflicted by an adult (i.e. uses more or less stringent criteria), the sensitivity and false positive rate will alter. At a given ‘‘cut off’’, particular sensitivity and false positive rates will be achieved. There are two extreme limits to this process: if no matter how certain the observer, no bite mark is identified as being made by an adult, both the true positive rate and false positive rate would be zero indicating that while the observer would not correctly identify any of the adult bite marks, neither would any injuries caused by children be incorrectly misdiagnosed. At the other extreme limit, if no matter how uncertain the observer is that the bite mark was made by an adult, all bite marks are nevertheless identified as inflicted by adults, both the true positive rate and the false positive rate would then be one. This indicates that while the observer would correctly identify all the bite marks made by adults inflicting non-accidental injuries, all of the bite marks inflicted by children would also incorrectly be identified as adult assault cases.

Holding a ‘‘cut off’’ point or threshold at some intermediate level between these two extremes results in both the true positive rate and false positive rate lying between zero and one. The relationship between the two rates varies with changing ‘‘cut off’’ points.

ROC analysis provides a graphical representation of how the true positive and false positive rates vary with varying ‘‘cut-off’’ points [12].

Such an experiment may be undertaken by asking the observer to rate a series of cases on a rating scale (such as that used in this study, shown in Appendix A) to indicate how certain he/she is that the bite mark was made by an adult. True positive and false positive rates can then be calculated at each level of certainty (i.e. threshold) according to a gold standard (in this report, the court verdict). An ROC curve is then constructed by plotting these false positive rates against the corresponding true positive rates, at each level of certainty (i.e. at each action threshold).

The area beneath the ROC curve thus provides a graphical representation of the ability of an observer to discriminate between adult bite marks and child bite marks, at all possible levels of uncertainty. ROC curve analysis provides an objective measure of the observers' ability to identify adult/child bite marks, over all levels of certainty. If the observer were to make random treatment decisions the ROC curve would be a straight line equi-distant from both axes. The ROC curve for a perfect observer given perfect information would be a horizontal line from (0,1) to (1,1) and would contain the maximum area. It follows that the further above the random line, a particular observer's curve lies, the better his discrimination ability. Statistical tests exist to determine whether there is any significant difference between two ROC curves [13]. Changing the observer while keeping the clinical information identical, and comparing the areas under the curves, provides a statistically robust method of comparing two or more observers' decision making ability [14].

The comparison of the results between data obtained from the groups of the observers as described above and the ‘‘gold standard’’ was made using this established ROC methodology. ROC curves were constructed for grouped data for each observer type and the area beneath the curves compared [13]. It has been shown that combining data between observers into one group in this way is statistically valid [15].

3. Results

The ROC curves of each group are shown graphically in Fig. 1 while the areas beneath the ROC curves developed for each group are shown in Table 1, together with standard error data for each. The areas beneath the curves vary between 0.618 and 0.693. As previously stated, the nearer this area approaches the value of 1, the better the decision making of the group.

Table 2 shows the significance of differences between areas beneath ROC curves of each group in pairwise comparison. As can be seen from this table, the respondents could be divided into three groups. The best decisions, judged against the gold standard, were made by senior/junior forensic experts or final year dental students. There were no significant differences in ability to correctly classify a bite mark as adult/child between any of these three groups on the basis of performance. A second slightly anomalous group were social workers who performed significantly worse than senior forensic experts or students but no differently from junior forensic experts. A third group

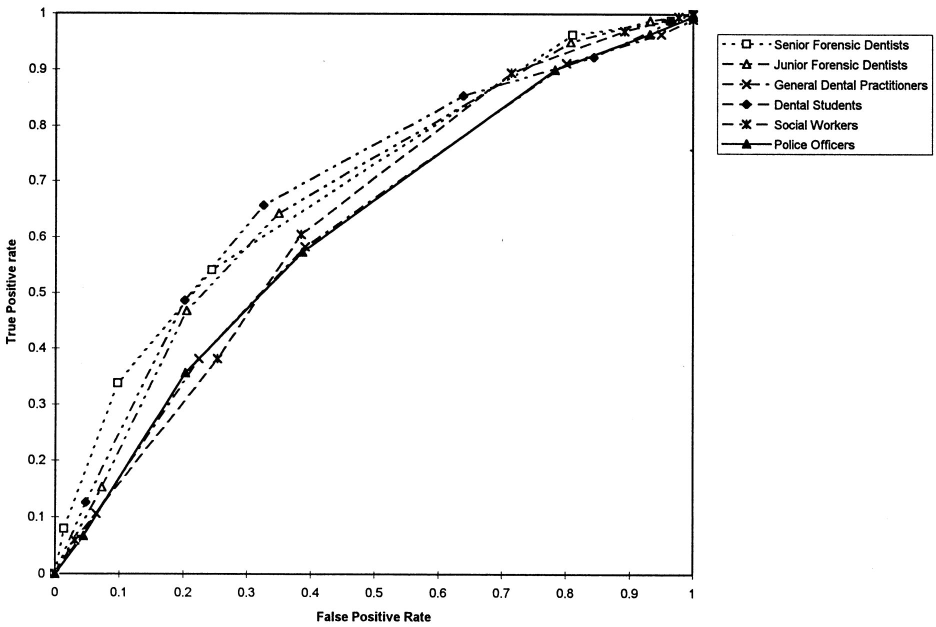

Fig. 1. Performance of six professional groups in bitemark classification.

consisting of general dental practitioners and police officers were least able to differentiate between adult and child bite marks.

4. Discussion

The literature abounds with reports of the assessment of bite marks in criminal injury cases, and subsequent opinion as an expert in court [9] Many of these have been associated with N.A.I. to children [10,16,17]. In many jurisdictions no formal training as a Forensic Odontologist is required and courts may choose to regard any dental surgeon

Table 1
Areas beneath ROC curves of different groups of observers classifying bite mark's child/adult in origin

Observer group	Area beneath ROC curve	Standard error
Senior forensic expert	0.693	0.0248
Junior forensic expert	0.680	0.0206
General dental practitioner	0.618	0.0262
Student dentist	0.690	0.0157
Police officer	0.618	0.0171
Social worker	0.634	0.0295

Table 2
Significant differences between the different groups of observers of the area beneath the ROC curve

Senior forensic expert	Junior forensic expert	Dentist	Student	Police officer	Social worker
Senior forensic expert	$Z=0.42$ $P=0.3372$	$Z=2.08$ $P=0.01876$	$Z=0.10$ $P=0.4602$	$Z=2.50$ $P=.00621$	$Z=1.54$ $P=0.0618$
Junior forensic expert		$Z=1.85$ $P=0.0322$	$Z=0.40$ $P=0.3446$	$Z=2.31$ $P=0.01044$	$Z=1.28$ $P=0.1003$
Dentist			$Z=2.36$ $P=0.00914$	$Z=0.00$ $P=0.5000$	$Z=0.40$ $P=0.3446$
Student				$Z=3.11$ $P=0.00094$	$Z=1.69$ $P=0.0455$
Police officer					$Z=0.47$ $P=0.3192$
Social worker					

as an expert in bite mark cases. Justification of an expert in relation to his training and experience is to be expected in court, and a dentist without considerable experience in bite mark analysis would be unwise to become involved in a criminal trial. Assessment of bite mark evidence can be difficult even for experienced forensic odontologists and no attempts appear to have been made to assess the importance of experience in this area. We have chosen to compare the ability of dentally trained and interested lay personnel to make an apparently simple decision as to whether a bite mark was produced by a child or an adult. This decision is frequently crucial in determining whether a case is proceeded with, and even whether an expert is called in to examine the victim [18]. The decision as to whether a bite mark was produced by a child or adult is dependant upon a number of factors which may include size, shape, size of individual tooth marks and recognition of individual teeth. The placement of an assailant in the ‘‘child’’ or ‘‘adult’’ group depends upon the definition of the terms. Dentists, and particularly forensically trained dentists may use different criteria to lay people less versed in the development of the occlusion. It was therefore decided to allow each experimental group to make their own decision as to what was meant by the terms child and adult. No guidance was given to any of the groups.

The groups of observers were selected using the following criteria:–

The senior and junior forensic dentists were chosen at random from the list published by the British Association of Forensic Odontology. All the seniors would have at least some experience of decision making in relation to bite marks and all the juniors would have received theoretical training and may have dealt with a small number of cases. The general dental practitioners were randomly chosen and included a wide range of experience and undergraduate training. None had any experience in the forensic field and had not seen any human bite marks professionally. The dental students were in their final year in the Cardiff Dental School and all had attended an undergraduate course in forensic dentistry including theoretical aspects of bite mark analysis.

The police officers were chosen from those working in family support units in South Wales and all had an interest, and in many cases personal experience, in bite mark cases. The social workers were chosen from those who had experience of non-accidental injury to children and bite mark injuries.

The senior forensic dentists showed no significant differences from the juniors in their decision making. It is commonly supposed that extensive experience is required to assess bite marks [19] but in so far as the decision of a child or adult bite is concerned, the seniors and juniors related to the ‘‘gold standard’’ in the same way. In the absence of more detailed information about the case, experience seems to be unimportant when photographs alone are available for study.

The seniors were better than general dental practitioners and police officers and there was a non-significant trend for them to be better than social workers. Juniors were also better than general dental practitioners and police officers. It seems likely that formal training (which had not occurred for the general dental practitioners) is more important than extensive experience in this decision making process. It is interesting that only two senior forensic dentists pointed out the limitations of being able to make a satisfactory decision from photographs alone. Those who responded understood the purpose of the exercise which was not to be able to make a clear decision as to child or adult – but to respond if necessary that the information provided was insufficient to allow a firm decision to be made.

It is interesting that the final year students were better at approaching the ‘‘gold standard’’ than were the more generally experienced qualified dentists. It appears that conventional undergraduate training and subsequent clinical experience does not assist a practitioner in making good judgements about this aspect of bite mark analysis. The brief exposure of the students to a formal course, perhaps coupled with fewer pressures on their time may be important. The students, but not the dentists were better than both police officers and social workers, implying that a knowledge of teeth and their arrangement per se may not be as important as a theoretical knowledge, however simplistic, of the principles of forensic dental bite mark analysis.

Lay persons with an interest in, and a knowledge of bite marks were not as good as any of the dental professionals at reaching satisfactory decisions in relation to whether bites were by children or adults and this may be due to a different appreciation of the definition of child and adult in this context or to difficulty in relating information in the photographs to their decisions.

This first attempt to study one single aspect of decision making in bite mark cases confirms the widely held view by the courts that an ‘‘expert’’ in this field should be dentally qualified. However, it suggests that conventional undergraduate education does not equip the general dental practitioners to deal with at least this aspect of decision making any more than does an interest in the subject by lay personnel and provides support for the concept of formal postgraduate training in this area. The effect of training is paramount and suggests that benefits would be gained by ensuring that all undergraduates receive some forensic training [20] and that police and social workers involved in these cases would also be better equipped to make decisions concerning the need for further advice in cases of this nature. The precise effects of training schemes needs to be assessed in more detail in future studies, as do the effects of providing comprehensive information about the bite marks and the circumstances surrounding them.

The use of this ROC technique, although widely used in other studies, has not been applied to the field of forensic odontology (and rarely to forensic science as a whole), this technique excels at assessing objective differences in performance of different observers and as such, would be applicable to other areas of the discipline.

Appendix A

You are presented with photographs of 50 cases, each showing a human bite mark. Examine each bite mark, and rate using the following scale, the certainty with which you would assign the bite mark being made by an adult or a child.

1. I am certain that this bite mark was made by an adult.
2. I am fairly certain this bite mark was made by an adult.
3. It is slightly more likely that this bite mark was made by an adult than by a child.
4. I am unsure whether this bite mark was made by an adult or by a child.
5. It is slightly more likely that this bite mark was made a child than by an adult.
6. I am fairly certain this bite mark was made by a child.
7. I am certain that this bite mark was made by a child.

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EXHIBIT C
APPENDIX F

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Results of the 4th ABFO Bitemark Workshop—1999

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Abstract

Thirty-two certified diplomates of the American Board of Forensic odontology (ABFO) participated in a study of the accuracy of bitemark analysis. Examiner experience as board-certified odontologists ranged from 2 to 22 years.

Examiners were given sets of photographs (a cast in 1 case) of 4 bitemark cases and asked to report their certainty that each case was truly a bitemark and the apparent value of the case as forensic evidence. Participants also received 7 occluding sets of dental casts, 1 correct dentition for each case and three unrelated to any of the cases, and asked to rate how certain they were that each set of teeth had made each bitemark. Receiver operating characteristic (ROC) analysis resulted in an accuracy score of 0.86 (95% CI $= 0.82-0.91$). Youden's index was used to determine a cutoff point for determining an accuracy score for each case. Accuracy scores were significantly correlated with bitemark certainty and forensic value ($P < 0.001$ in both cases) but not with examiner experience ($P = 0.958$). The use of individual ROC analysis with weighted Youden's index to calibrate individual accuracy was also demonstrated.

Keywords: Forensic science; Bitemark effectiveness; Accuracy; Validity; Diplomates; ROC

1. Introduction

There have been few controlled investigations of the accuracy of bitemark analysis. In a study reported by Whittaker in 1975, two experienced examiners could match bitemarks in wax with the appropriate models of perpetrator teeth with 99% accuracy. However, with experimental bitemarks in recently excised porcine skin obtained from an abattoir, they were able to identify the teeth of the biter in only 72% of cases [1]. It was suggested that similar results might be expected with human bitemarks.

Beginning in 1998 and completed at the 4th American Board of Forensic odontology (ABFO) Bitemark Workshop in 1999, a survey of the diplomates of the ABFO was conducted. The purpose was to assess the accuracy of examiners in distinguishing the correct dentition that made a bitemark. Individual conclusions reached by certified forensic odontologists after analyzing test bitemarks were compared. This paper reports the results of that study.

2. Materials and methods

2.1. Examiners

Thirty-two certified diplomates of the ABFO agreed to participate as examiners in this study, according to the procedure discussed in the Section 2.3 below. The examiners had an average of 12.5 years of experience as diplomates (S.D. $= 6.3$) with a range of 2–22 years. Within the certification procedure for the ABFO, diplomates are required to have experience with bitemarks from both theoretical and practical grounds and must have been a principle investigator in at least 1 criminal bitemark case. This assumption of knowledge among the diplomates ensures a measure of homogeneity of experience within the group, despite the fact that differences in experience were noted.

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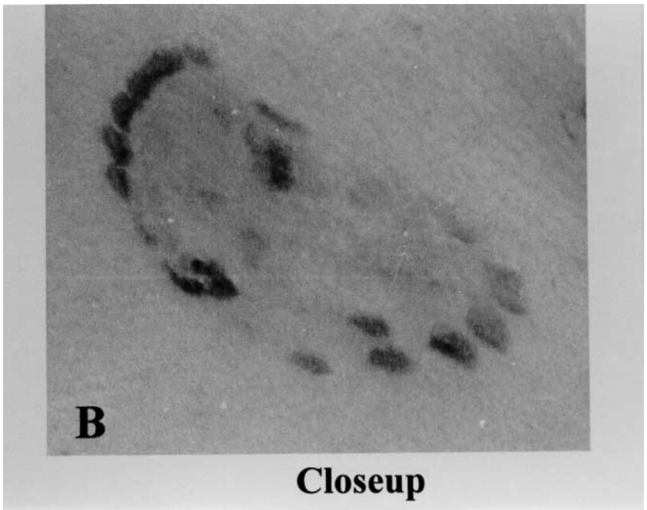

Fig. 1. A representative photograph from bitemark Case 1, a bitemark on human skin, as supplied to examiners. Other photographic views containing a measurement scale were also supplied.

2.2. Instrument

Submitted to every examiner were 4 sets of scaled and unscaled colour photographs of bitemark cases (Figs. 1–4), 7 sets of dental models with which to compare the bitemarks, and a workbook with instructions and sheets on which to record the responses for each bitemark case. The ABFO Bitemark Committee, from examples submitted by diplomates, selected the 4 cases. Three were actual bitemark cases, each of which was on the skin of a deceased individual, and which had been previously analyzed in an actual criminal case and subsequently litigated. One (Case 2) was a bitemark made purposely by the teeth of a diplomate in a block of cheese (a dental stone cast of this bitemark was also submitted with the photographs for this case). Each of the 7 sets of dental models consisted of occluding mandibular and maxillary casts, among which were the 4 dentitions that had actually made the bitemarks. The three other sets of models were randomly selected from patients in the private dental office.

For each case, the examiners were asked to rate their degree of certainty that the case was a bitemark on a 7-point

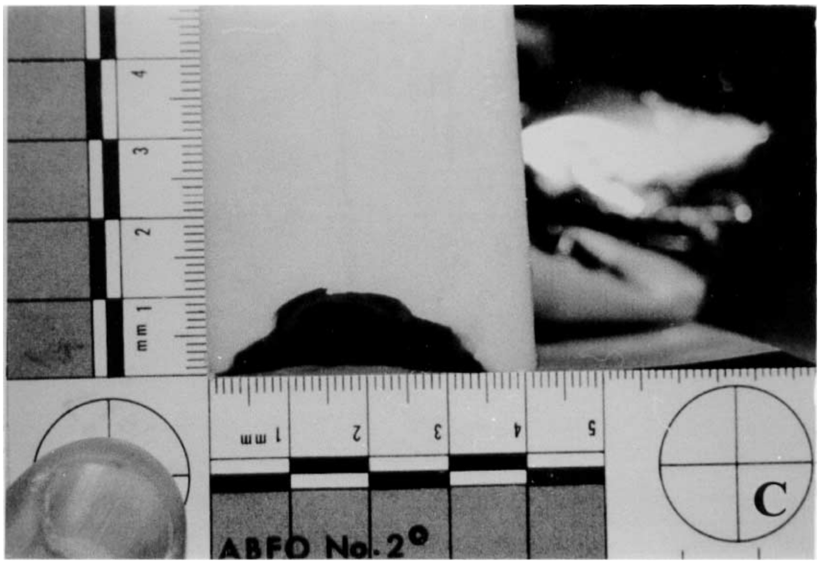

Fig. 2. A representative photograph of bitemark Case 2, a human bite in cheese, as supplied to examiners. Other photographic views containing a measurement scale were also supplied, as was a dental stone cast of the bite.

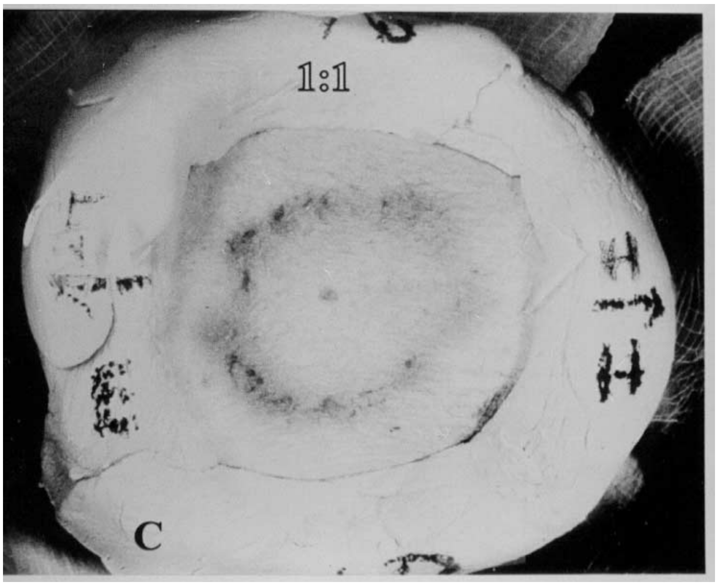

Fig. 3. A representative photograph of bitemark Case 3, an excised bite on human skin, as supplied to examiners. Other photographic views containing a measurement scale were also supplied. Note the curvature of the skin.

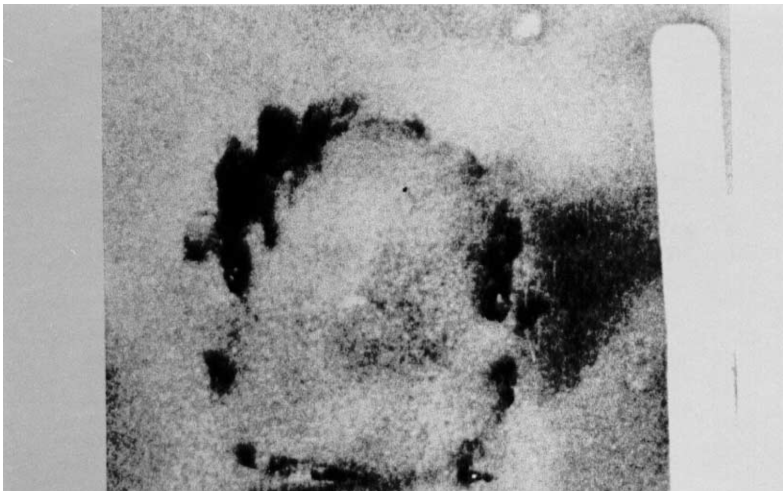

Fig. 4. A representative photograph of bitemark Case 4, a bite on human skin, as supplied to examiners. Note that the scale demarcations are not visible. Another photographic view containing a measurement scale was also supplied.

Likert-like scale coded (1) indeterminable, (2) incompatible, (3) unlikely, (4) possible, (5) probable, (6) reasonable certainty, and (7) definite. Next, the examiners were asked to rate the evidentiary value of the case on a 4-point Likert-like scale. They were coded (1) high forensic value, which could support a reasonable certainty/very probable identification as well as an exclusionary finding, (2) medium forensic value, which could support a possible or consistent with type of identification as well as an exclusionary finding, (3) low forensic value, which would not support a ''linking'' type of finding but could be used for an exclusionary finding, and (4) no forensic value, which should not be used in an investigation to either link or exclude. Finally, the examiners were asked to give their opinion on the strength of the link between the particular bitemark case with each of the 7 sets of dental models. Using a 7-point Likert-like scale they were coded (1) reasonable medical certainty, (2) probable, (3) possible, (4) improbable, (5) incompatible, (6) inconclusive, and (7) non-diagnostic.

2.3. Procedure

The workbook, case photographs, a model of the bite in the cheese, and the 7 sets of dental models were sent to each examiner, who were given approximately 6 months to complete and return the work. The investigators were instructed to perform a complete analysis of each bitemark case and complete all questionnaires associated with the cases. They were also asked to complete an actual forensic report regarding the case, following the ABFO guidelines for report writing, which were included with the booklet. Also included in the workbook were the names of the submitters of the 4 cases, so that an examiner could get additional verbal information on the cases, if necessary.

2.4. Statistical methods

The primary objective of this study was to determine the accuracy of examiners in distinguishing the correct dentition that made a bitemark. Receiver operating characteristic (ROC) analysis was used to determine their accuracy. Accuracy, defined as the area under the ROC curve, is a measure of the ability of the examiners to correctly choose the true dentition that made the bitemark [2]. The ROC curve combines and generalizes the concepts of sensitivity and specificity into a single measure of accuracy. Sensitivity, also called the true positive fraction (TPF), is defined as the proportion of examiners that correctly identify the dentition that made the bitemark [3]. Specificity is the proportion of examiners that correctly identify the dentition that did not make the bitemark. In ROC analysis, the false positive fraction (FPF), the number of examiners who incorrectly identify a dentition as having made a bitemark, is the complement of specificity (1-specificity). When the examiners' responses are the degree to which they believe a particular dentition made a bitemark, each degree of the response can be used as a cutoff point, creating an array of corresponding TPF, FPF pairs. Plotting these pairs with FPF on the *X*-axis and TPF on the *Y*-axis [4,5] forms the ROC curve. The area under the ROC curve is defined as the diagnostic accuracy (AUC). The area ranges between 0 and 1. Areas between 0 and 0.5 indicate that an inverse relationship exists between the rating scale and correct identification, i.e. a rating of probable would correspond to a dentition that did not match the bitemark; an area of 0 is a perfect inverse accuracy. An area of 0.5 indicates that the examiners are guessing; they are right 50% of the time [3]. Areas between 0.5 and 1 indicate a positive relationship between the rating scale and correct identification, i.e. a rating of probable would correspond with a dentition that matched the bitemark; an area of 1 is a perfect accuracy. The closer the ROC area is to 0 or 1, the higher is the accuracy [3].

Ninety-five percent confidence intervals for accuracy were calculated using the bootstrap technique. Bootstrap is a method of repeatedly sampling the data, with replacement, to estimate the parameters of the distribution of a statistic [6]. This technique is often used to estimate statistical parameters when the correct distributions are unknown or extremely difficult to compute. To calculate the confidence intervals for this study, samples of size 32 were taken from the examiners 20,000 times. The upper and lower 2.5% of the distribution of the 20,000 ROC areas generated from the bootstrap samples determined the upper and lower 95% confidence bounds.

Secondary objectives in this study were to determine whether examiner experience, bitemark certainty, or forensic value had an effect on accuracy. To conduct these analyses, a score was calculated for each of the 4 cases for each examiner. One point was given for each correct determination, i.e. 1 point is given for correctly determining whether or not the dentition made the bitemark. Case scores range from 0 to 7, and the composite score is an average of the 4 case scores.

The optimal cutoff point for determining positive and negative examiner responses was determined by using Youden's index (J) which is calculated as $J = \text{TPF} - \text{FPF} = \text{sensitivity} - (1 - \text{specificity}) = \text{sensitivity} + \text{specificity} - 1$. This index can be calculated for any point on the ROC curve and is usually calculated at each rating point, i.e. points 1–7 in this study. The point with the index value closest to 1 is the optimal point. This index is very simple to calculate and easy to interpret, however, it assumes that sensitivity and specificity are weighted equally [7]. If 1 feels that sensitivity is more important than specificity or vice versa, a weighted Youden's index can be calculated as $J^* = 1 - \text{wt}_{\text{sens}} - \text{wt}_{\text{spec}} + \text{wt}_{\text{sens}} \times \text{sensitivity} + \text{wt}_{\text{spec}} \times \text{specificity}$, where wt_{sens} and wt_{spec} are greater than or equal to 1. Weighting sensitivity gives more importance to detecting a true positive while weighting specificity gives more importance to avoiding false positives. To reduce the chances of mistakenly identifying a biter, give a value greater than 1 to wt_{spec}.

The relationship of accuracy with bitemark certainty and forensic value was analyzed, using partial correlation to remove examiner effects. Correlation was used to determine the relationship of examiner experience with overall accuracy.

3. Results

3.1. Combined data analysis

The data for the 32 examiners were combined over the 4 cases and 7 dentitions (Table 1). Youden's unweighted index indicates that "possible" is the best cutoff point for the combined data in this study.

The ROC curve is shown in Fig. 5. The actual points are plotted from Table 1, and the curve is plotted from a maximum-likelihood approximation (ROCFIT program by C. E. Metz et al., University of Chicago, Chicago, IL). Note

Table 1
Sensitivity, specificity and Youden's score for each level of conclusion[a]

Rating	Correct dentition		Incorrect dentition		Unweighted Youden's index
	n	TPF (sensitivity)	*n*	FPF (1-specificity)	
Reasonable medical certainty	25	0.1953	1	0.0013	0.1940
Probable	43	0.5312	13	0.0182	0.5130
Possible	35	0.8046	73	0.1133	0.6913
Improbable	5	0.8437	126	0.2774	0.5663
Incompatible	15	0.9609	536	0.9753	–0.0144
Inconclusive	4	0.9922	13	0.9922	0.0000
Non-diagnostic	1	1.0000	6	1.0000	0.0000
Total	128		768		

[a] Data from combined results of all examiners. The optimal cutoff point was "possible".

that the diagonal line running from bottom left to top right represents a test whose specificity and sensitivity are 50%, i.e. no better than chance (AUC of 0.50). The line running from the top left to the top right represents a perfect diagnostic test, i.e. sensitivity and specificity are 100% (AUC 1.0). The ROC area calculated by the non-parametric trapezoidal method is 0.86, a fairly high accuracy, indicating that the examiners are able to correctly identify the dentition belonging to a particular bitemark. Bootstrap 95% confidence intervals are 0.82–0.91.

Bitemark certainty and forensic value were significantly associated with the score. The partial correlation coefficient for bitemark certainty and score was -0.33 ($P < 0.001$) that indicates that higher scores are significantly associated with higher certainty. High scores are also significantly related to higher forensic value (partial $r = -0.36$, $P < 0.001$). Note that high certainty is 1 and low certainty is 7, and high value is 1 and low value is 4, while good scores are high and bad scores are low. Thus, the negative correlation indicating an inverse relationship actually shows that high scores are associated with high bitemark certainty and forensic value. Table 2 illustrates the accuracy for each of the cases. Years of experience as a diplomate was not significantly related to score ($r = 0.01$, $P = 0.958$).

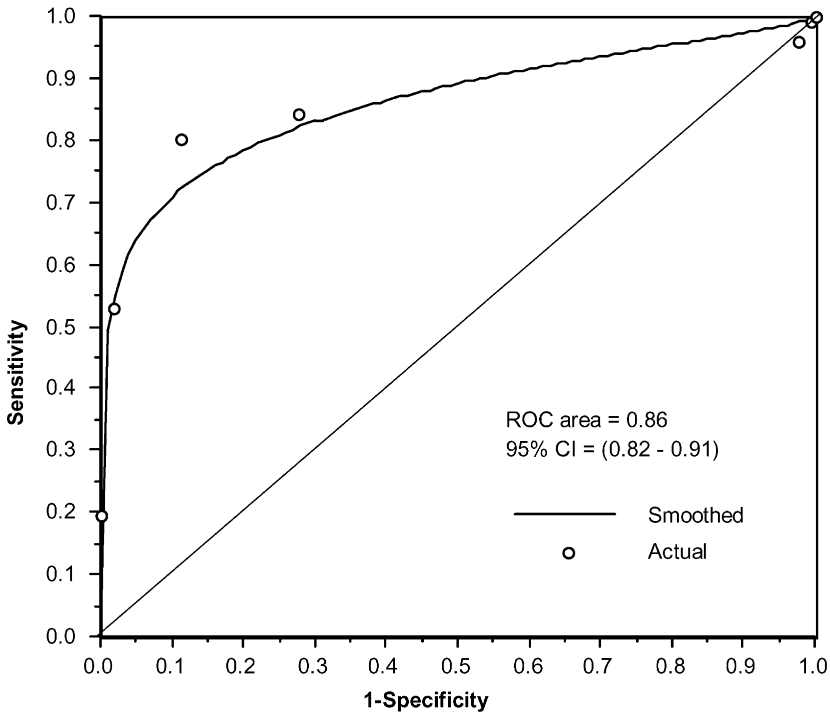

Fig. 5. ROC curve from the combined data (all examiners).

Table 2
Accuracy (ROC) values for each case, combined results

Case	Forensic value (% of $n = 32$)					ROC accuracy (95% CI)	Mean accuracy score (S.D.)
	High (1)	Medium (2)	Low (3)	N1 (4)	Mean		
1	59	38	3	0	1.44	0.81 (0.72–0.92)	6.1 (1.2)
2	75	22	3	0	1.28	0.94 (0.86–1.00)	6.4 (0.9)
3	47	34	16	3	1.75	0.89 (0.81–0.97)	6.1 (1.5)
4	3	72	22	3	2.25	0.77 (0.68–0.87)	5.9 (0.9)
Composite	46	41	11	2	1.74	0.86 (0.82–0.91)	6.1 (0.8)

3.2. Individual data analysis

ROC analysis for individual examiners may not be appropriate for this study because the small number of cases makes the results unreliable. However, this section is included to illustrate how individual ROC analyses could be used to guide examiners in their own practices. Individual ROC analyses was performed for each of the examiners (PEPI, Statistical Software for Epidemiologists, Gahlinger PM, Abramson J, Brixton Software, London). In these calculations, the ROC data for sensitivity and specificity (for each level of conclusion), AUC and the optimal cutoff point (as determined by Youden's index) were determined. Also included are cutoff points determined by weighted Youden's index with increasing or decreasing weight for both false positives (specificity) and false negatives (sensitivity). These data were made available for each of the examiners. The individual examiners AUC and optimal unweighted cutoff points are shown in Table 3. The mean AUC score was 0.86 (the same as the combined AUC score) with standard deviation of 0.14 and a range of 0.52–1.00. It should be noted that the relatively large variation in some of the individual accuracy scores as evidenced by the large confidence intervals is an indication of the low reliability caused by having too few cases on which to base the accuracy estimate.

Table 3
ROC data for individual examiners[a]

Examiner	AUC	95% CI	Optimal cutoff[b]
1	0.74	0.45–1.00	2
2	0.84	0.55–1.00	3
3	0.82	0.55–1.00	3
4	0.96	0.88–1.00	4
5	0.68	0.36–1.00	4
6	0.98	0.94–1.00	3
7	0.84	0.57–1.00	3
8	1.00	1.00–1.00	3
9	0.75	0.33–1.00	3
10	1.00	1.00–1.00	3
11	0.72	0.38–1.00	2
12	0.99	0.96–1.00	3
13	0.92	0.78–1.00	4
14	0.59	0.27–0.91	1
15	0.97	0.91–1.00	3
16	1.00	1.00–1.00	2
17	0.62	0.37–0.88	3
18	0.82	0.54–1.00	4
19	1.00	1.00–1.00	3
20	0.64	0.24–1.00	2
21	0.74	0.41–1.00	4
22	1.00	1.00–1.00	3
23	0.71	0.36–1.00	4
24	0.96	0.88–1.00	3
25	0.99	0.96–1.00	3
26	0.72	0.39–1.00	4
27	0.74	0.33–1.00	4
28	0.92	0.78–1.00	3
29	0.98	0.93–1.00	4
30	0.99	0.96–1.00	3
31	0.99	0.96–1.00	3
32	0.76	0.39–1.00	3

[a] Note the inter-examiner variations in AUC score.
[b] Optimal cutoff point determined by unweighted Youden's index.

4. Discussion

This survey indicates that analysis of bitemark evidence is a relatively accurate procedure among experienced forensic odontologists when the results are examined in combination. It is important to note that in order to generalize the findings of this study to different cases and examiners, it is necessary to have a good cross-section of cases and examiners. In this study, there are a sufficient number of examiners with various amounts of experience. However, there are only 4 cases and these cases are not representative of the range of cases encountered in the real world. Cases 1 and 2 are rated as having high forensic value by the majority of the 32 raters; Case 3 is slightly less highly rated than Cases 1 and 2; and Case 4 has medium forensic quality. Therefore, the findings of this study generalize only to cases having moderate to high forensic value. In future studies, a larger number of cases covering a wider range of forensic values should be used to increase the generalization or cross-section and to facilitate the use of individual ROC analyses.

Using the same 7 sets of dental models for all 4 cases may have violated the assumption that responses for each case are independent within examiners. There may be a systematic relationship among the cases if the examiners considered the cases in the same order and eliminated a dental model as being a viable candidate for subsequent cases once it had been selected for the current case. The use of global casts also altered the prevalence of biters versus non-biters as the cases progressed. For example, by the last case, the examiner may have considered only 4 casts instead of 7. This lack of independence has prevented the use of statistical measures such as positive predictive and negative predictive values. In future studies, 1 dental model or a unique set of dental models should be used for each case.

The use of real forensic casework for the determination of the truth is also a potential weakness of this study that must be recognized when considering the results. With the exception of Case 2, the bite in cheese, the correct answer was considered to be the casts that the original examining forensic dentist determined to be the biter. There is always a possibility that the original examining dentist was wrong. In order to control this situation, simulated cases should have been employed, although these may have affected the authenticity of the study. Whittaker, who used ROC to determine the ability of a variety of professionals to identify a mark as a bite injury, utilized the Court decision to determine the truth, but accepted that inaccuracy could be introduced by this method [8]. This study showed that the quality of the evidence is positively related to the accuracy of the odontologists' analyses, and many examiners may have collected the evidence differently or even obtained additional evidence. These aspects of the study must be considered in tandem with the results. In spite of the flaws found in the construction of this study of examiner reliability, it is a strong indication of the continuing efforts of the ABFO to achieve high professional standards. Guidelines in both the analysis of bitemark evidence and in the terminology to express conclusions have already been adopted by the ABFO. Neither of these standards is static, with efforts made annually at revision.

Similar absence of consistency has been reported in other forensic pattern comparisons. In a recent survey of shoe print analysis by 23 experts from 7 criminology laboratories in six different countries, there was a broad range of conclusions to include "identification", "highly probable", "probable", "possible", and "inconclusive" for each of the two cases examined. In some instances, experts in the same laboratory totally disagreed on conclusion [9]. The authors of this shoe print study stated the view that variance in those areas of forensic science where the comparative parameters are not solid cannot be totally eliminated, but can be diminished by following established guidelines, particularly with regard to terminology expressing the degree of certainty of a match.

Even in fingerprint analysis with its rigidly based standards of comparison and in some venues, a specified number of points for establishing identity, there is variability among conclusions reached by experts. A 1996 survey of fingerprint examiners also revealed a broad scatter of opinions among the participants [10].

These studies make the point that forensic pattern analysis is, to a certain degree, subjective and not an exact science, even in the best of conditions. This fact should be considered when evaluating any type of pattern comparison evidence.

The results of the present survey indicate that bitemark examination is an accurate forensic technique, at least with cases such as used in this study. However, some might question whether it is accurate enough. According to Swets, a ROC value above 0.9 indicates "high accuracy", 0.7–0.9 means "useful for some purposes", and 0.5–0.7 represents "poor accuracy" [11]. Thus, the overall value in this study (0.86) indicates less than optimal accuracy. Examination of the responses to individual cases (Table 2) reveals that only the value for Case 2 falls into the "high accuracy" category. The Youden's index scores, when weighted, show that the cutoff points can be altered for each individual examiner to minimize either false positives or false negatives. The authors believe that, in the spirit of "innocent until proven guilty", forensic dentists must minimize false positives at all costs. The repercussions of forensic determinations are serious and often intractable, affecting the suspect's life forever.

This study, despite its limitations, has opened the debate into evidence-based forensic dentistry. Forensic odontologists must ensure that the techniques they employ are backed by sound scientific evidence and that the decisions they present in Court serve to promote justice and to strengthen the discipline. Committed to these high professional standards, the ABFO is proactive in the continuing education of odontologists.

To reach those goals, it is recommended that further accuracy studies be made, using more rigorous methodology.

Acknowledgements

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EXHIBIT C
APPENDIX G

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Error rates in bite mark analysis in an *in vivo* animal model

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ABSTRACT

Recent judicial decisions have specified that one foundation of reliability of comparative forensic disciplines is description of both scientific approach used and calculation of error rates in determining the reliability of an expert opinion. Thirty volunteers were recruited for the analysis of dermal bite marks made using a previously established *in vivo* porcine-skin model. Ten participants were recruited from three separate groups: dentists with no experience in forensics, dentists with an interest in forensic odontology, and board-certified diplomates of the American Board of Forensic Odontology (ABFO). Examiner demographics and measures of experience in bite mark analysis were collected for each volunteer. Each participant received 18 completely documented, simulated *in vivo* porcine bite mark cases and three paired sets of human dental models. The paired maxillary and mandibular models were identified as suspect A, suspect B, and suspect C. Examiners were tasked to determine, using an analytic method of their own choosing, whether each bite mark of the 18 bite mark cases provided was attributable to any of the suspect dentitions provided. Their findings were recorded on a standardized recording form.

The results of the study demonstrated that the group of inexperienced examiners often performed as well as the board-certified group, and both inexperienced and board-certified groups performed better than those with an interest in forensic odontology that had not yet received board certification. Incorrect suspect attributions (possible false inculpation) were most common among this intermediate group. Error rates were calculated for each of the three observer groups for each of the three suspect dentitions. This study demonstrates that error rates can be calculated using an animal model for human dermal bite marks, and although clinical experience is useful, other factors may be responsible for accuracy in bite mark analysis. Further, this study demonstrates that even under carefully controlled conditions, albeit in a forced-decision model, errors in interpretation occur even amongst the most experienced analysts.

1. Introduction

Forensic odontologists examine, interpret, analyze, and prepare reports on bite marks [1]. On occasion they offer expert opinion testimony. Implications of incorrect bite mark analysis, that falsely inculpate a suspect, may lead to erroneous incarceration or worse. The 100th wrongly convicted person on death row, Raymond Krone of Arizona, the so-called "snaggletooth killer," may have been convicted in part based on testimony associating his dentition to a human dermal bite mark in a homicide victim [2]. In the DNA-era there have been other exonerations of persons convicted, partially or wholly on misinterpreted dermal bite mark analysis. The United States Supreme Court in Daubert v Merrel Dow [3] held that trial judges are gatekeepers for the admission of scientific opinion evidence and that an opinion posited by an expert will qualify as scientific knowledge only if it's proponent demonstrates that it is the product of sound "scientific methodology". Specifically the following queries need be addressed: has the theory or technique been tested?; is there a known or potential error rate?; has it been subjected to peer review and published?; and is it generally accepted within the field?

It follows that "judge-gatekeepers," must assess the probative value of expert testimony by ensuring that in bite mark analysis, the foundation of the opinion, and subsequent interpretation are scientifically sound; these comparisons have estimable error rates; are reliable; and methods are ultimately published in peer-reviewed journals. An essential requirement in comparing a suspect dentitions to a bite marks is to calculate error rates where possible [4].

There is little doubt that if examined closely enough no two sets of human teeth are completely identical in their three-dimensional

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physical properties. This however is not, or should not, be at issue in bite mark interpretation [5]. Interestingly most bite mark interpretations involve, at least in part, two-dimensional photographs of bite marks with two-dimensional overlays of a suspect dentition [6]. This is problematic since Blackwell et al. [6] showed, using a highly-accurate three-dimensional laser scanning technique, that experimental bite marks in a positive made from a wax bite substrate showed a high potential for mismatch whereby the wrong dental model could not be distinguished from the true match in as much as 15% of cases. In analysis of the uniqueness of the human dentition, highly detailed models of the teeth are frequently used. These models are most often made using some form of dental impression material. Conversely, the substrate for human dermal bite marks is skin—a material that, in addition to being a poor impression material, is a biological system that reacts to injury in various and perhaps individualistic ways. Even after death human dermal bite mark analysis can be problematic. Bush et al. [7] analyzed simulated human bite marks on a cadaveric human skin model. They demonstrated that bite marks from similar dentitions made on these surfaces could not be differentiated from other dentitions that were grossly similar that were not used to make the bite marks [7]. While cadaveric human skin can be used as a substrate for human bite marks it is likely not the perfect analog for recording dermal bite marks. While it seems obvious that the most externally valid bite mark model would be one enraged person biting another during the commission of a violent act, it is impractical and unethical to incorporate this scenario into a study. It is for this reason that live juvenile pigs have been proposed as a model for human dermal bite marks [8].

In addition to determining the efficacy and error rates in bite mark analysis, there is, minimally, a presumption that experience and the achievement of qualifications may have influence on the ability to correctly interpret bite marks. Soomer et al. [9] found that odontologists with a greater degree of case experience and training performed body identification significantly better than their less experienced or less qualified colleagues.

The aim of this study therefore was to determine the ability of examiners to attribute the ‘‘correct’’ dentition to its corresponding bite mark in an *in vivo* bite mark analog of human skin, specifically, live anesthetized juvenile pigs.

By extension, error rates may be calculated for different groups of examiners with different levels of experience and qualification. Additionally, inter-examiner and intra-examiner agreement and evaluation of the accuracy of observer groups with different levels of training and experience was undertaken.

Finally, although groups of examiners of varying experience were used, the presence of poor-performing outliers were noted. The purpose of this last portion of the study is justified because in courts of law, groups of experts do not proffer opinions—individuals do.

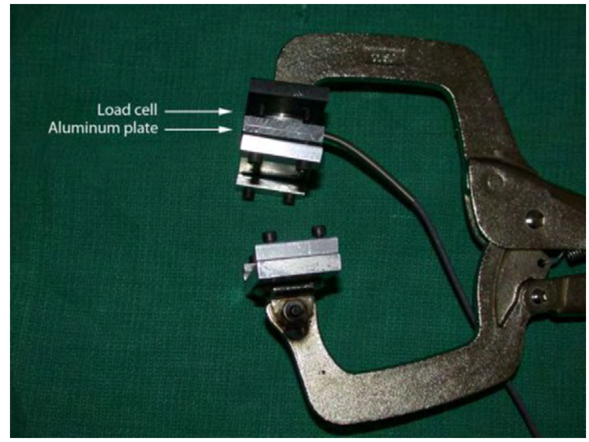

Fig. 1. The improved biting device consisted of a vice grip with an aluminum plate fixed to the upper anvil. This aluminum plate receives the pressure of the dentition during the biting action and transfers it to a load cell that is connected to a calibrated digital readout.

2. Materials and methods

2.1. Biting device

This study used a device that simulates human bite marks. A previous version of this device was originally used at the American Board of Forensic Odontology (ABFO) first bite mark workshop in Anaheim, CA in 1984 to produce experimental bite mark injuries on workshop participants [1]. A modified version, manufactured by one author (SLA), was used to make bite mark injuries at known intervals before and after death on pig skin *in vivo*. This new device was designed to allow in-line metering of a controlled force when a bite mark was applied to skin. It also permitted efficient change in suspect dentitions and improved the robustness of a highly similar device used in a prior pilot study [2].

The new device consisted of an upper anvil of a vice grip (C-Clamp #11 vice grip, Master Craft®, Canadian Tire Corporation, Toronto, ON, Canada) to which an aluminum plate was fixed (Fig. 1). This both receive the force of the dentition during biting, and transferred this force to a load cell and ultimately a preconfigured indicator (A-Tech Instruments Ltd., Scarborough, ON, Canada). Three sets of upper and lower anterior teeth that could be attached and detached from the device were fabricated from acrylic prosthetic teeth (Densply Canada Ltd., Woodbridge, ON, Canada). After finalizing the position of each individual tooth, an impression of the montage was made with irreversible hydrocolloid impression material (Supergel, Harry L. Bosworth Company, item #0921825, Skokie, IL, USA). Once the material hardened, the montage was removed and melted wax (Baseplate wax #3001101, Denplus Inc., Montréal, QC, Canada) was poured into the impression for duplication. Each piece of the dentition was then prepared for chrome–cobalt transformation using the same casting technique as used for chrome–cobalt removable dental prostheses (Fig. 2). The three sets of teeth had identical inter-canine arch width, and arch depth. All individual teeth were similarly sized and similarly shaped and their vertical position relative to the plane of occlusion was held constant. Tooth position differed only with respect to the individual horizontal position of the teeth, i.e. angulation and rotation. Additionally, all sets of teeth had the same biting surface area to make sure that force applied, as much as possible, was equally distributed amongst the dentitions. The chrome–cobalt dentitions were labelled ‘‘Suspect A’’, ‘‘Suspect B’’, and ‘‘Suspect D’’. The dentition of ‘‘Suspect D’’ was used to make the

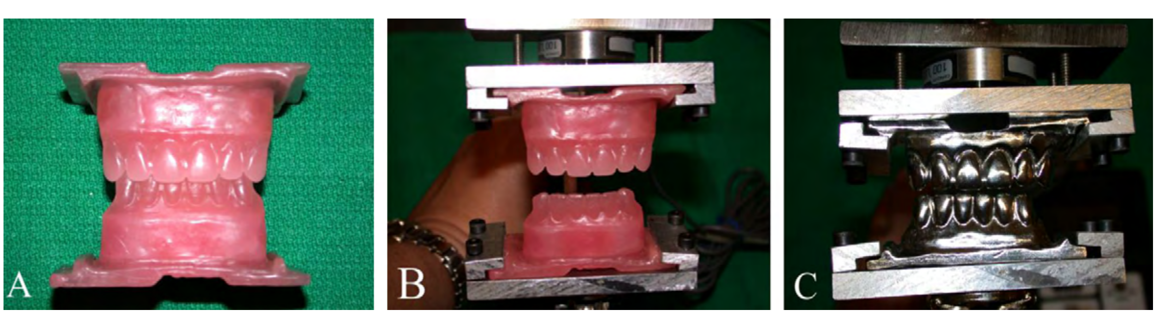

Fig. 2. Depiction of procedure used in fabrication of test bites for one dentition. A at left shows waxed-up dentition where teeth are of similar individual widths and similar arch depth and arch width but differing individual positioning from case to case. B shows wax-up placed in biting apparatus and C shows finalized chrome–cobalt dentition place in biting apparatus.

Table 1
Depiction of the role of each dentition in the making of bites and in the sample sent for analysis.

Suspect dentition	A	B	C	D
Dentition used for bite marks	6 bite marks	6 bite marks	No bite marks made	6 bite marks
Dentition sent to analysts as a suspect	Yes	Yes	Yes	No
Possibility of correct match	Yes	Yes	No	No

bite marks in the porcine model but was not sent to the examiners, creating a situation where the teeth of one of the biters was never seen by any examiner. A 4th set of teeth labelled "Suspect C" was prepared in an similar fashion, was not used to make any of the bite marks, differed with respect to the positions of the biting teeth from all the models and was sent to the examiners creating another complication for the examiner. None of the bite marks was made by this set of teeth. Table 1 provides a key of those dentitions used to produce bite marks and those sent to the bite mark examiners.

2.2. Experimental bite mark production

The study was approved by the Division of Comparative Medicine Committee as well as the Research Committee of the Faculty of Dentistry of the University of Toronto. The pigs were acclimated to a temperature of 22 °C and light–dark (12 h/12 h) regulated facility. Each pig received a complete physical examination and blood tests to rule out the presence of systemic diseases or haematological disorders. On the day of the experiment, all blood tests were normal. Sedation of the pigs was achieved via intramuscular injection of 16.0 cc of ketamine (10 mg/ml) in the right thigh. With the animals under general anaesthesia, the simulated bite marks were created on the abdominal area with the biting device. Three juvenile female pigs, weighing approximately 35 kg received 4 ante-mortem and 2 post-mortem bite marks. Previous investigations [10–12] showed that pressure exerted by human incisor teeth ranges from 6.0 to 23.5 kg (mean 8.9–11.4 kg). Pressure consistency was selected at 23 kg for this study as a representative force applied by human incisor teeth. This force exerted by the upper and lower arches of the device was applied to the tissue continuously for a total of 60 s. The same force and time were used in previous studies [5,8,10,13]. These prior pilot studies showed that this technique yielded clearly visible bite mark-like injuries when marks were made at or around the time of death. The bite marks in the present study were therefore made 5 min before euthanasia for the ante-mortem marks and at least 5 min after euthanasia for the post-mortem marks. The dentition labelled "Suspect A" was used on pig #1, the dentition labelled "Suspect B" on pig #2, and "Suspect D" similarly on pig #3. Once the biting procedures were completed, the pigs were humanely sacrificed with Tanax® (T-61, Intervet Canada Ltd., Whitby, ON, Canada) using a dose of 0.3 ml kg^{-1} body weight through an ear vein. The pigs were transported to the Coroner's office and held under standard mortuary conditions until necropsy the following day.

2.3. Bite mark impressions and casts

The day after the bite marks were made, each of the three pigs was prepared for the collection of evidence. This evidence included impressions of the bite marks for the fabrication of bite mark models. To facilitate this, a rigid thermoplastic mesh (Orthopedic mesh polyflex, Sammons & Preston Roylan, Cedarburg, WY, USA) such as one used for head and neck radiation therapy positioning devices was used as a backing support for the impression material. This plastic tray of 6.0 cm × 7.0 cm was placed under hot water so it could be molded and shaped to fit the skin surface. Each tray was identified according to its corresponding bite mark.

Working on one bite mark and on one anatomic side of the pig at a time, vinyl polysiloxane impression material was used for making impressions of the bite marks. Light and regular viscosity material (Reprosil light and regular viscosity, Ash Temple Ltd., Don Mills, ON, Canada) was applied on the skin and the custom-molded mesh tray. The mesh tray, filled with impression material, was then applied on the bite mark area and left to set. Once the impression material had cured, the trays were removed and set aside for the fabrication of stone casts (Velmix #31006, Kerr Corporation System, Dental Specialties Inc., Romulus, USA) of each bite site.

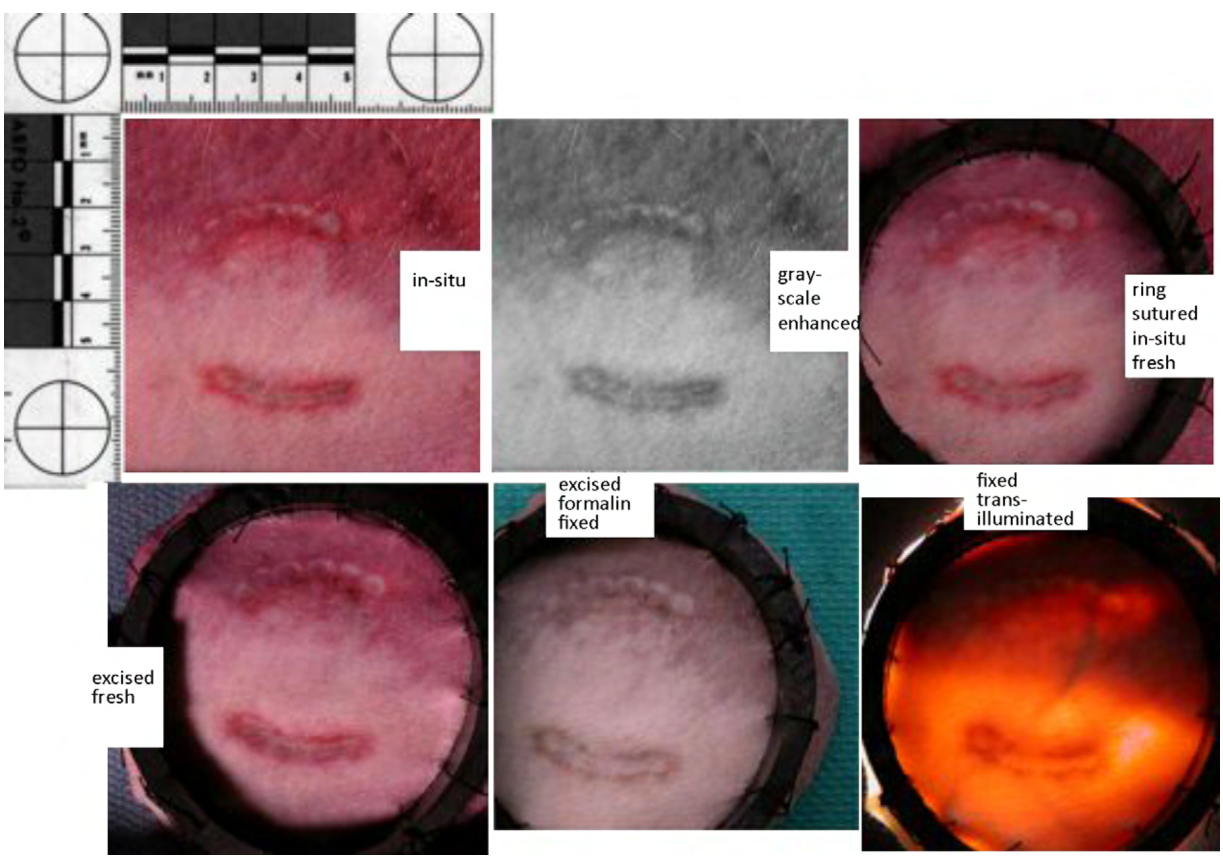

Fig. 3. Serial photographs and montage of bite mark procedure at different times: in situ post-depilitation, black and white post-depilitation, in situ post-ring fixation, following excision, post-formalin fixation, and transilluminated.

Fig. 4. Complete dentitions of three suspect dentitions (A, B, and C as labeled) with wax-ups at left of each and stone casts at right. Stone casts were sent to each examiner.

2.4. Serial photographs of bite marks

Documentary photographic procedures included serial photographs using a digital camera (Nikon 5700, Nikon Corporation, Japan) with and without flash, and with flash set at "off" angles. The photographs were completed throughout the bite mark documentation period during various aspects of the bite mark procedure. They were made with and without an ABFO No. 2 reference scale: after hair removal, after ring fixation, after specimen excision, following formalin fixation, and during the transillumination procedure. Two of the investigators, an oral pathologist (SLA) and a board-certified forensic odontologist (RW) selected the best representative photograph of each procedure independently. Where there was a dispute the two examiners discussed the case and mutually chose the best photograph. A montage of the photographs including a black and white photograph of the specimen after hair removal was prepared for each bite mark in a life-size dimension (1:1) using Adobe Photoshop 6.0 (Fig. 3).

2.5. Suspect dentitions

From the anterior chrome–cobalt dentitions of suspect A and suspect B, complete sets of teeth including posterior teeth were made. The original anterior wax teeth from suspects A and B were transferred onto a wax base that served for the eventual complete sets of teeth. Posterior acrylic teeth were added to the wax base to complete the sets of dentition. Since dentition D was not sent to the bite mark examiners, a third set of teeth was fabricated. Suspect dentition C was made from the same mould of teeth used to make dentitions A and B keeping the identical dental and arch characteristics referred to above. The three sets of dentitions were then cast in pink stone (Fig. 4).

2.6. Bite mark examiners

Ten participants were recruited from each of the three groups: inexperienced local dentists who were clinical demonstrators at the Faculty of Dentistry of Laval University (termed "novices"), dentists with an interest in forensic odontology but without board-certification status such as members of a forensic association or society (termed "members"), and experienced examiners who were board-certified diplomates of the ABFO (termed "diplomates").

For each examiner, bite mark cases were labelled from #1 to #18. A statistical software package (SAS v9.0, Cary, NC) was used to randomize the order of bite mark cases among the examiners such that case #1 for one examiner would differ from the case #1 given to the other examiners. The boxes were prepared and verified by one of the investigators (SLA).

Each participant received 18 simulated bite mark cases, that contained: three sets of "suspect" dental models identified Suspect A, Suspect B and Suspect C; 18 casts of the bite mark injury sites from the each bite mark respectively identified; a CD-ROM of the serial photographs of each of the bite mark cases; and three envelopes. One envelope contained a detailed explanation of the project and background demographic information to be completed. A second envelope contained eighteen 1:1 serial photographs (on photographic paper) of each of the bite mark cases. A third envelope contained the blank answer sheets for each of the 18 bite mark cases to be completed. A total of 11 questions were asked per case. The examiners had to decide, among other tasks, whether the bite mark could be attributed to one of the suspect dentitions. The examiners were not permitted to keep or copy the materials. They were asked to return the material to the investigators when the analysis was completed. After a washout period of at least six weeks, the examiners were asked to repeat the same exercise in a second assessment using the same case material. The second box the examiners received was identical to the first but the labels for the cases had been changed on all the case material. The same material was re-labelled between the periods using the same randomization method used in the first assessment. This allowed the authors to calculate inter-examiner and intra-examiner error.

2.7. Statistical analysis

All statistical analyses were completed using SAS version 9.0 (Cary, NC). For the purposes of this study statistical findings where, $p < 0.05$ alpha level were considered statistically significant. Data from the questionnaires sent to examiners were verified for accuracy. Distributions of all variables were checked for outliers and invalid responses.

Demographic data (sex and age) and data on participants' clinical experience (degree, specialty, years since graduation, location of primary practice, number of days of forensic training, and number of bite mark cases previously analyzed) were collected to assess any differences between the composition of examiner groups and to determine if these factors were associated with an ability to correctly attribute bite marks to suspect dentitions. These distributions of the demographic and clinical factors were compared between each of the three groups using Fisher's exact test for categorical factors. Continuous variables (age, years since graduation, and number of days of forensic training) were compared between groups using analysis of variance. When an association between a given factor and an examiner group was found, Bonferonni-corrected *post hoc* tests were used to compare groups in a pair-wise fashion.

3. Results

3.1. Novices

Ten examiners, 7 women and 3 men completed the first and second assessment. At the time of examination the mean age of these dentists was 38.5 years (s.d.: 6.6 years) with a mean number of years of dental experience of 14.9 years (s.d.: 6.4 years). There were 2 specialists, one in oral surgery and another in paediatric dentistry. One dentist was working full time in a local hospital, another one was working part time at the university while the rest maintained private dental practices. None were associated with any forensic association, board or society nor had they received any training in the field prior to or as part of this study.

3.2. Members

The second group were labelled "members" and were members of at least one forensic association and had some forensic odontology training. Ten examiners, all men, completed the first assessment with 9 completing the second assessment of bite mark analysis. Drop out by one of the members was due to his need to attend the Asian tsunami multiple-fatality incidents. The mean age for this group of dentists was 53.2 years (s.d.: 7.8 years) with a mean number of years of dental experience of 29.1 years (s.d.: 8.0 years). There were no specialists. One dentist was employed full time at a university while the rest were in private dental practice. All members except one had examined at least one bite mark case in the course of their careers. The number of cases of bite mark analysis varied from none to in excess of 20 cases while the number of days of forensic-training courses ranged from 10 to 200 days. All these examiners were members of the American Academy of Forensic Sciences (AAFS) and 9 were members of the American Society of Forensic Odontology (ASFO).

Table 2
Demographic information and experience of participant examiners.

	Novices (n = 10)	Members (n = 10)	Diplomates (n = 9)	p-Value for difference
Gender, % (n)				
Female	70.0 (7)	0.0 (0)	22.2 (2)	0.002
Male	30.0 (3)	100.0 (10)	77.8 (7)	
Specialty, % (n)				
Yes	30.0 (3)	0.0 (0)	11.1 (1)	0.185
Degree, % (n)				
DDS/DMD	100.0 (10)	100.0 (10)	100.0 (9)	1.000
FRCD	20.0 (2)	0.0 (0)	0.0 (0)	0.310
Practice, % (n)				
Private office	80.0 (8)	90.0 (9)	66.7 (6)	0.645
University	10.0 (1)	10.0 (1)	22.2 (2)	
Military	0.0 (0)	0.0 (0)	0.0 (0)	
Medical examiner	0.0 (0)	0.0 (0)	11.1 (1)	
Hospital	10.0 (1)	0.0 (0)	0.0 (0)	
Research facility	0.0 (0)	0.0 (0)	0.0 (0)	
# Bite mark cases, % (n)				
0	100.0 (10)	10.0 (1)	11.1 (1)	<0.001
1–9	0.0 (0)	70.0 (7)	11.1 (1)	
10–19	0.0 (0)	10.0 (1)	22.2 (2)	
20+	0.0 (0)	10.0 (1)	55.6 (5)	
Age, years*				
Mean (s.d.)	38.5 (6.6)A	53.2 (7.8)B	55.8 (10.4)B	0.002
Years since graduation*				
Mean (s.d.)	14.9 (6.4)A	29.1 (8.0)B	30.3 (11.7)B	0.001
Number of days in forensic training*				
Mean (s.d.)	0.0 (0.0)A	57.7 (58.9)B	66.3 (36.9)B	0.003

DDS: Doctor in dental surgery; DMD: Docteur en médecine dentaire; FRCD: Fellow of the Royal College of Dentists.
* Means with different letters are significantly different at the 0.05 level based on Bonferroni adjusted *post hoc* tests.

3.3. Diplomates

Nine diplomates, 2 women and 7 men completed the first assessment. On the second assessment, 6 of them, 1 woman and 5 men completed the bite mark analysis. Some examiners from this group withdrew either on the first or second round of the project for the same stated reason as the one in the member group. This was due to the overlap of serious multiple-fatality incidents requiring their attendance. The mean age for the diplomates was 55.8 years (s.d.: 10.4) with a mean dental experience of 30.3 years (s.d.: 11.7 years). There was one specialist in oral pathology, 2 dentists worked full time at a university, one in a medical examiner's office while the rest maintained private dental practices. Diplomates had examined more bite marks cases than members, with the majority (56%) having examined over 20 cases. The number of days of forensic-training courses taken ranged from 15 to 100 days. All of them were in good standing with the ABFO as well as members or fellows of the AAFS and members of the ASFO. Table 2 presents the demographic and experiential characteristics of the examiners that participated.

3.4. Predictors of correct/incorrect attribution of a dentition to a bite mark

To examine whether certain bite marks were more readily matched, the percentage of correct attributions was calculated for each bite mark. As shown in Fig. 5, the identification of the correct suspect was considerably lower for bite marks made with dentition A than dentitions B and D. It should be remembered that a "correct" response for bite marks attributed to dentition D would rule all suspects out. That is, there was no bite mark that should be linked to that model. There appears to be little variation between the three examiner groups, although diplomates frequently had higher levels of correct responses. Interestingly, novices often performed as well as diplomates, and better than members. Fig. 5 also demonstrates that there was no apparent change with the second evaluation. Specifically, examiners did not appear to improve on their second evaluation.

Fig. 6 shows the percentage of time that examiners within each group incorrectly attributed one of the suspect dentitions to the bite mark. Attributing the wrong dentition to a bite mark constitutes a critical error as it would be analogous to inculpating an "innocent" person. Incorrect inculpatory attribution of a dentition to a bite mark was most common among members. Therefore of the 3 examiner groups, members were more likely to falsely inculpate someone as being the biter who was not. Dentitions A and B were the only true possible suspects sent for bite mark analysis. Dentition D although used for biting was not provided to the examiners and all 3 groups had higher percentages of incorrect attribution to a bite. For dentition D, members' incorrect responses were significantly higher than those of diplomates ($p < 0.0001$). Examiners were also given models of suspect C that was not used to make any of the bite marks. Overall, only 3.7% of all bite marks was incorrectly attributed to suspect C. Although the novices incorrectly attributed a bite mark to dentition C twice as frequently as the diplomates, there was no significant difference between diplomate and novice examiners identifying suspect model C as a biter (0.8% vs. 1.9% of the time respectively; $p = 0.556$). Conversely, members identified suspect model C in 7.8% of the cases, which was significantly higher that both novice and diplomate examiners ($p < 0.001$).

Fig. 7 shows the percentage of time that examiners within each group did not identify any of the suspects, when the bite mark was made by a suspect dentition that was provided. This is essentially an error—but not a critical one. In this graph, there are no values for dentition D since this is not a possible source of error. A finding of "no match" or "inconclusive" represents a correct response for bite marks created with dentition D (see Fig. 3). A finding of "no match"

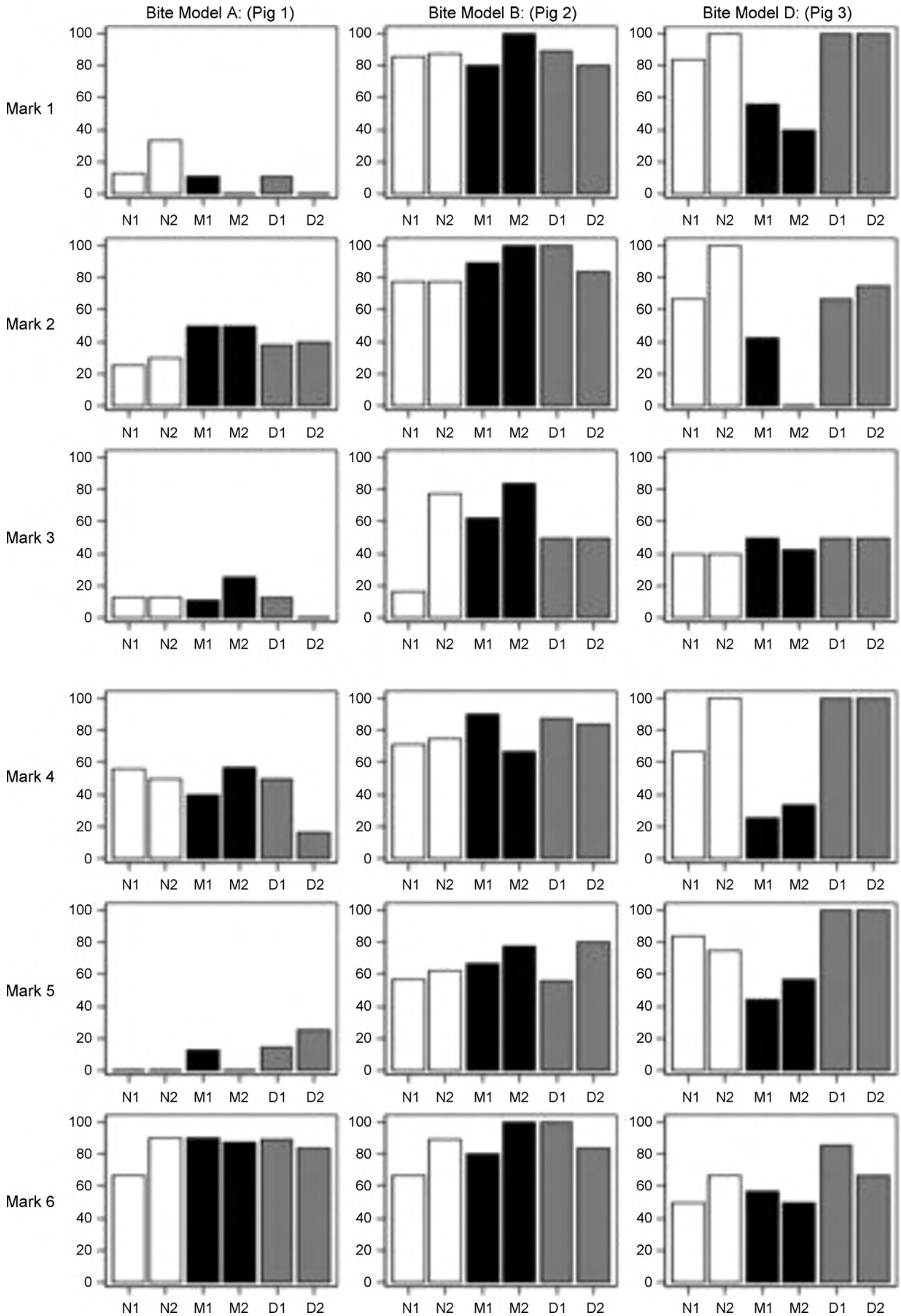

Fig. 5. Percentage of correct response of suspect identification by bite mark, suspect (model), examiner group and time of evaluation. The first vertical column of six graphs on the left is pig 1—bites were made by dentition A. The middle column of six graphs is pig 2—bites were made by dentition B. The right vertical column of six graphs is pig 3—all bites were made by a dentition not provided to the examiners. N1: novices, first assessment; N2: novices, second assessment; M1: members, first assessment; M2: members, second assessment; D1: diplomates, first assessment; D2: diplomates, second assessment.

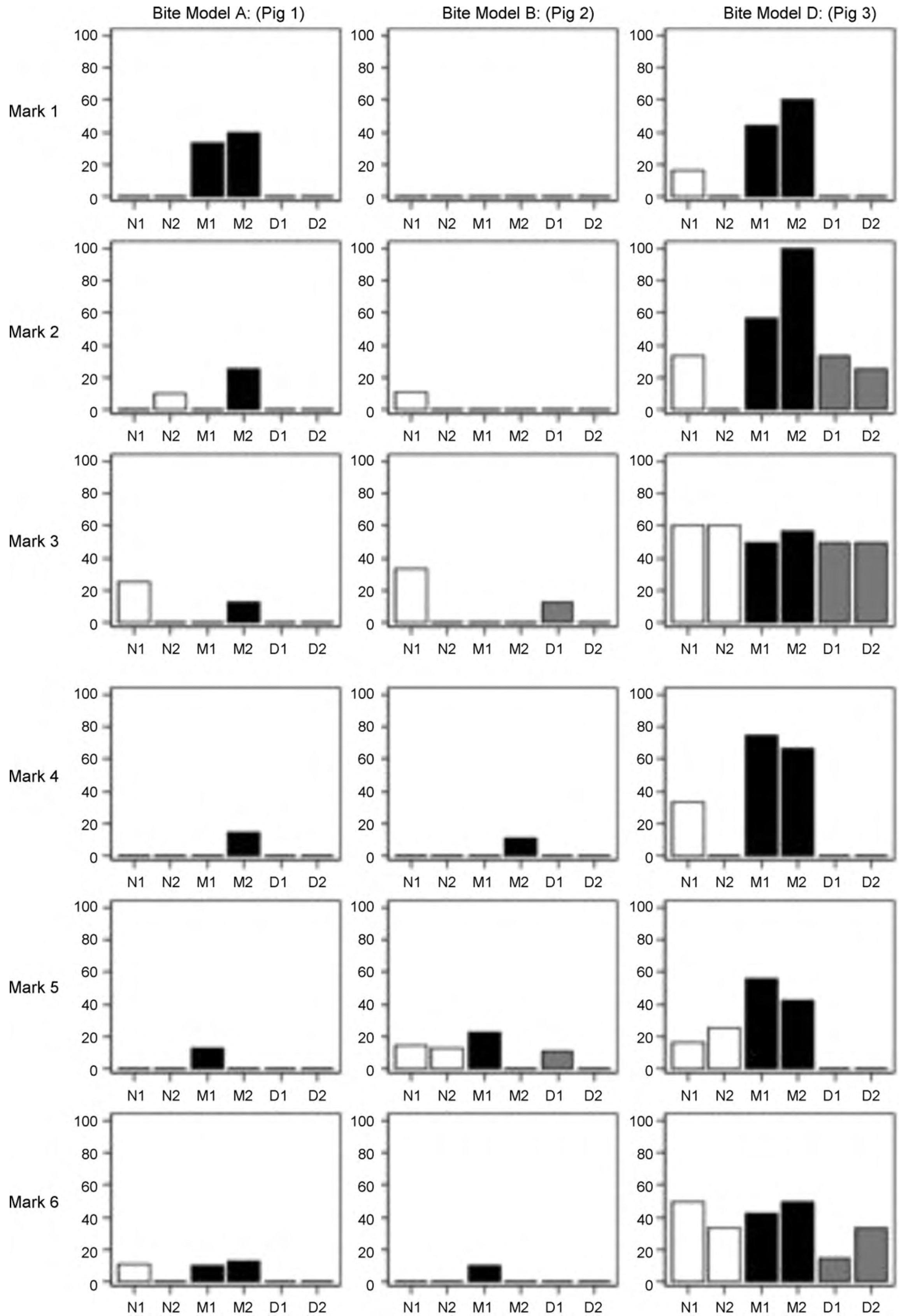

Fig. 6. Percentage of incorrect suspect identification by bite mark, suspect (model), examiner group and time sequence of evaluation. The first vertical column of six graphs on the left is pig 1—where all bites were made by dentition A. The middle column of six graphs is pig 2—where all bites were made by dentition B. The right vertical column of six graphs is pig 3—where all bites were made by a dentition not provided to the examiners. N1: novices, first assessment; N2: novices, second assessment; M1: members, first assessment; M2: members, second assessment; D1: diplomates, first assessment; D2: diplomates, second assessment.

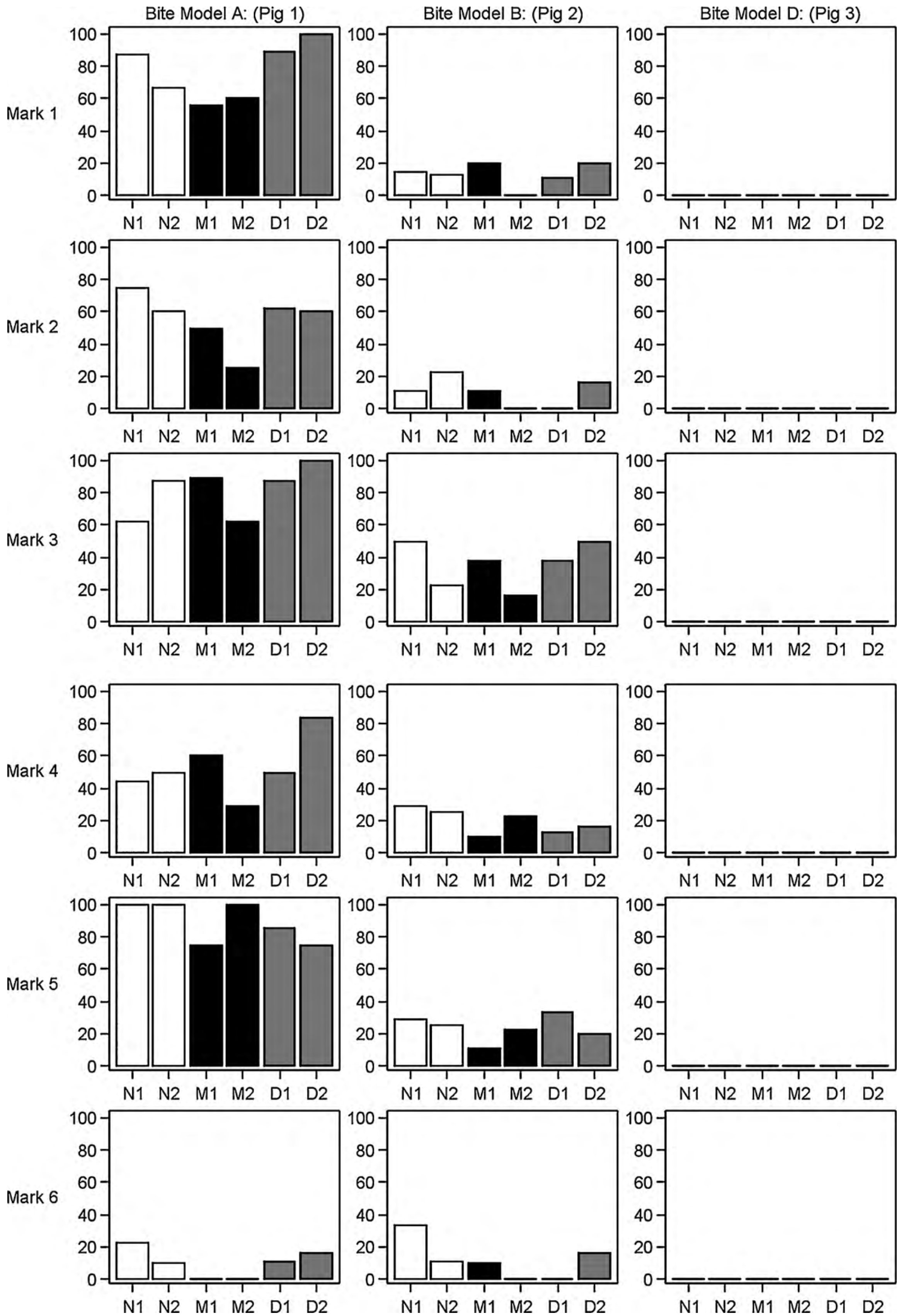

Fig. 7. Percentage of inability to attribute a suspect identification by bite mark, suspect (model), examiner group, and time of evaluation when the biting dentition was represented in the models provided. This is essentially a "false negative" situation where the biting models were provided but the biter was not identified by the examiner but is not a critical error since a subject is not falsely inculpated. The first vertical column of six graphs on the left is pig 1—where all bites were made by dentition A. The middle vertical column of six graphs is pig 2—where all bites were made by dentition B. There are no values on the right vertical column of six graphs pig 3 since no association for dentition D was the correct answer. These results are shown in Fig. 5. N1: novices, first assessment; N2: novices, second assessment; M1: members, first assessment; M2: members, second assessment; D1: diplomates, first assessment; D2: diplomates, second assessment.

Table 3
Error rates and types of examiners for dentitions A, B, and D for the different examiner groups.

	Dentition A	Dentition B	Dentition D	All dentitions
Groups	Overall: 64.0% Critical: 5.8% Non-critical: 58.2%	Overall: 22.0% Critical: 4.0% Non-critical: 18.0%	Critical: 34.8%	
Novices	Overall: 64.6% Critical: 4.0% Non-critical: 60.6%	Overall: 28.1% Critical: 5.2% Non-critical: 22.9%	Critical: 28.6%	Overall: 42.2% Critical: 9.6% Non-critical: 32.6%
Members	Overall: 61.0% Critical: 12.6% Non-critical: 48.4%	Overall: 17.6% Critical: 3.9% Non-critical: 13.7%	Critical: 56.3%	Overall: 43.7% Critical: 22.0% Non-critical: 21.7%
Diplomates	Overall: 66.7% Critical: 0.0% Non-critical: 66.7%	Overall: 20.0% Critical: 2.5% Non-critical: 17.5%	Critical: 16.9	Overall: 35.3% Critical: 6.0% Non-critical: 29.3%

or "inconclusive" for dentitions A and B when those dentitions produced the bite mark was incorrect. Translating this to a clinical situation it simply represents an instance where, for whatever reason, a bite mark could not be attributed to a dentition.

Of particular importance in a medical-legal context, and specifically in the post-Daubert era is the critical error rate in bite mark analysis. The critical error rate for novices as a group was 4.0% for dentition A, 5.2 for dentition B, and 28.6 for dentition D. The lowest critical error rate for any individual novice on all cases was zero and the highest critical error rate for any individual novice examining all cases was 36%.

Members as a group had critical error rates of 12.6% for dentition A, 3.9% for dentition B, and 56.3% for dentition D. The lowest critical error rate for any individual member on all cases was zero and the highest critical error rate for any individual member examining all cases was 37%.

Diplomates had no critical errors for dentition A, a critical error rate of 2.5% for dentition B and a 16.9% critical error rate for dentition D (Table 3). The lowest critical error rate for any individual diplomate examiner that examined all cases was zero and the highest critical error rate for any individual diplomate examiner was 11%.

4. Discussion

Bite marks analyzed in the present investigation were made under highly controlled experimental conditions and did not involve movement between dentition and skin. While this differs from clinical bite marks, the complexity of this study design, that required an examiner to attribute a bite mark to a suspect was much harder to establish than in a real life situation. These bite marks were experimentally produced bite marks *in vivo* but the case material was challenging since dental arch width, arch depth, vertical tooth position and even individual tooth size were held constant. Similarly bite pressure was held constant as much as possible as was time of contact between teeth and skin. Individual tooth position in the horizontal plane was the only difference between dentitions.

Further complicating the analysis was the use of study-design deception of the examiners by purposely holding back one set of teeth (suspect D) that was used to make bite marks while supplying a set of teeth that was not used to produce any of the bite marks (suspect C). There may have be, in the mind of some examiners that suspect D must have made at least some of the markings or why would the authors included it? Stated another way it is possible examiners might have thought that one of the three dentitions included for study must have made at least one of the bite mark cases supplied. One might also argue that additional deception was introduced by giving each bite mark a different case number for each examiner and on each occasion (examination and re-examination).

It is common practice for forensic odontologists to gather their own raw data. Although in the present situation bite mark examiners were supplied with a plethora of comparative material, they did not personally view the fresh case material, gather their own evidence or even direct the methods with which the material was collected. It is possible that three-dimensional viewing of an actual case or collection of material outside of what was provided may have improved or made the attribution process worse. This could be the subject of further study.

Finally the use of a forced-decision data collection model, and forbidding examiners, by way of study design to exchange information, or undertake peer-review of their case-work with more experienced colleagues made this comparison exercise extremely challenging.

Correct suspect attribution was considerably lower for bite marks made with dentition A than for the other dentitions (see Fig. 5). Dentition A bite marks also had significantly higher inconclusive findings than dentition B (see Fig. 7). This may be an indicator of less "visually-striking" evidence when teeth are in perfect alignment as they were in dentition A. Bite marks made from this dentition, where all the teeth were perfectly aligned without any feature, trait or pattern that would represent an individual variation may have made it more difficult for an examiner to associate the pattern injury to a suspect dentition. It may be argued that dentition A, lacking individualizing unusual traits represents a particularly difficult case for bite mark analysis.

The bite marks examined in this study, independent of dentition, were most likely of variable evidentiary value. Further research should include evaluation of the evidentiary value of the bite marks against a standard reference scale such as the one developed by Pretty [4,14].

It would be interesting to utilize the current photographic material database of several hundred cases gathered in this study and have a series of diplomates rate the evidentiary value using a bite mark severity and evidentiary value scale. This might have been inadvertently introduced a source of bias in this process already. Both of these factors could, and should be the subject of further study.

Overall, diplomates, those analogous to Soomer's more qualified identification experts, were indeed better at attributing bite marks to suspect dentitions, and critically, were better able to discriminate those cases where bite marks could not be attributed to any of the dentitions. However outliers in all three groups may have adversely affected the overall group score. One diplomate accounted for a disproportionate number of errors in interpretation. This may incline certifying boards, including odontology, to include periodic proficiency testing of their members to maintain standards. This has been done in other forensic endeavors [15]. Interestingly, the novices, those without any formal forensic training, performed similarly to diplomates in identifying bite marks that were not associated with models but even so did not reach their low critical error rate. Both may be a result of being more cautious. Diplomates may be cautious because they are aware of the importance of a critical error in attributing a bite mark to the "wrong person". While novices may be more cautious because of inexperience, i.e. they do not want to risk making a mistake when they are unsure. Members with an interest in, and knowledge of bite marks who were not board-certified were not as effective as novices at reaching correct decisions in relation to whether a bite could be attributed to one of the biters or not. Members were more likely to incorrectly associate one of the suspect dentitions as being the biter when it was not. There is also a possibility that some examiners may not have given as much attention to the case material as they would a *bona fide* case, resulting perhaps in less accurate answers. Members have an interest in the subject, but they may not have had the training or knowledge of diplomates. The issue of confirmation bias was not measured in this study. As Blackwell et al. alluded to in their 2007 paper "The natural tendency to see what one wants to see, thereby tempting examiners to over-interpret bite mark evidence, has led to serious difficulties when bringing such evidence before the courts." [6] It is at least possible that those of intermediate experience (members) may have been more subject to confirmation bias in so far as they have an interest in the subject but may not have undergone board-examination nor had a large number of judicial cases.

The differences in individual critical error rates (attribution of the bite mark to the wrong models) indicate that outliers exist in both directions. Some are highly skilled at the task and others are not very efficient. The issue of isolating critical errors alone is problematic with this study design since it is possible for an examiner to lower their individual critical error rate by simply answering that they could not attribute any case to any bite mark. This would result in a critical error rate of zero but the process of bite mark analysis, if deliberately practiced thus, would be useless. If one never offers an opinion, they will never be wrong. It is apparent that in all three groups there are some individuals with very low critical error rates and others whose error rates indicate that they did not take the process seriously or they really should not be undertaking bite mark analysis. Further research is required to elucidate how to differentiate the two.

Finally there were no statistically measurable improvement or worsening of the ability to attribute the bite marks to models between the two time periods. The error rates after the washout period were essentially the same and occurred in the same direction.

Compared to this study, similarities with other studies exist. In 1999, the 4th ABFO bite mark workshop [16] where 32 certified diplomates of the ABFO participated in a study of the accuracy of bite mark analysis. Bite mark analysis showed that the accuracy from three actual forensic cases (and one bite mark in a piece of cheese) was significantly related to bite mark level of certainty and forensic value but not with examiner experience. The study from Pretty and Sweet [17] using a series of simulated post-mortem bite marks on pig skin also resulted in different conclusions. Although the method was relatively similar in certain aspects, these authors studied the performance of ABFO diplomates, ASFO members and general dental practitioners with the use of transparent overlays. Additionally the dermal model was *in vitro*, not *in vivo*. The results of that study showed that experience and training of the examiners was found to have little effect on the effective use of overlays. In the present study, examiners were neither trained in any particular technique nor advised how or what technique to use. They could use the technique(s) of their choice. This may more closely mirror the decision-making process in their own forensic odontological practice. Finally Whittaker in 1998, used 50 actual photographic bite mark cases, in an effort to determine the ability of examiners to decide whether bite marks had been produced by adult or paediatric teeth. The examiners were comprised of 109 professionals: senior and junior forensic odontologist experts, dentists, dental students, police officer and social workers. That study showed that the most accurate decisions were made by the senior and junior experts but as far as the decision of a child or adult bite marks was concerned there were no significant differences in their decision-making ability [18].

5. Conclusions

Statements and findings reported by an expert witness must be based on scientifically derived techniques and scientifically sound principles. This project attempted to address *some* of the issues identified by the Daubert and similar judicial decisions since the technique could be controlled and tested, and rates of error could be calculated. Error rates may be influenced by the individual examiner, the dentition, and the bite mark evidence available. The study also demonstrated that training and certification, and perhaps proficiency testing of professionals who offer opinion in cases of bite mark injuries, may be important to the successful outcome of the analysis. Nevertheless, even expert diplomates as a group and individually make critical mistakes. This might support the contention that bite mark analysis is entirely subjective. Dermal bite mark evidence recovered from a victim must be of high quality and the examiner must be a well-trained, certified professional if the error rate of analysis is to be kept low. If bite mark analysis is to aid the courts, the examiner must ensure that the bite mark under study merits undertaking a comparison, that techniques used are based on scientific principles and that conclusions of the bite mark testimony are not over-stated nor inadequately contextualized.

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The authors would like to thank the examiners, those who shall remain anonymous (as per research ethics board approval) who participated in this study. We would also like to express our gratitude to the staff of Princess Margaret's Hospital, Toronto, Ontario: Mr. Roger Woods, Master Tool and Die maker for the design and finishing of the modified biting appliance and Mr. Joseph Li, dental technician for his masterful work in the preparation of the suspect's dentitions. A special thanks to Mr. Louis Beauchamp and the staff of Groupe Dentachrome Laboratory, Montreal, Quebec for the chrome–cobalt dentitions.

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EXHIBIT C
APPENDIX H

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Replication of Known Dental Characteristics in Porcine Skin: Emerging Technologies for the Imaging Specialist

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REPLICATION OF KNOWN DENTAL CHARACTERISTICS IN PORCINE SKIN; EMERGING TECHNOLOGIES FOR THE IMAGING SPECIALIST

FINAL TECHNICAL REPORT

Award NIJ 2010-DN-BX-K176

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Replication of Known Dental Characteristics in Porcine Skin:

Emerging Technologies for the Imaging Specialist

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Abstract

This research project was proposed to study whether it is possible to replicate the patterns of human teeth (bite marks) in porcine skin, be able to scientifically analyze any of these patterns and correlate the pattern with a degree of probability to members of our established population data set.

The null hypothesis states: It is not possible to replicate bite mark patterns in porcine skin, nor can these bite mark patterns be scientifically correlated to a known population data set with any degree of probability.

Bite marks were produced on twenty-five pigs with a bite pattern replication device using 50 sets of models of blinded dentitions. The models were selected randomly from a previously quantified data set of 469. Prototyped dental models were mounted on a semi-automated mechanical device which records the model number, physical location on the pig where the force applied and the duration it was applied. Four patterns were created on each side of twenty-five anesthetized pigs in predetermined areas. These sites were tested previously in a pilot study; notably the hind quarter, abdomen, thorax and fore limb. Digital photographs of the patterned injuries (bite marks) were exposed following the guidelines of the Scientific Working Group on Imaging Technology (SWGIT) and the American Board of Forensic Odontology

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(ABFO). Two hundred images of each dental arch were selected from the eight hundred photographs taken during the laboratory sessions and analyzed biometrically using a previously validated software program. Images were categorized as complete, partially complete or unusable, based on the presence, partial presence or absence of the six anterior teeth in each arch. Intersecting angles, the widths of the lateral and central incisors and the arch width measured on the scaled images of the unknown models. The images were analyzed independently by two investigators. Their measurements were then statistically compared to an established population data set of 469 males, ages 18 to 44 years. Statistical analysis was achieved using two models; Pearson's correlations and distance metric analysis. Pearson's correlation results based on width only, angle only and widths plus angles were reported by each investigator. Angles measured along with widths and compared to the known data set ranked each set of models from 1 to 469 with a ranking of one showing the lowest p values. Investigator #1 ranked 5 out of 143 images as number 1, 10 out of 143 in the top 1%, 34 out of 143 in the top 5% and 59 out of 143 in the top 10 %. Investigator #2 ranked 2 out of 156 as number 1, 13 out of156 in the top 1%, 36 out of156 in the top 5% and 54 out of 156 in the top 10%. The second statistical model using distance metric analysis had a sample count of 102 images with 3 out of 102 within 1% of the population, 16 out of 102 within 5% of the population and 23 out of 102 within 10% of the population when evaluating the results of the upper jaw only from investigator #1. The concept of using an incisal line is based on geometric principles of line segments and the angles they form when extended. The use of this concept will aid the crime laboratory imaging specialist and forensic odontologist in their analysis of bite marks (patterned injuries).

MeSH terms; forensic odontology, bite mark, dental characteristics, bite force, incisal line, quantification of dental characteristics, statistical analysis, load cell, FlexiForce sensor.

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Executive Summary

The National Academy of Science (NAS) 2009 report, *Strengthening Forensic Science in the United States: A Path Forward*, challenged the forensic science community to develop comprehensive reforms in research using scientific methodology, guidelines and standards for the analysis and reporting of an examiner's conclusions.

A research project was proposed to study whether it is possible to replicate the patterns of human teeth in skin (bite marks) and be able to scientifically analyze any of these patterns correlating them with a degree of probability to members of our established population data set.

The null hypothesis states; It is not possible to replicate bite mark patterns in porcine skin, nor can these bite mark patterns be scientifically correlated to a known population data set with any degree of probability.

A template was developed to be able to analyze and quantify the individual tooth characteristics in bite marks (patterned injuries) as they appear in a porcine skin. In order to establish a bite mark pattern, several considerations needed to be addressed.

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These included selecting a suitable material to strong enough to duplicate natural tooth strengths, developing a mechanism to and accurately transfer a pattern of dental characteristics to porcine skin and developing a standardized method of mounting the dental models on a device which would produce a patterned injury (bite mark). It was also necessary to determine the force necessary to create a legible pattern in skin and calibrate each of the fifty replication device to deliver a standardized bite force for a specific time period. To be able to establish the probability that an image of a bite mark (patterned injury) on the pig could be correlated to a member (target) of the population data set with a level of probability, ranking the patterned injuries to the population data set was accomplished using both Pearson's correlations and a distance metric analysis model

Research Design

The selection of a material with natural tooth strengths included a trial using Castone™ dental models, cold cured methyl methacrylate dental resin and prototyping models using sintered steriolithography (SLS). The sintered form of prototyping by the 3M™ Corporation produced a model of the strength required for this research.

The use of a modified Irwin C-clamp to transfer patterns of dental characteristics to skin was previously reported. [17]. The incorporation of a load cell to calibrate each FlexiForce® transducer in each of the 50 pattern replication devices required to record the force applied had not previously been used. Initial trials of a prototype pattern replication device resulted in torqueing of upper models when force was applied. The use of ten parallel pins placed in the base of the upper dental models prevented this

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and ensured that all forces were directed to the incisal edges of the six anterior teeth and directly against the FlexiForce® transducer.

Force transducers, load cells and piezoelectric concepts were incorporated in the replicator device. Accurate measurement of the forces involved experimentation with materials that had limited hysteresis or fade during force loading. Ultimately a machined aluminum button attached to the piezoelectric sensor (FFT) provided for the most sustainable of compressive forces when applied for any interval of time.

The literature provides for a wide range of pounds force calibration in the incisor region from 20 to 122 PSI. These forces are influenced by numerous factors including pain, gender, age, musculature and the individuals existing occlusion. This study's determination of bite force necessary to create a patterned injury was based on a sampling of individuals between the ages of 22 and 32 showing a range of 25 to131.1 pounds force consistent with previous reports.

Calibration of each of the force sensors in the 50 replication devices by bench testing was accomplished prior to each animal laboratory session. A means of recording and sustaining the bite force for a 15 second time interval was required. This was accomplished with a complete Phidgets data acquisition system which consisted of a voltage divider, a precision voltage reference source, an Analog to Digital Converter board (ADC), USB interface and a laptop computer. Using a modification of a similar apparatus used in an earlier study the models were mounted on a modified Irwin™ welder's vise grip. By incorporating a force sensor, (FlexiForce® 100 lb. sensor), the Phidgets® device was bridged to a notebook computer running Lab View® software creating an auto-recording pattern replication device. This device allowed the replication of patterned injuries to be repeatable, consistent and measurable. The calibration procedure involved connecting the embedded FlexiForce® Transducer (FFT) to the Phidgets® data acquisition system and verifying its operation on the connected laptop computer running the custom software application, Lab View®. The load cell was placed in the replication apparatus, arranged mechanically in series with the embedded FFT sensor such that both transducers experienced the same biting force. Force was applied at 25, 50 and 100 pounds-force increments then removed at 50, 25 and 0 pounds force increments. Corresponding data from the FFT and the load cell were taken at each force increment and stored in a time and date stamped computer file for each of the 50 models and 50 corresponding pig locations.

Animal Laboratory Sessions

Animal research sessions were conducted in accordance with the standards of the *Guide for the Care and Use of Laboratory Animals* (8th edition, National Academies of Sciences, 2011) and were approved by the Medical College of Wisconsin, Institutional Animal Care and Use Committee (IACUC).

Mixed-breed young pigs, weighing 30-40 kg were obtained from a commercial breeder and acclimated in the large animal laboratory research facility for a period of at least 2 days before the laboratory procedures were performed. Anesthesia was induced with a combination of tiletamine/zolazapam (Telezol®, 4.4 mg/kg) and xylazine (2.2 mg. /kg) administered intramuscularly. Following induction, an endotracheal tube was placed and hair from the anatomical sites of interest removed using a commercial hair clipper, razor, and/or depilatory cream. To conserve body temperature, animals were placed on heated pads on the surgical tables and covered with towels and a PolarSheild® Emergency Survival blanket (RothCo3015 Veterans Memorial Highway, Ronkonkoma, New York 11779-0512). The pigs' body temperatures were maintained between 36.2 and 39.3 degrees C and monitored by participating veterinary technicians. Using a rectal thermometer, the mean procedural temperature recorded was 38.1C (36.2C – 39.3C). The mean low 36.2C (33.9C – 37.0C) and the mean loss was 1.8C (0.2C – 4.3C). Following animal preparation, a surgical plane of anesthesia was maintained using isoflurane administered through the endotracheal tube using a precision vaporizer and compressed oxygen. Basal anesthesia was augmented as needed in some animals with pentobarbital administered intravenously to effect stage III general anesthesia.

The four designated sites to receive the patterned injury were the lateral aspects of the upper hind limb/thigh, abdomen/flank, thorax, and shoulder/upper forelimb of the animals. These were designated as site A, B, C and D referenced on the ABFO #2 scale label in the photographic image.

Photography

The injuries were digitally photographed at 1:1 scale (life size) by an forensic photographer 15 minutes after their creation, using a Cannon™ EOS 5d Mark II, ~ 21mp with a Cannon Macro EF 100mm 1:2.8 USM lens, set to autofocus. Lighting was provided with a Canon 580 EX II flash set to Manual 1:2 power. The flash unit was used off camera held oblique to the bite pattern. Camera settings were at the manual exposure of 1/200th @ f16-32, 100 I.S.O. with the white balance set on Flash. Large

JPEG format imaging process consisted of converting RAW images in Adobe Photoshop CS5 (cropped to 4x4 inches) and then calibrated to 1:1 at 300 ppi and saved in TIFF format. The calibration of the patterned injury proceeded by determining the total number of pixels within a known distance. The forensic photographer used the least distorted portion of the scale for the calibrations. A flat field lens was employed to help reduce optical distortion. At the lab, the images were calibrated to 1:1 and the analysis measurements were made using the technique previously reported for Tom's Toolbox©. Sorting and selection of the best image for each of the eight sites on the twenty-five pigs was accomplished. Since a scaled image of each dental arch was required to be analyzed separately by the semi-automated software, Tom's Toolbox©, a total of four hundred scaled digital images were calibrated at 300 dpi, duplicated and saved as working images in TIFF format. Those patterns which registered all six of the anterior teeth were considered complete, while those which registered only some of the anterior teeth were classified as partially usable. A third category, unusable, was assigned to those patterns which lacked sufficient detail. Duplicate working files were created for each of the investigators to independently measure the characteristics available. The duplicate working files were uploaded into the semi-automated computer application, Tom's Toolbox©, where they were measured by Investigators 1 and 2. The data was saved in an electronic data log.

Findings

The inter-observer agreement between Investigator 1 and Investigator 2 in the measurement of the 50 Coprwax™ exemplar patterns using SAS software was 0.984, showing an extremely high consistency when measuring widths of tooth patterns in an

American Dental Association (ADA) accepted dental bite registration material. Determination of the inter-observer agreement in measuring tooth widths of patterns registered in porcine skin was calculated with SAS software resulting in a correlation of 0.716.

Measuring the intersecting angles as a means of determining an additional dental characteristic has not previously been utilized in pattern research. The intersecting angles formed between incisor teeth identified as A and B, A and C, A and D, B and C, B and C and D were identified and compared to the corresponding angles from original data of the known population data set patterns. The correlations between bitemarks in porcine skin compared to the known measurements of the 469 dental models were ranked from 1 to 469. Each unknown model could only be ranked once as either 1 or some other number between 1 and 469. For Investigator 1, 84.6% of the measurement's showed that their true models were ranked in top 10%. For Investigator 2, 85% of the measurements showed that their true models were ranked in top 10%.

Pearson's correlation identified 2 and 5 ranking as number 1 by researcher 1 and 2 respectively when ranking from 1 to 469. In considering additional characteristics, correlations between a bite mark and its true dental model were highly ranked. For example, 10 out of the 143 (Investigator 1) and 13 out of the 156 (Investigator 2) were within in top 1%. Additional results can be interpreted similarly. All show a better performance than random with p-values < 0.0001. (Random in a statistical description indicates that selecting models until a match is made is not possible). Outliers were calculated using an N =469 to represent the population data. A calculated mean and standard deviation was recorded as ± 2×SD. Width and angle calculations revealed more outliers than considering width alone or angles alone.

To verify the initial statistical model of analysis, a second statistical model using distance metric analysis was employed. The Distance Metric family of models computes a distance in an *n*-dimensional factor space from a Sample (unknown pig pattern) to each member of the known population data set of 469. The score for a particular member of the Distance Metric family of models is the percentage of the Population that is closer to the specific sample (pig pattern) than the correct matching Target member of the population data set from which the sample image was made. In three (3) (2.9 %) of the 102 Sample images scored, only 1% of the Population was closer to the Sample than the Target; 16 (15.7%) of the Samples found their Target within 5% of the Population; and 23 (22.5 %) of the Samples found their Target within 10% of the Population. For this data set, the Distance Metric Model performs a little better on the upper jaw Samples than on the lower jaw Samples, and there was no appreciable difference in performance using the Sample and Population measurements of each researcher. In summary, in more than 20% of the Samples in this study, the Distance Metric Model finds the Target within the closest 5% of the Population. In more than 6% of the Samples, it finds the Target within the closest 1% of the Population. This demonstrates that it is possible to determine scientifically that a given Sample must belong to a very small (e.g., 5% or even 1%) proportion of the Population.

Conclusions

The production of a legible pattern replicating the teeth in skin depends upon multiple factors in addition to the substrate and the mechanism. Firm substrates such as

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cheese, soap, plastic and leather, to cite several media, register dimensions best. The mechanism of creating the bitemarks in skin can be divided into two categories; dynamic and static. Dynamic distortion occurs when there is movement by either or both victim and assailant. Static distortion is less common and in the opinion of the authors occurs more often in the pattern of the lower teeth because it is not fixed in position as is the maxilla. A variable even in a static bite is the degree of elasticity in the skin and the inability to capture the exact dimensions of the teeth. The evidentiary value of the injury pattern is related to the amount of distortion in the bite mark (injury pattern). However, even a distorted bite mark may still contain measureable characteristics that provide evidentiary value. When agreement exists in the analysis of a pattern between all examiners, there still is a need for a scientific basis and level of confidence for their opinion.

Prior to this report, to accomplish the frequency distribution of the dental characteristics, making an individual's dentition distinctive, a series of studies were instituted to establish a methodology for quantification dental characteristics in both two and three dimensions. This was initially utilized to build a data set of seven dental characteristics. Additional research confirmed the reliability of measurements, testing both intra-operator and inter-operator agreement in analysis. The initial quantification of width, damage, angles of rotation, missing teeth, diastema characteristics (spaces) and arch width were subsequently augmented by a study of the displacement of the anterior teeth, labially or lingually, from the individual's physiologic dental arch form. Later a three-dimensional study of the position of the incisal edge of the anterior teeth on the horizontal (Z) plane was conducted. This study adds a practical application to this data set. It incorporates a geometric approach to determining the angles of rotation of the four maxillary and mandibular incisors. This concept utilizes the measurement of the angels at the intersection of the extended incisal lines, projected through the mesial and distal markers of each of the incisors. This method of measuring rotation of the intersecting angles of the incisal lines is beneficial for several reasons. It eliminates subjective establishment of an X (horizontal) axis. It is also more universal. One or more teeth may be missing or indistinct. If two or more anterior teeth can be identified (e.g. tooth 7 and 9), computation of the angle of the intersecting incisal lines can still be determined. This method of establishing tooth rotation also provides an expanded scope of search analysis, since it includes two additional characteristic items. In the earlier studies when an x axis could be established from the presence of posterior teeth, it was possible to determine four angles of rotation using a standardized and adjustable x/y axis template. With the alternate method of the intersecting angles formed by the incisal lines, it is possible to measure six angles of rotation.

Although the actual width of the pattern of the incisor in skin may be less than that of the known source, the angle of rotation remains a constant. Most significant in predicting probability of a correlation to a target in the population data set will be the presence of outlying angles of rotation. This procedure adds four additional characteristics to statistically calculate the probability of correlation between the unknown and a known source.

The interpretation of the combination of quantified dental characteristics making up the initial two-dimensional data set, also utilized the data obtained in the three-dimensional study, since the anterior teeth are not always all at the same level of eruption on the horizontal plane (Z plane). In knowing this, questions regarding whether certain teeth are present or missing in a patterned injury cited by past investigators could be addressed. This groundwork research is only the beginning. By establishing a scientific template continued research should continue to develop this relatively new scientific approach to pattern analysis.

Whether dental characteristics are reliably replicated in a bite mark in human skin is the current challenge. The scientific validation of the correlation of bite marks, or tooth patterns to their origin, in the opinion of the authors, predictably will be established by statistical probability. That is, how many outlying characteristics demonstrated in a pattern(s) would reliably predict the probability of another individual in the population having the same combination of dental characteristics? For those images of the bitemarks that include all six anterior teeth, or several teeth that enable the investigators to insert all ten, or at least some of the markers from Tom's Toolbox©, measurements of distances and angles could be determined, saved, calculated, stored in an internal data set ranked in percentiles. This application establishes outliers for those specific characteristics for a data set that includes males between the ages of 18 and 44 years in the State of Wisconsin. This is not to imply that only males bite. Women children, and animals also bite others and even inanimate objects. In the personal experience of the authors, perpetrators of human bites in violent crime are predominately males 18-44 years of age. This and limiting the number of samples required was the rationale for our original study to that group. The study is meant to augment the established guidelines of the American Board of Forensic Odontology. It should not be used in testimony or legal proceedings.

Introduction

The National Academy of Science (NAS) report *Strengthening Forensic Science in the United States: A Path Forward* (2009) challenged the forensic science community to develop comprehensive reforms in using scientific methodology, guidelines and standards for the analysis and reporting of an examiner's conclusions. [1] This research is the culmination of ten years of applied science, studying bite mark analysis. It demonstrates that human bite patterns can be replicated in porcine skin under some conditions. The study also illustrates that analysis and recovery of meaningful data in these patterns can be accomplished using a software application that recognizes the systematic placement of markers and calculates angles and distances (Biometrics). This pattern analysis software was developed by the investigative team in earlier research. This basic drag and drop marker program was developed as a tool for the forensic image specialists and forensic odontologists' use in the evaluation of patterned injuries. It also would initially assist crime laboratories and investigating agencies in determining whether there is the need for the expert services of a forensic odontologist to interpret the patterns.

Statement of Problem

The scientific basis for bite mark analysis has been questioned. The National Institute of Justice awarded a three-year research grant to determine whether the patterns of human teeth can be replicated in skin and correlated to the source with a degree of probability. Additionally a proposal was made to develop a template for forensic odontologists and forensic imaging specialist in ascertaining the forensic value

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of the pattern. This template is not rigid in the software and materials that future researcher use. It is only a general plan (template) for future researchers to follow to expand the testing of a scientific method in the replication and analysis of bite marks in human skin. Prior research provided the accuracy and validation of a software application (Tom's Toolbox©) which demonstrated it was reliable, repeatable and consistent with acceptable scientific methods. A blind study was designed and used to determine the statistical probability of a best fit. Two hundred patterned injuries were produced in porcine skin, documented by scaled digital images and analyzed. Two statistical models were used to establish the probability of a correlation of a replicated pattern with the known model in the population dataset. Confidence intervals and levels are reported. Factorial conclusions are presented based on the demographics of a male population between the ages of 18 and 44 years in the State of Wisconsin.

Literature Review

In prior research, the investigative team developed a means of measuring and quantifying seven specific characteristics of the human dentition. [2] This established a population dataset of 469 samples from males 18 – 44 years old that closely mirrors the distribution of the ethnic population in the State of Wisconsin. [3] The methodology employed was validated by testing repeatedly for reliability and accuracy. [4] Inter-operator and intra-operator agreement was studied and found to be extremely high. The result of repeated testing demonstrated that the methodology and protocol have a confidence level of 95% and a confidence interval of ±1.55.

The methods of bite mark analysis, used over time, have ranged from:

- Simple observation;
- The direct comparison of a known dental model to the injury pattern;
- Hand-traced outlines on clear acetate of a model of known dentition;
- Radiographs of Barium filled wax imprints of the known model as an overlay;
- Photographic transparent prints of images of the teeth utilized as an overlay;
- The use of optically scanned images of the dentition to produce overlays in Adobe Photoshop®
- Computer assisted analysis.

All of these techniques have their limitations, which include the viscoelasticity of skin, distortion from movement, photographic distortion and many other problems that are frequently cited and are well known to forensic examiners. Although these problems can occur, bite mark patterns may still provide details which have value. It is also important to point out, though most bite marks involve those observed in human skin; human tooth patterns have been recovered from inanimate objects and analyzed by the authors, e.g. kid gloves, automobile visors and steering wheels, a soft burrito, a bar soap, a wad of chewing gum and an apple.

An additional study of a seventh dental characteristic, quantifying the displacement of anterior teeth from the physical or native curve of each dental arch, was subsequently conducted and published. [5]

To establish the amount of displacement of the teeth, a baseline was necessary. Testing was conducted to determine whether an ellipse, a Bezier curve, or polynomial curve would provide the best fit. A third degree polynomial curve was determined to be the most appropriate. An algorithm was written for the ten markers to be placed in a 1:1 scaled image of the anterior teeth. The markers were placed at the center of the contra-lateral canine teeth to serve as the anchors and a marker was placed at the center point of each of the four incisors. This generated a third degree (best fit) polynomial curve. Based on this technique of establishing a baseline which follows the physiologic curve of the specific jaw and from which measurements could be made, the investigators were able to quantify displacement in labio-version or linguo-version, a seventh individual dental characteristic. It was also possible in this study to again establish inter-observer and intra-observer error rates. .

Adding to the data of the pattern reflecting width of the incisors which may not all be on the same horizontal (Z) plane, a three dimensional study was undertaken. Advances in Cone Beam Computer Technology (CBCT) have established that linear measurements in 3-D imaging programs are statistically no different than using a direct digital caliper measurement method considered by orthodontists to the most accurate for these measurements. [6] [7] [8] [9] This three-dimensional, expanded data set on the width of the eight incisors in 0.5 mm incremental “slices” on the Z plane has been reported and published. [10]. Three-dimensional, digital Imaging communication in Medicine (DICOM) images were obtained from the scanning the dental stone models, utilizing Cone Beam Computer technology. These DICOM format files were then converted to an STL format. The width of the incisors in the three-dimensional images of the dentitions were measured on the "z" plane using Materialise® MiniMagics© software. (Figure 1)

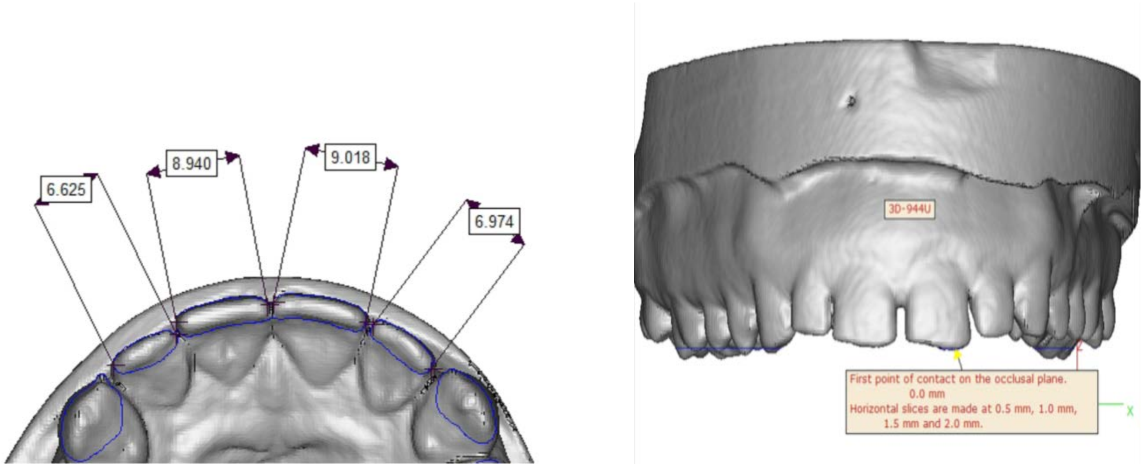

Figure 1. Illustrates the width of the maxillary incisor teeth measured at 1.0 mm above the first point of initial contact on the horizontal (Z) plane using the MiniMagics© software.

An additional paper providing data on the correlation of arch width with ethnicity was published.[3] McFarland, Rawson, Barsley and Bernitz have all contributed to the quantification of individual characteristics of the human dentition and identified problems that existed regarding a statistical evaluation of individuality. [11] [12]13] [14] None of these papers included a data set of significant statistical size, compared to that developed by the current research team, nor did they include the analysis in the third dimension on the (Z plane).

Statement of Null Hypothesis

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It is not possible to replicate bite mark patterns in porcine skin, nor can these bite mark patterns be scientifically correlated to a known population data set with any degree of probability.

Methodology

To obtain pattern characteristic correlations using a two-dimensional comparison of the unknown injury patterns (bite marks) to the known population data set, this study proposes to:

- Demonstrate whether it is possible to replicate, in vivo, known dental pattern characteristics (bite marks) in porcine skin.
  - In a blind study, use 50 models randomly chosen from 500 previously measured Castone® models to be prototyped in a hard polymer by sintered stereolithography (SLS),
  - Document, analyze the patterns recorded and develop analytic models which could establish the statistical probability of a correlation of any of the pattern registrations in the pig skin (pattern replication), would have to the authors' population data set of known characteristics.
  - Determine the circumstances; area of the skin, the number of pounds force (lb^f) and duration of the applied force which produced identifiable and measureable patterns.
  - In the absence of the other landmarks to establish an X axis, develop modifications of Tom's Toolbox©, enabling the measurement of the angles of

rotation of individual incisor teeth using the intersection of an extended incisal line, based on Euclidean geometry. Determine the range of pounds force (lb^f) produced by males, age 18 – 44 when creating a bite mark.

- Based upon all of the preceding, establish a basic template and technology for the forensic imaging specialist and forensic odontologist to use in analyzing and evaluating patterned evidence.
- Provide a scientific template for future research with an enlarged population database and more sophisticated imaging software.

Establishing bite forces

Bite force measurements in the central incisor area were established using a mini load cell from Omega Engineering, Inc. (One Omega Drive, P.O. Box 4047, Stamford, Connecticut 06907-0047), serial no. 291633 and recorded using a precision Bridge Excitation voltage, V_B. = 5.000 VDC. Subjects were instructed to bite as hard as they could over a 10 second period. The initial output offset voltage, V_{OS}, mV and the resultant maximum load cell output reading Vout, were mV recorded. All output voltages were corrected by subtracting V_{OS} and subsequently converted to actual biting forces in pounds force (lb^f). These conversions were accomplished using manufacturer calibration data (5-Point NIST Traceable Calibration) that accompanied the load cell. The results were plotted graphically using lb^f for the y axis and individual results on the x axis. Those results that fell outside two standard deviations were discarded. The resulting N of 31 was totaled and the average recorded.

In replication of patterns utilizing the pounds force (lb^f) citied in the literature by Anusavice, the authors determined that the 20 to 30 lb^f cited in the text was insufficient to produce the degree of tissue injury commonly observed in bite marks. [15] In order to ascertain whether this observation was valid, an additional study was developed.

Caucasian male dental students who volunteered to participate were examined. The initial IRB protocol limited participation to 50 individuals. Nineteen individuals were dropped, making the final total thirty-one. Three were eliminated because they exceeded the 22 to 32 age range of dental student volunteers cited in the IRB protocol. Sixteen were excluded because the initial design of the load cell force transducer produced evidence of hysteresis or fade.   A modification in the design of the bite force transducer included an intervening strip of stainless steel and a vinyl index to guide the lower incisor directly over the location of the load cell. The average bite force for males between the ages of 22 and 32 years with N=31 was 62.5 lb^f or 278.01N. This is significantly higher than the average bite force reported by Anusavice [15]. The actual minimal to maximum forces generated was 19.2 lb^f to 132.1 lb^f or 111.21 N to 587.61N**.**

The force was calculated using an Omega™ model LCKD-100 load cell force transducer sandwiched between two parallel wooden tongue depressors with a metal plate directly over the sensor to avoid compression [Figure 2], that could result in hysteresis in evaluating applied force. Sample results are shown in [Table 1] which indicated an average of 62.5 pounds force, with a maximum of 132.1 pounds force and a minimum of 19.2 pounds force for a group of volunteers on a given recording date.

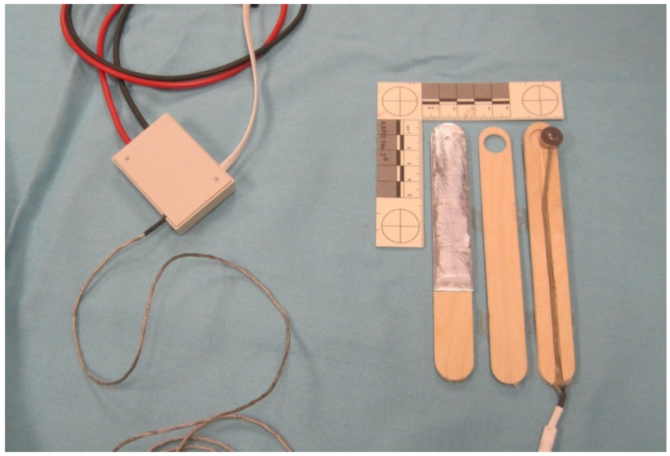

Figure 2. An exploded view of the prototype bite force transducer using the Omega™ model LCKD-100 mini load cell, to determine the range of pounds force (lb^f) generated by twenty males ages 22 to 32. The insertion of a sheet of stainless steel controlled hysteresis.

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Bite Measurements

Dates 14 December 20 2012,4 Jan 2013,11 Jan 2013

Load cell Serial No.-291633

By: D Jeutter and T. Radmer

Bridge Excitation V= 5.000

SoD Room 106D

Note: Stainless steel inner layer and incisal alignment guide added to transducer

Subject Code Number	Subject age	Initial offset V_{out} mV	Load cell V_{out} mV	Actual Bite Force #F	Notes
617	29	0.146	9.475	132.1	
34	26	0.142	2.76	37.1	
519	26	0.142	1.78	23.2	
409	24	0.137	3.57	48.6	
225	26	0.154	5.76	79.4	
599	27	0.137	3.47	47.2	
41	25	0.137	3.7	50.5	one incisal restoration
218	26	0.134	5.66	78.2	
415	24	0.134	3.98	54.5	
259	27	0.141	3.164	42.8	
398	24	0.138	4.378	60	
945	39	0.142	1.863		dropped
797	25	0.147	5.46	75.2	
322	34	0.144	3.66		dropped
380	25	0.146	1.5	19.2	
540	31	0.134	5.66	78.2	
67	25	0.136	4.1	56.1	
199	25	0.117	8.097	112.7	
52	23	0.028	6.355	89.6	
376	26	0.032	6.849	96.5	
326	25	0.059	3.78	52.7	
35	27	0.046	6.13	86.2	
496	23	0.047	6.399	89.9	
662	27	0.04	3.95	55.4	
591	25	0.045	3.78	52.9	
749	25	0.039	2.146	29.8	
804	25	0.057	2.56	35.4	
303	26	0.048	4.96	69.6	
576	25	0.62	1.826	25	
530	33	0.45	5.08		dropped
51	27	0.044	5.721	80.4	
643	22	0.067	4.84	67.6	
850	22	0.064	3.769	52.5	
568	26	0.09	3.98	55.1	
88	24	0.042	3.96	55.5	
318	26	0.036	5.22	73.4	
			Sum	2062.5	
			average 31 subjects	62.5	

Table 1. Illustrates the range of bite force (lb^f) that can be generated by thirty-one males age 22–32 in the region of the maxillary incisors. The average (mean) was 62.5 lbs/Force.

Procedure for measuring bite mark patterns.

Using in-vivo porcine skin to research patterned injuries in human skin has had widespread acceptance in the medical and dental literature.

A literature review of the use of a porcine model in bite mark research and analysis provides only two examples when using the terms bite mark and porcine skin as search criteria [16], [17]. Past and current literature compares the porcine skin model closely with human skin [18].

In previous studies, a template for the measurement of individual characteristics of the human dentition in two-dimensions was established by the authors [4]. This included the development of an original software application, copyrighted as Tom's Toolbox©. [Figure 3] This software is a semi-automated software application using a palette of ten markers which when inserted by the analyst in a scaled digital image, calculates distances and angles based upon the Pythagorean Theorem. It is licensed to governmental and non-profit organizations by Marquette University The markers are inserted in specific locations on a scaled digital image of the bite mark at the starting and ending point of the areas to be measured. The software recognizes the location of each of the markers by column and row. It first performs a quality control procedure to assure that all of the markers have been inserted and are in the correct order. It then calculates distances and angles of rotation.

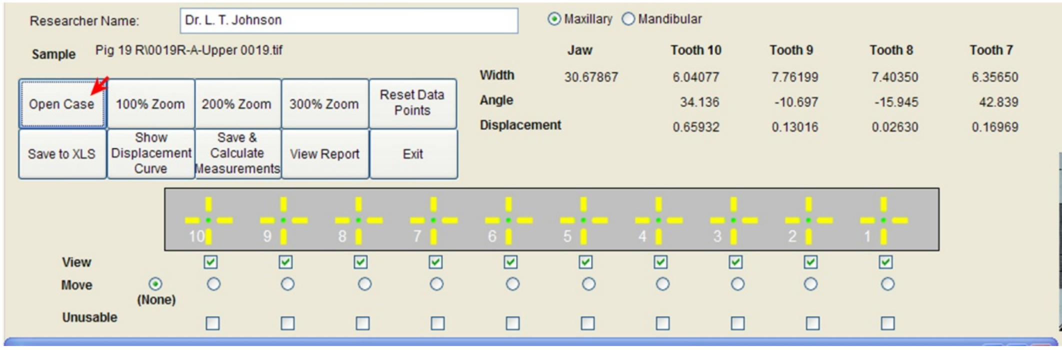

Figure 3. The tools panel used in pattern analysis. The arrow indicates the tool used to open a case for analysis in Tom's Toolbox©i

Calibration of the FlexiForce® Sensors

A method of providing standardized forces, duplicating the human bite forces was addressed using FlexiForce®, sensors (0-100 lbs.), mounted in a custom designed recording pattern replication device. The FlexiForce® sensor is a versatile, durable piezo-resistive, force sensor that can be constructed in a variety of shapes and sizes. The device senses resistance inversely proportional to an applied force. It has a patented ultra-thin (0.008 inches) flexible printed circuit that senses contact force. It acts as a force sensing resistor in an electrical circuit. When the sensor is not loaded, resistance is very high and when the force is applied the resistance decreases proportionately. The FlexiForce® sensors were coupled with an application that measures force-to-voltage in a circuit. [Figures 4, 5, 6 and 7].

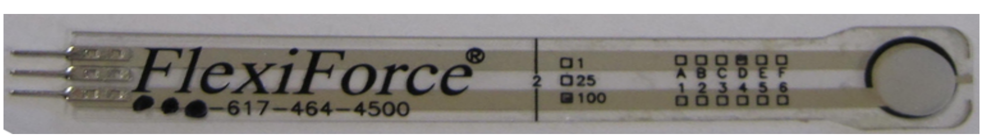

Figure 4. Illustrates a 0-100 lb. FlexiForce® sensor with the supplied silastic pressure button, which resulted in fade, (hysteresis) when recording applied force.

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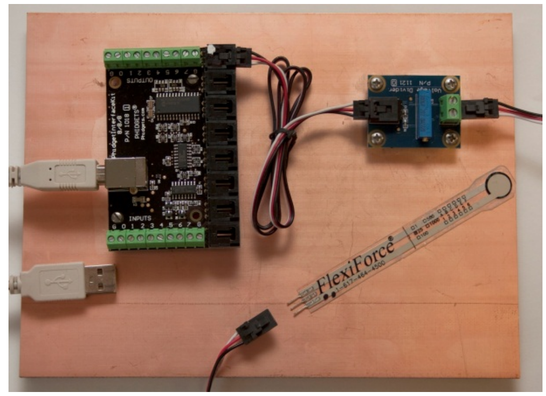

Figure 5. Omega LCKD 100 mini load cell. **Figure 6.** The Phidgets data system

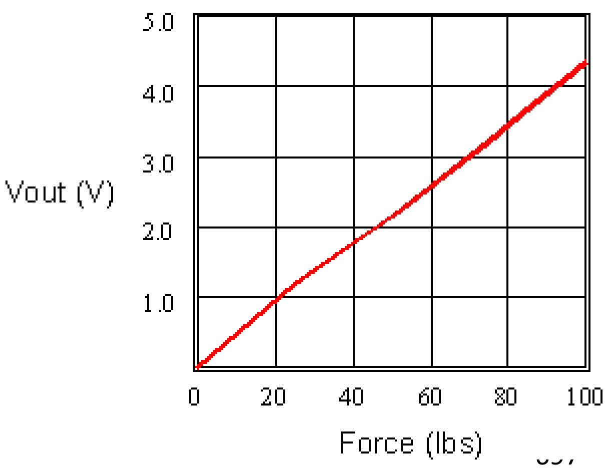

Figure 7. Illustrates the FlexiForce® Sensor response graph www.trossenrobotic.com [20]

FlexiForce® Transducers (FFT) [20] were incorporated into the apparatus to measure the applied force, as described elsewhere.[21] These thin transducers are in the Force Sensing Resistor (FSR) family that changes resistance from open circuit at 0 lb^f, applied forces to a resistance that progressively decreases as additional force is applied. The resistance output is linear (±3%) with applied input force. The FFTs were calibrated *in situ* after mounting in the bite replication model. Calibration of each FFT in the pattern replication device was accomplished by inserting a commercial subminiature industrial compression Omega load cell model LCKD-100 with a capacity of 0 to 444.82 N (Omega Engineering Inc., Stamford, Connecticut, U.S.A., 06907-0047) in series with the

FFT while forces were applied. This is the same Omega load cell which was used directly in the tongue depressor bite force transducer, measuring the dental students' bite force. Each bite replication model's calibrations data was recorded in spreadsheets.

The FFT selected for bite force measurement, (0-100 lb. FlexiForce® resistive sensor) is manufactured by Tekscan, Inc. (model A201 E) 134 Tekscan Inc. 307 West First Street, South Boston, Ma., U.S.A. 02127-1309). It is basically a flexible plastic film printed circuit approximately 0.22mm thick by 102mm. long by 14 mm. wide. The sensitive force registration area is 0.375 inch (9.53mm) diameter.

The FFT was incorporated into a voltage divider circuit to obtain a voltage change that is proportional to the change in applied force. This voltage divider is part of a commercial data acquisition system, a 1120 FlexiForce Adaptor that was purchased from Phidgets, Inc. (Phidgets® Inc. Unit 1, 6115- 4th Street S.E., Calgary, Alberta, Canada T2H 2H9) leading into a Phidgets Interface Kit 8/8/8 P/N 1018. [figuren8]

The complete Phidgets data acquisition system consisted of a voltage divider, a precision voltage reference source, an Analog to Digital Converter board (ADC), USB interface and a laptop computer [figure 9]

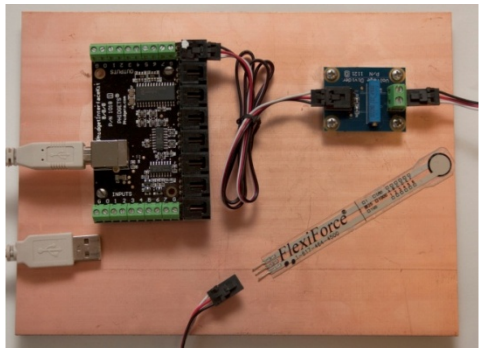

Figure 8. The Phidgets / FlexiForce® transducer (FFT) system block bridged to a display and storage application custom designed for the PC laptop by the team's IT manager.

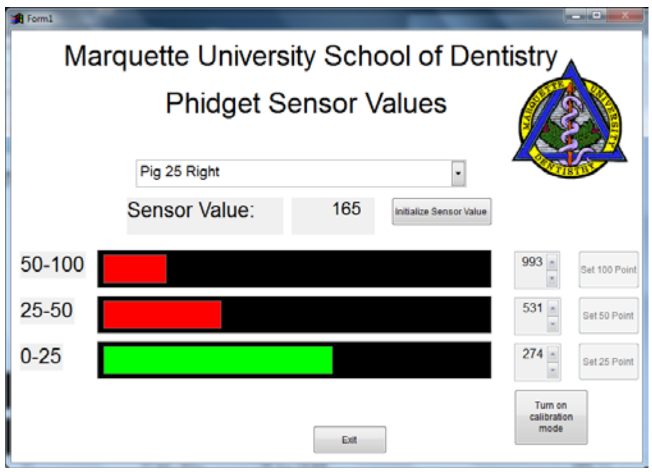

Figure 9. A screen capture of the computer display of the application which provides a visual and an audible indication of the applied lb$^{\text{f force}}$ and the duration it was applied. The application also creates a complete log of the session.

Model duplication and mounting

The dental stone models proved to be brittle and porous and were unsuitable for this study. They would not withstand the forces applied [figure 10].

Fig. 10. Illustrates one of the original dental stone models used to create the population data set in prior research.

Fifty sets of upper and lower dental stone models were randomly selected from the population data set which was established and reported in previous studies. [2][3][5][10] The statisticians for the project created a blind list of models for the investigators numbering the fifty pairs of models in random order, using the identifier of Pig 1R and Pig 1 L to identify the first two sets of models that were selected from the data set of N= 469. Subsequent models were similarly identified in alpha numeric fashion by pig numbers 1-25. The fifty hard polymer models were produced by stereolithography, using a 3M™ ESPE Lava COS scanner and Lava Software 3.0. (3M ESPE Divisions, 3M Center, St. Paul, MN 55144-1000, U.S.A.).

The method determined to be the most expeditious for the duplication of the models was to prototype them in a durable resin capable of withstanding the forces to be applied. The dental stone models were scanned in STL format files utilizing the 3M™ Lava COS® scanner, a chair-side optical scanner originally designed to capture a three-dimensional image and directly generate a prototype model of the dentist's prepared tooth for laboratory procedures. It replaced the necessity for an indirect dental impression. (3M™Corporation, St. Paul, MN). (Figure 11A and 11B)

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3M™ESPE Lava COS® scanner [11A]   Screen capture of a scanned model [11B]

Figure 11 A and Figure 11 B. Illustrates the 3M™ ESPE COS chair side optical scanner and a screen capture of a three-dimensional image of the dental stone models in STL format.

After the models were prototyped by the 3M™ Corporation using sintered stereolithography (SLS) the prototyped models were returned in a hard 3M™ proprietary polymer with sheer strengths equal to or exceeding bite forces of the natural dentition of 20-25 pounds force. [15] (Figure 12)

Figure 12. Illustrates the 50 blind prototyped models returned by the 3M™ Corporation.

A protocol standardizing the replication of dental characteristics in porcine skin was developed using a modification of an apparatus reported in an earlier study. [19][21] The models were mounted on a modified Irwin™ welder vise grip, using dental laboratory acrylic. (Figure 13) (Figure 14) A means of recording the applied pounds force (lb$^{f)}$ and the duration of the applied force in a log was developed. By incorporating a force sensor, (FlexiForce® 100 lb. sensor), a Phidgets device to bridge the sensor to a notebook computer running Lab View software, an auto-recording, pattern replication device was designed. The models were articulated utilizing a custom jig to standardize the mounting of the models on the 50replication devices which were required.

The models were mounted, using a custom mounting jig developed to align the dental models in a normal occlusal relationship.

Figure 13. Illustrates the mounting jig on the left. The upper mounting base in the center showin the dowels permitting the vertical travel, yet maintaining the inter-arch relationship of the models. On the right, a FlexiForce® sensor is shown inserted directly over the anterior teeth.

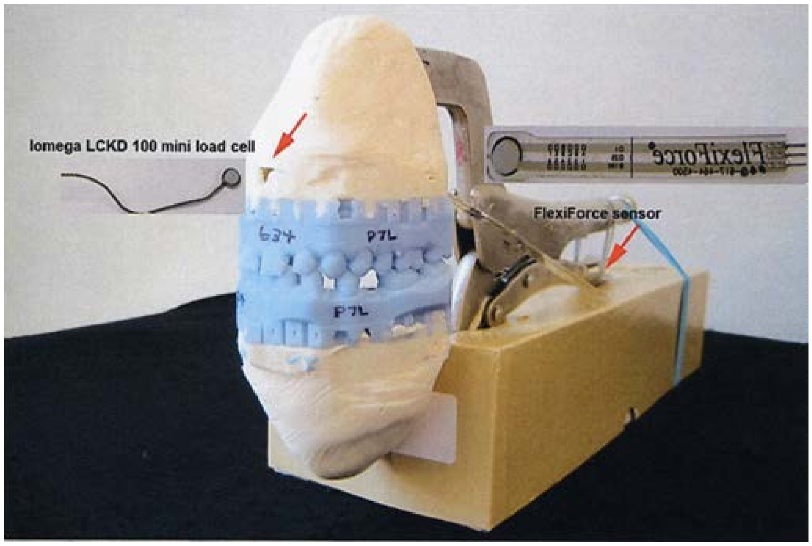

Figure 14. Illustrate a completely assembled pattern replication device with a channel above the maxillary incisors for the introduction of the Omega load cell for the calibration of the FlexiForce sensors in each of the 50 pattern replication devices.

The mounting was designed so the upper dental model does not adhere to the upper acrylic base. Its position is maintained, but allowed to travel vertically, using ten parallel brass dowels, keyed to the upper model's anatomic relation to the lower model. The dowels were placed in the maxillary molar, premolar and canine locations before the upper model is mounted to the C-clamp with the laboratory acrylic. Tin foil substitute was used to permit the model to be separated later for the insertion of the omega load cell for calibration of a FlexiForce® pressure sensor. This step was necessary to prepare the replication apparatus for the calibration of each FlexiForce® sensor.

Biomedical Engineering Laboratory Procedures

Once dismounted from the C-clamp device, a flat bottomed, one half inch recess was created in the base of the maxillary model with a Forstner 1/2 " drill bit to accept a

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mini load cell used to calibrate the FlexiForce© sensor in each of the 50 pattern replication devices. (Figure 15)

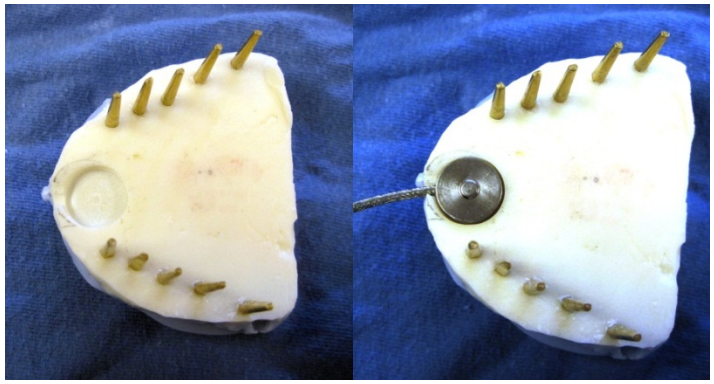

Figure 15. Illustrates the recess created for insertion of the Omega model LCKD-100 mini load cell.

To mate the Omega mini load cell and the pressure sensing area of the FlexiForce© sensor and minimize hysteresis, a button was machined from a 3/8th aluminum rod, the exact diameter of the pressure sensing area of the 8 inch FlexiForce® 0-100 lbs. resistive force sensor (Trossen Robotics, 2749 Curtiss Street, Downers Grove, IL 60515). This ensured that the force transmitted through the incisal edges of the maxillary incisors were compressing the entire area of the force sensor and that the force was directed perpendicular to this contact point. (Figure 16)

The calibration procedure was carried out by connecting the installed FlexiForce® Transducer (FFT) to the Phidgets data acquisition system and verifying its operation on the connected laptop computer, running the software application. (Lab View). Next, the load cell was placed in the replication apparatus, arranged mechanically in series with the embedded FFT sensor so that both transducers experienced the same biting force. Force was applied at 0, 25, 50 and 100 pounds-force increments then removed at 50,

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25 and 0 pounds force increments. Corresponding data from the FFT and the load cell were taken at each force increment and stored in a time and date stamped computer file for each of the 50 models and 50 corresponding pig locations.

Initial experience with the calibration of the FFT revealed that a means of applying force explicitly to its 0.375 inch diameter force sensing area with an uncompressible interface is essential. The rigidity of the button material and its diameter are critical to avoid fade or hysteresis in the recording of sustained forces. The solid aluminum discs, machined from aluminum rod, provided the least fade in the pressure force measurements when the anterior dentition was loaded for 15 seconds and provided the desired FFT adaptation to the pattern replication device. The button thickness was selected to properly couple the force generated by the anterior teeth sensing area on the FFT to the button sensor of the mini load cell. The resultant remaining hysteresis in our measurements was that contributed by the FFT at <4.5% of full scale.

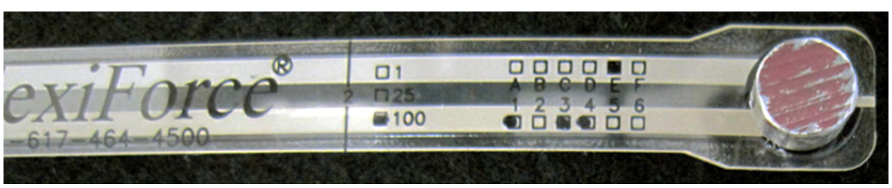

Figure 16. Illustrates the 0-100 lb. FlexiForce® sensor with the custom machined aluminum pressure button.

Procedures were developed early on to enable initial testing, evaluation and calibration of the FlexiForce® sensors. This allowed for an informed design of the interface buttons, the signal conditioning circuits for the load cell and the Phidgets system for FFT data acquisition. Bench testing was done by placing the load cell mechanically in series with the FFT in a small hobby vise with careful alignment of the FFT, button and load cell. (Figure 17)

Bench testing was done by placing the load cell mechanically in series with the FFT in a small hobby vise with careful alignment of the FFT, button and load cell. (Figure 17)

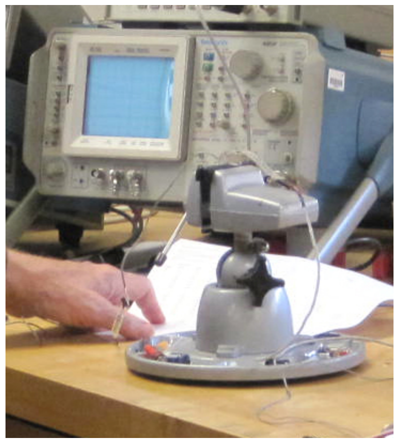

Figure 17. FFT transducer calibration was accomplished in series with the Omega load cell in a small bench vise.

This simple means of applying a variable force to the FFT and the load cell allowed for an informed incorporation of the FFT sensors into the bite models as well as for system development.

The Omega model LCKD-100 load cell force transducer was specifically selected for this force measurement and calibration efforts because of its small size. The 0.5 inch diameter by 0.25 inch thick load cell came with a five point NIST documented calibration with a ±0.25% accuracy, sensitivity of 2mV/V (i.e.: ratio metric), full scale output of 100 pounds-force (444.82 N), linearity of ±0.25% of full scale output, ±0.25% hysteresis with respect to full scale output, and a repeatability of ±0.10% repeatability with respect to

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the 100 pound-force scale capability. The transducer is temperature compensated. This precision load cell provides a force proportional voltage output signal to a custom designed amplifier signal conditioner. These specifications ensured that the load cell could be used as a precision calibration reference for the FFT sensors.

The load cell's internal strain gauge sensors are connected in a full 350 Ohm bridge. The bridge was excited with a stable, precision 5 VDC and the differential bridge output signal was connected to the input of a custom designed signal conditioner. The signal conditioner was configured with two stages of gain, regulated power supply voltage and a novel automatic zero calibration. The two operational amplifier (OP AMP) gain stages provided a total gain of A_v =200V/V. The two gain stages included an instrumentation Amplifier (IA) cascade with a non-inverting gain amplifier for signal conditioning. The IA has a voltage gain of A_v =100. A negative feedback circuit (A to D and D to A converters) was added to the circuit to automatically cancel input offset voltage from the load cell bridge prior to recording data.

The output from the load cell conditioning circuit is given by:

- V_{out}=Load cell sensitivity[mV/pound –force] x signal conditioner voltage gain [V/V]
- The load cell sensitivity is provided by the manufacturer: e.g. S = 7.1 mV at 100 pounds-force (or 71µV per pound-force).
- For example, it the applied force is 50 pounds-force, the load cell output is 3.55 mV. So the system output is: V_{out}= 3.55mV x 200 V/V= 710mV.

Calibration was performed on each instrumented bite model prior to its use. (Figure 18A, 18B)

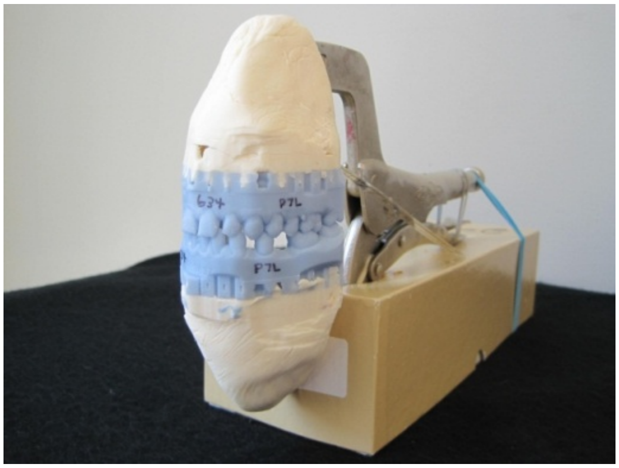

Figure18A. Depicts an articulated replication device.

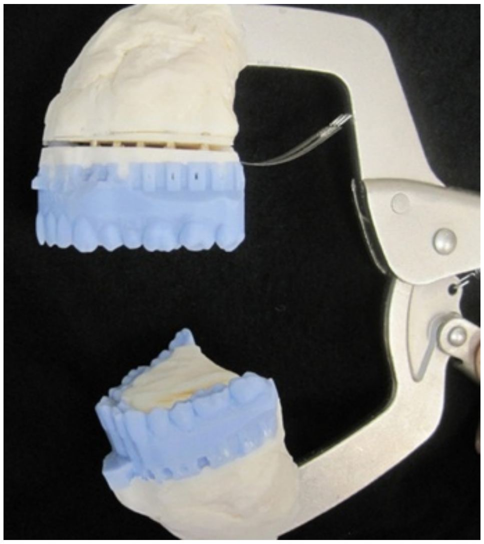

Figure 18B. Upper model travels vertically on ten brass dowels.

Animal Laboratory Procedures

Animal research sessions were conducted in accordance with the standards of the *Guide for the Care and Use of Laboratory Animals* (8th edition, National Academies of

Sciences, 2011) and approved by the Medical College of Wisconsin, Institutional Animal Care and Use Committee (IACUC). (Figure 19)

Figure 19. Illustrates the Biomedical Resource Center's large operating suite at the Medical College of Wisconsin where the animal research was conducted.

Mixed-breed young pigs, weighing 30-40 kg were obtained from a commercial breeder and acclimated in the large animal laboratory research facility for a period of at least 2 days before the laboratory procedures were performed. Anesthesia was induced with a combination of tiletamine/zolazapam (Telezol®, 4.4 mg/kg) and xylazine (2.2 mg. /kg) administered intramuscularly. Following induction, an endotracheal tube was placed and hair from the anatomical sites of interest was removed using a commercial hair clipper, razor, and/or depilatory cream. To conserve body temperature, animals were placed on heated pads on the surgical tables and covered with towels and a PolarSheild® Emergency Survival blanket (RothCo 3015 Veterans Memorial Highway, Ronkonkoma, and New York 11779-0512). The pigs' body temperatures were

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maintained between 36.2 and 39.3 degrees C. Using a rectal thermometer, two veterinary technicians monitored the pigs' body temperature and respiration.

The mean procedural temperature was 38.1C (36.2C – 39.3C). The mean low 36.2C (33.9C – 37.0C) and the mean loss was 1.8C (0.2C – 4.3C).Following animal preparation, a surgical plane of anesthesia was maintained using isoflurane administered through the endotracheal tube using a precision vaporizer and compressed oxygen. Basal anesthesia was augmented as needed in some animals with pentobarbital administered intravenously.

The four designated sites to receive the patterned injury were the lateral aspects of the upper hind limb/thigh, abdomen/flank, thorax, and shoulder/upper forelimb of the animals. (Figure 20)

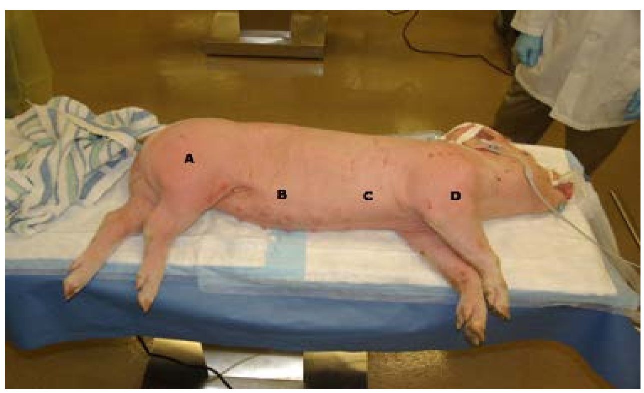

Figure 20. Depicts the four standard sites selected on each side of the animal for the replication of bite marks (patterned injuries).

Because the surface and sub-surface features of porcine skin, *Sus scrofa*, vary with the anatomic location, much the way they do in human skin, multiple sites were chosen to receive the replicated bite. In their confocal laser scanning microscopy of porcine skin

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in wound healing, Vardaxis et al, have demonstrated that the success of such studies is dependent on control and standardization of the injury infliction protocol. [22] The size of the pigs used (20-40 kg) and the skin structure made the production of patterns possible at similar anatomical locations bilaterally, with observations and photography made 15 minutes post-infliction to introduce as little variation between areas on the same animal. There were a total of eight (8) replicated bites on each animal. The pounds force (lb^f) necessary to produce the patterns were standardized from 50 to 99 lbs. and were continuously monitored using the described FlexiForce® sensor connected to a force-to-voltage circuit and data acquisition system.

Each application was held for a minimum of 5 seconds to a maximum of 15 seconds, or the estimated time that a human with normal musculature and tempro-mandibular joint function can maintain a sustained force without muscle fatigue. [23] [24]

Forensic Digital Photography

The patterned injuries were created with the custom designed, semi-automated, recording pattern replication apparatus. The injuries were digitally photographed at 1:1 scale (life size) by a highly experienced forensic photographer, beginning 15 minutes after their creation, using a Canon™ EOS 5d Mark II, ~ 21mp with a Canon Macro EF 100mm 1:2.8 USM lens, set to autofocus. Lighting was provided with a Canon 580 EX II flash set to Manual 1:2 power. The flash unit was used off camera held oblique to the bite pattern. Camera settings were at the manual exposure of 1/200th @ f16-32, 100 I.S.O. with the white balance set on Flash. Large JPEG format imaging process consisted of converting RAW images in Adobe Photoshop CS5 (cropped to 4x4 inches) and then calibrated to 1:1 at 300 ppi and saved in TIFF format. Calibration and correcting for perspective distortion can be two different issues. Even though they are related, they are separate entities. An orthogonal object may not be 1:1 (or calibrated).

The calibration of the patterned injury proceeded by determining the total number of pixels within a known distance. Once determined, that known pixel count can be provided into the image size box with the known distance set and the calibrated resolution, for that distance, will be revealed. That resolution is used to determine the exact size of the image by placing it into the image size box with all three known (length, width and resolution) "locked". When perspective distortion is introduced (and most all systems/lenses have some - optical and linear) the calibration may (most will dependent upon amount) become skewed. The forensic photographer used the least distorted portion of the scale for our calibrations. As an alternative, there is a correction for this distortion in Photoshop (especially if it is slight). The other option was to be certain that our scale is perfectly flat upon the pig and the camera plane is parallel and perpendicular. The forensic photographer employed a flat field lens to help reduce optical distortion. At the laboratory, the images were then calibrated to 1:1 and the analysis measurements made using the technique previously reported for Tom's Toolbox©. [28]

Image Selection

A total of 800 digital images were exposed, four for each of the 200 sites, exposing digital images from all four compass points following the guidelines of the Scientific

Working Group on Imaging Technology (SWGIT) [25] and the guidelines for bite mark evidence of the American Board of Forensic Odontology (ABFO) [26].

Sorting and selection of the best quality image for each of the eight sites on the twenty-five pigs was accomplished. Since in Tom's Toolbox© a scaled image of each dental arch must analyzed separately by the semi-automated software, a total of four hundred scaled digital images were calibrated at 300 dpi, duplicated and saved as working images in TIFF format. Those patterns which registered all six of the anterior teeth were considered complete, while those which registered only some of the anterior teeth were classified as partially usable. A third category, unusable, was assigned to those patterns which lacked sufficient detail.

Image analysis and measurement

Duplicate working files of the 200 images were created for each of the investigators to independently measure the characteristics available. The duplicate working files were uploaded into the semi-automated computer application, Tom's Toolbox©, where they were independently measured and the data saved in an internal log.

The semi-automated software application, Tom's Toolbox©, utilizes ten markers which are inserted in a specific order into the image at the starting and ending points of the pattern to be measured. The application recognizes the location of each marker by column and row, to calculate distances and angles of rotation.

The usable and partially usable images were measured for arch widths, tooth widths, angles of rotation, and spacing. The application provides the operator a check box option for indicating whether any or all of the markers for measuring dental characteristics cannot be placed. (Figure 21) Tom’s Toolbox© saves the measurements in a data set in an internal log. From the data saved in the internal log a software application can then generate a report on the frequency distribution of the pattern in the population dataset.

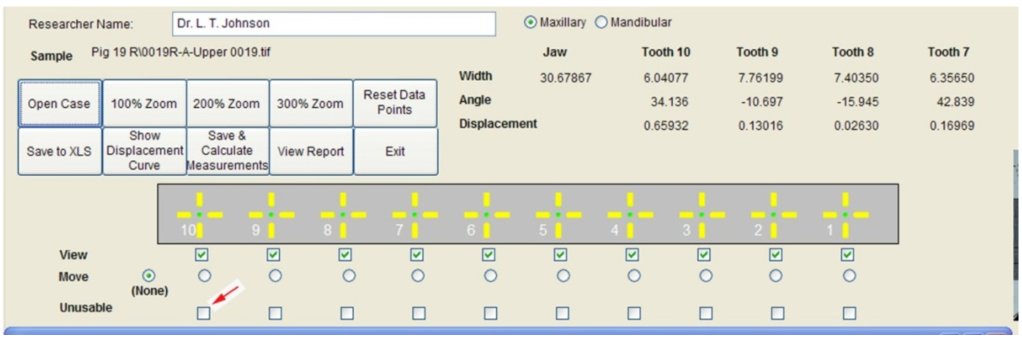

Figure 21. The arrow indicates the location of the control button used to indicate that a specific site in the bite mark pattern image where a Toolbox marker could not be inserted at that site.

The measurements from each examiner’s image files were saved in a log within Tom’s Toolbox© and then transferred to an Excel spreadsheet for statistical analysis. The spreadsheet is programmed to check for data entry errors.

Quality control was accomplished by identifying and correcting any errors or omissions in measurement or missing image files and a revised spreadsheet was created.

Once the investigators were satisfied that all of the data in the spreadsheet was correct, it was transmitted to the collaborating statisticians for statistical analysis. Statistical programs were created by the consulting statisticians from the Medical

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College of Wisconsin and Marquette's University's College of Engineering, Department of Electrical and Computer Science. These resources were utilized to develop models enabling the determination of the probability that measurements of the individual characteristics in the injury patterns could be correlated with a degree of probability to the known model in our population data set, testing the stated hypothesis of pattern replication.

Image selection

In the process of evaluating and sorting the suitability of the best 200 image, the inter-observer agreement on suitability was highest for those considered to be complete (these images exhibited recognizable sites for the insertion of all ten of the markers in Tom's Toolbox©). Both examiners agreed there were 87 of the 200 upper arch patterns determined to be complete. Agreement differed somewhat in that examiner 1 determined 116 lower arch patterns were considered complete, while examiner 2 determined 110 were complete. (Table 2)

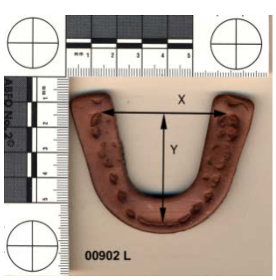
	Investigator 1 Lower	Investigator 2 Lower	Investigator 1 Upper	Investigator 2 Upper
Number of Images Considered Partially usable	17 (8.5%)	39 (19.5%)	17 (8.5%)	34 (17%)
Number of Images Considered Completely Unusable	67 (33.5%)	51 (25.5%)	96 (48%)	79 (39.5%)
Number of Images Considered Complete	116 (58%)	110 (55%)	87 (43.5%)	87 (43.5%)
Total	200	200	200	200

Table 2. Illustrates the extent of the intra-observer agreement in the selection of images for analysis.

An observation related to the finding of image patterns that was considered completely unusable, is whether the production of the pattern was static or dynamic. There is little or no movement in a static bite and consequently there is a more distinct pattern registered.

Determination of Angles of Rotation

In the earlier studies of complete patterns of the entire dental arch, angles of rotation were computed for each of the four anterior incisors. Computation was based on an x-axis established by the principal investigator. To establish an x-axis, an adjustable template consisting of both an X and a Y member was developed, which would superimpose a reference line (x axis) between the distal most points of the contra-lateral first molar teeth. The automatically adjusted Y axis bisects the X axis and establishes the midline of the arch. Adjustment to the specific landmarks on the image was accomplished in Adobe Photoshop, using the Edit > Transform > Scale, or >Rotate. (Figure 22A and Figure 22B)



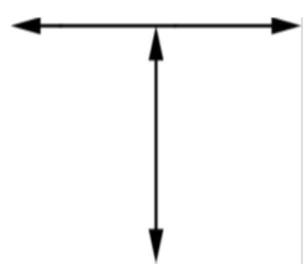


Figure 22A. The X Y axis inserted in a scaled image for measurement.

Figure 22B. The adjustable X Y template used to establish the X axis.

In the current pattern replication research project, only the registrations of the six maxillary and mandibular anterior teeth were imprinted. It then became necessary to establish an alternate method of determining angles of tooth rotation, independent of the posterior dentition. This approach measured tooth rotation in relation to the intersecting angles of an extended line projected on the incisal edge of each of the four incisors. This was accomplished through a modification of the use Tom's Toolbox© and the absence of X and Y coordinates for the pixel marker placed for each tooth. The incisal line is defined as a straight line along the incisal edge of the incisor teeth, connecting the directly opposite mesial point to the distal most point on the tooth's incisal edge. The extension of this line intersects with an adjacent incisal line of the other teeth forming a measurable intersecting angle**.** The computed angle of intersecting lines based on all combinations of the four anterior teeth was recorded. Assuming the four anterior teeth are A, B, C, and D, the computed angles of intersection would be: AB, AC, AD, BC, BD, and CD.

Recording force and duration

Using the SAS System and incorporating the Means Procedure, the electronic Phidgets logbook for the bite pattern replication study recorded 4684 points of data during the 25 sessions.

The mean recording for all points in which pressure was applied was 545.6, with a standard deviation of 278.7 within the range of pressures recorded for each event between 0 and 997.0 on the FlexiForce™ sensing device. Each of the FlexiForce™ sensors were bench calibrated for pounds force (lb^f) with an Omega™ model LCKD-100 mini load cell. Force versus Time was plotted for each pig location. As an example, Pig25_L_A (left side, pig 25, position A) is represented in figure23 and the resultant bite pattern can be seen in figure 24. Each of the 200 patterns was similarly correlated to the maximum force of the device over a period of 15 seconds.

start_side_site=Pig_25_L_A

Analysis Variable : value				
N	**Mean**	**Std Dev**	**Minimum**	**Maximum**
47	665.5531915	168.9966309	152.0000000	817.0000000

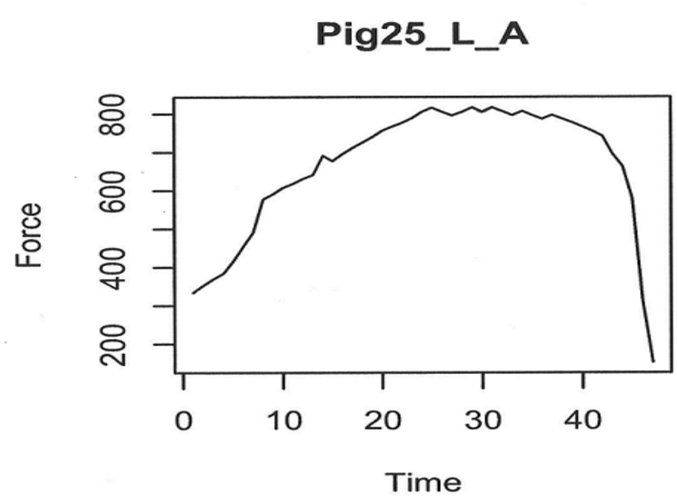


Figure 23. Analysis variable for pig number 25 left side, site A (hind limb) representing the mean force of 665.553191 Phidgets sensor reading with minimum and maximum loads over 15 seconds of maximum load force.

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Figure 24. bite mark replication pattern for pig number 25L A (left side, position A) representing the mean force of 665.553191 Phidgets sensor reading with minimum and maximum loads over 15 seconds maximum load force.

Image analysis

Analysis using Tom's Toolbox© began once the images had been reviewed and selected. Of particular importance were the images and resultant forces producing them that led to a high level of inter- observer agreement. For example the patterns on Pig 19R appeared highly consistent with model 945, when a transparent overlay comparison was conducted. (Figure 25)

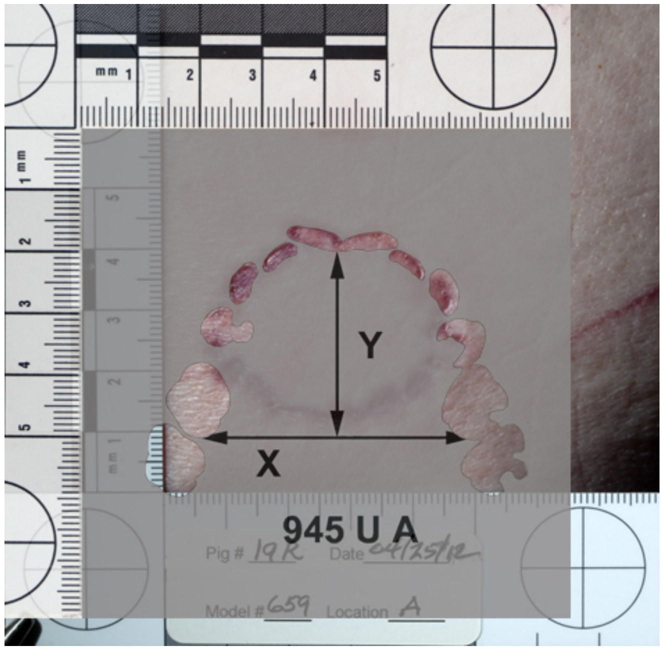

Figure 25. Illustrates the consistency of the pattern in dental characteristics in bite pattern 19R A and the population Target member 945 U A, using a computer generated semi-transparent overlay.

Consistency in all characteristics does not quantify the frequency with which the pattern occurs in the population. The strength of the correlation of model number 945 with pattern 19R, site A, required constructing statistical models. The resultant pixel placement and forces used to create the bite mark are illustrated in Figure 26A, 26B and 26C.

Figure 26A. Illustrates the placement of the measurement markers in Tom's Toolbox© for the maxillary incisors in the replicated bite mark for pig 19R, site A.

Analysis Variable : value				
N	Mean	Std Dev	Minimum	Maximum
58	784.7586207	101.9286490	551.0000000	997.0000000

Figure 26B. Depicts the force applied to produce the replicated pattern of the bite mark on Pig 19 R, site A

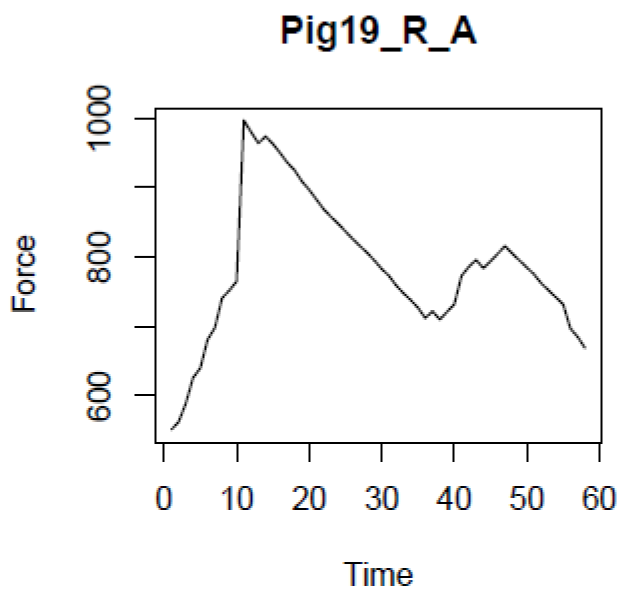

Figure 26C. Illustrates the FlexiForce scale recording of the force at 10 seconds to 25 seconds over the 60 second duration of the contact with porcine skin, Pig 19R, site A.

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Results

Statement of Results Using Pearson Correlations

Statisticians evaluated width measurements for outliers utilizing two different analytic models. The results are found in table 3 for widths for standard deviation, median, minimum, and maximum width measurements in porcine skin for each tooth in each jaw.

	Mean ± StDev	Median	Minimum	Maximum
Upper				
Tooth 7	5.07 ± 1.05	5.15	2.12	7.88
Tooth 8	6.47 ± 1.16	6.66	2.29	8.39
Tooth 9	6.50 ± 1.18	6.70	2.86	8.87
Tooth 10	4.83 ± 1.07	5.00	1.22	7.80
Lower				
Tooth 23	4.97 ± 0.76	4.98	2.01	6.99
Tooth 24	4.74 ± 0.74	4.81	1.86	6.80
Tooth 25	4.64 ± 0.81	4.68	1.53	6.58
Tooth 26	4.91 ± 0.69	4.94	2.92	7.30

Table 3. The measured widths for each tooth in porcine skin expressed in millimeters

These widths were compared to the known widths established by the two investigators using Coprwax™ exemplars, a standard dental material for bite

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registration. An illustration of the results when searching for outliers in individual tooth widths is found in Table 4.

	Investigator 1	Investigator 2
Width and angle	23.42%	26.83%
Width	35.3%	50.1%
Angle	15.33%	10.21%

Table 4. The percentage of outliers in tooth widths plus angles, widths and angles only by investigators 1 and 2.

The viscoelasticity of the skin and the rebound that occurs restricted meaningful comparison when width was considered as a single characteristic. Analysis found that there were many bite mark patterns in porcine skin which exhibited several outlying measurements for each tooth**.**

The inter-observer agreement using SAS software between Investigator 1 and Investigator 2 in the measurement of the 50 CoprWax™ dental patterns was 0.984, showing an extremely high consistency when measuring widths of tooth patterns in CoprWax™, an American Dental Association (ADA) accepted bite registration material. Determination of the inter-observer agreement in measuring tooth widths of patterns registered in porcine skin was calculated with SAS software resulting in a correlation of 0.716.

Measuring the intersecting angles as a means of determining an additional dental characteristic has not previously been utilized in pattern research. The intersecting angles between teeth identified A and B, A and C, A and D, B and C, B and D and C and D were identified and compared to the corresponding angles recorded in the dataset. (Figure 27) The correlations between bitemarks in porcine skin compared to

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the known measurements of the 469 dental models were ranked from 1 to 469. For Investigator 1, 84.6% of the measurements showed that their true models were ranked in top 10%. For Investigator 2, 85% of the measurements showed that their true models were ranked in top 10%.

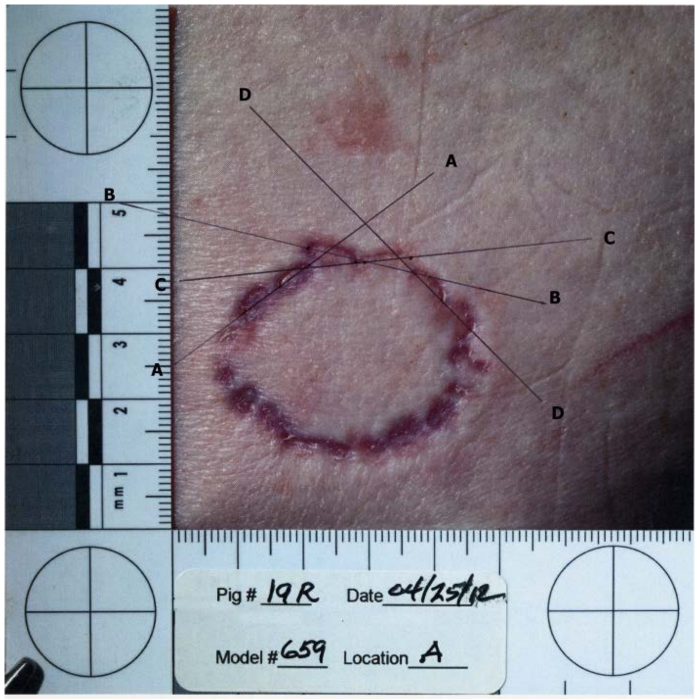

Figure 27. Illustrates the intersection of the extended incisal lines used to calculate the angle of rotation of the incisors. Outliers in these angles are used to quantify their occurrence in the sample population.

Based on the angle correlation, the list can be further narrowed for a comparison of porcine skin patterns and the set of models used to create true model candidates that had a confidence interval of 0.984.

The Pearson correlation was used to select a dental model based on the bite mark patterns. Two hundred bite marks were examined against 469 dental models. For each bite mark, 469 correlations with the dental models were calculated. Then, the 469 correlations were ranked from 1 to 469. The dental model having rank #1 correlation

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was the predicted model. Table 5 illustrates the results based on the all measurements, i.e., the width and the angles. 143 (Investigator 1) and 156 (Investigator 2) bite marks out of the 200 had at least one non-missing data entry. The data of the remaining 57 (Investigator 1) and 44 (Investigator 2) bite marks were completely missing (i.e., non-measurable). As can be seen in Table 5, five (5) out of the one hundred forty-three (143) (Investigator 1) and two (2) out of the one hundred fifty-six (156) (Investigator 2) selected correct dental models from the population data set. The models ranked number one in the data set were from separate members of the population. The P-values of less than 0.05 shows that this selection is better than random. For example, identifying 2 correct models out of the 156 (Investigator's Rank #1) shows a better performance than selecting a correct model completely at random (p-value = 0.0431), and 5 correct models out of the 143 case (p-value < 0.0001). Although correlation identified only 5 and 2 correct models, respectively, a lot of the correlations between a bite mark and its true dental model were still highly ranked. For example, 10 out of the 143 for Investigator 1 and 13 out of the 156 for Investigator 2 were within in top 1%. The rest of the results can be interpreted similarly. They all show a better performance than random (p-values < 0.0001).

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	Investigator 1		Investigator 2	
	Proportion	P-value	Proportion	P-value
Rank #1	5/143	< 0.0001	2/156	0.0431
Top 1%	10/143	< 0.0001	13/156	< 0.0001
Top 5%	34/143	< 0.0001	36/156	< 0.0001
Top 10%	59/143	< 0.0001	54/156	< 0.0001
Top 20%	78/143	< 0.0001	76/156	< 0.0001
Top 30%	93/143	< 0.0001	105/156	< 0.0001

Table 5. The results of an analysis based on the measurement of both width and angles.

Table 6 shows the results based on width measurements only. 141 (Investigator 1) and 153 (Investigator 2) bite marks out of the 200 had at least one non-missing data entry. The data of the remaining 59 (Investigator 1) and 47 (Investigator 2) bite marks were completely missing. The correlations from Investigator 2 identified 3 correct models out of the 153, which is better than random (p-value = 0.0043). The correlations from Investigator 1 did not identify any correct models. Although Investigator 1 measurements did not show better performance than random selection, investigator 2's measurements showed a better performance than random (all p-values are less than 0.05).

	Investigator 1		Investigator 2	
	Proportion	P-value	Proportion	P-value
Rank #1	0/141	1	3/153	0.0043
Top 1%	0/141	0.4106	8/153	0.0002
Top 5%	7/141	1	15/153	0.0136
Top 10%	14/141	1	26/153	0.0067
Top 20%	32/141	0.4014	45/153	0.0060
Top 30%	41/141	0.8546	64/153	0.0019

Table 6. This table illustrates the investigators' difficulty in measuring incisor width only. This is due to the viscoelasticity of the skin, resulting in inaccurate measurements in distance.

Table 7 shows the results based on angular measurements only. 136 (Investigator 1) and 131 (Investigator 2) bite marks out of the 200 had at least one non-missing data entry. The data of the remaining 64 (Investigator 1) and 69 (Investigator 2) bite marks was not useable. . The correlations from Investigator 1 identified 3 correct models out of the 136, which is better than random (p-value = 0.0031). Although the correlations from Investigator 2 did not identify any correct models, some correlations between width measurements of a bite mark and its true dental model's width was still ranked high, which is better than random (p-value < 0.0001 for top 5% to top 30%).

	Investigator 1		Investigator 2	
	Proportion	P-value	Proportion	P-value
Rank #1	3/136	0.0031	0/131	1
Top 1%	10/136	< 0.0001	10/131	< 0.0001
Top 5%	30/136	< 0.0001	32/131	< 0.0001
Top 10%	46/136	< 0.0001	43/131	< 0.0001
Top 20%	75/136	< 0.0001	67/131	< 0.0001
Top 30%	87/136	< 0.0001	85/131	< 0.0001

Table 7. Illustrates the Investigators accuracy and consistency in an analysis based on angular measurements only.

Outliers were calculated using an N =469 to represent the population dataset. For each column (for example, the width of Tooth 24 or the angle of AB for upper tooth), a calculated mean and standard deviation was recorded as ± 2×SD.

Since the location of the observations is unknown, an iterative algorithm was used to find the best dental model to match the bite marks. To do this, all possible combinations between observations and dental models were examined. The best matched bite mark and dental model was determined by choosing the dental model and teeth marks that produced the minimum sum of absolute values of the differences between observations and measurements of the dental models. For example, when there were four observations of widths, a comparison was made using these four observed widths and all possible four measurements from all known dental models. Starting with the first tooth of each model, the absolute difference of teeth marks and models was compared.

This was then repeated around the entirety of the model until every combination of matching had been compared. The corresponding, dental model was chosen by producing the absolute minimum difference between observations and measurements from the dental models. For analysis, the outcome was whether the chosen dental model was correct, which created binary outcomes. Finally, generalized estimating equations (GEE) were employed to perform multivariate analysis of the predictability of the model selection.

In addition to the above multivariate analysis, further investigation of outliers such as missing teeth and significantly large/small measurements remain to be calculated beyond the scope of this investigation. In cases where there were outliers in observations, only dental models which had outliers were considered in order to perform the multivariate analysis as mentioned above.

Statement of Results Using a Distance Metric Model

A second scientific model was also selected to compare the population to the unknown injury patterns based on distance metric analysis. The Distance Metric Model addresses the question; W hat proportion of the population (CoprWax® exemplars) is similar to a specific sample image of an injury pattern on one of the pigs? The Distance Metric family of models computes a distance in an *n*-dimensional factor space from a sample (pig injury image) to each member of the population (CoprWax® images). The score for a particular member of the Distance Metric family of models is the percentage of the population that is closer to the specific sample, than the correct matching target member of the population from which the sample image was made as suggested by Figure 28.

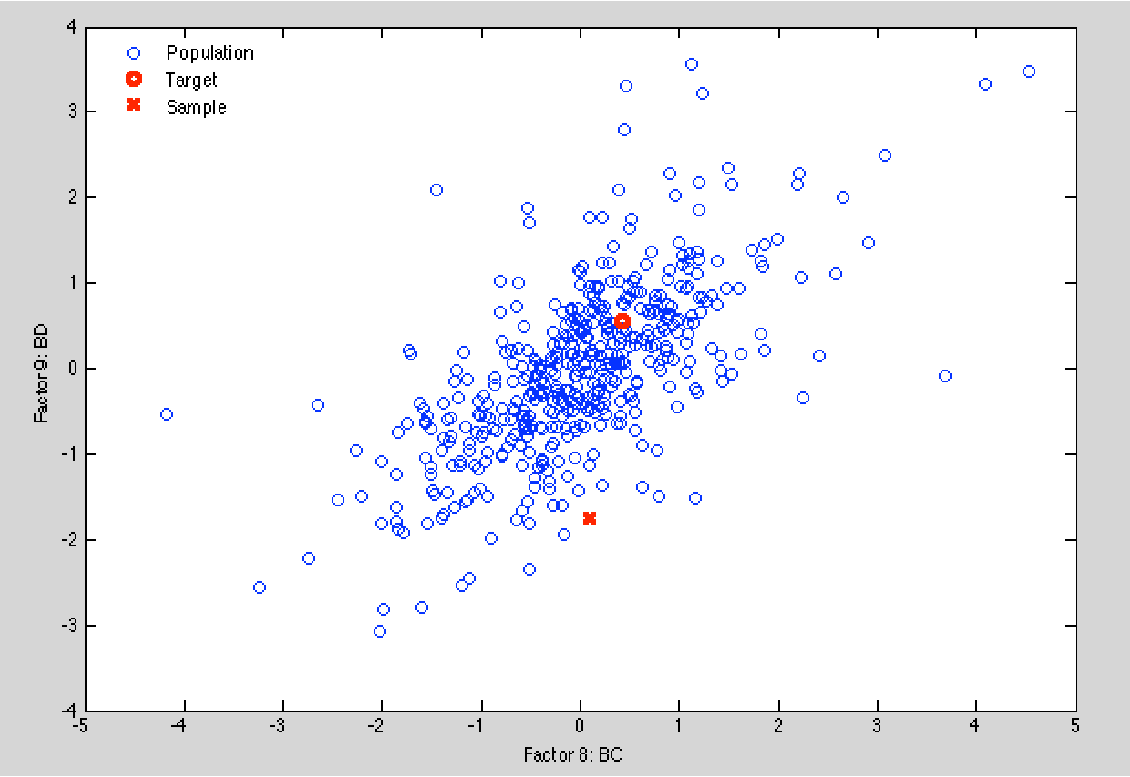

Figure 28. A visualization of the Distance in factor space from the Sample to the matching Target of the Population.

In Figure 28, "**X**" denotes a Sample image, and the heavy "**O**" denotes the matching target member of the population, represented in two of the angle measurement factors for upper jaw measurements by Investigator 1. In this view, it appears that most of the populati theon is closer to the sample than the target member of the population, but less than 5% of the population is closer to the sample than the target.

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For analysis, data from 469 pairs of lower and upper jaws was provided and scored by two researchers independently. The factors scored were:

- Lower jaw: Tooth 23 width, Tooth 24 width, Tooth 25 width, Tooth 26 width, and angles AB, AC, AD, BC, BD, and CD.

- Upper jaw: Tooth 10 width, Tooth 9 width, Tooth 8 width, Tooth 7 width, and angles AB, AC, AD, BC, BD, and CD.

The lower jaw images had 7 missing teeth noted by the two independent researchers. The upper jaw images had 9 - 11 missing teeth. So that distances could be computed using multiple factors, each width and angle measurement was replaced by its corresponding z-score by subtracting factor means and dividing by factor standard deviations, ignoring missing teeth, and considering scores from each researcher separately

For analysis, 50 members of the population were selected as blind samples. Four separate simulated bite marks were made from each sample, giving 400 images each from lower and upper jaws. The two investigators independently scored the same 10 factors for each of the 400 images. Some of the population selected for the samples had missing teeth, but of the 800 teeth measured from each jaw by each researcher, between 276 and 420 (investigator 1 and investigator 2) missing teeth could not be distinguished in the images with sufficient clarity to assign factor measurements. Not all impressions were clear enough for analysis.

So that distances could be computed using multiple factors, each factor was normalized by subtracting population factor means and dividing by population factor standard deviations, considering scores from each researcher separately.

Before applying the Distance Metric Model, the data was visualized by looking at histograms for each factor (e.g., Figure 29), Normal Probability Plots (e.g., Figure 30), and scatter diagrams of each pair of factors (e.g., Figure 31). Figures 31, 32, and 33 show the plots for the upper jaw measurements from researcher 1; corresponding plots for lower jaws and for researcher 2 are very similar.

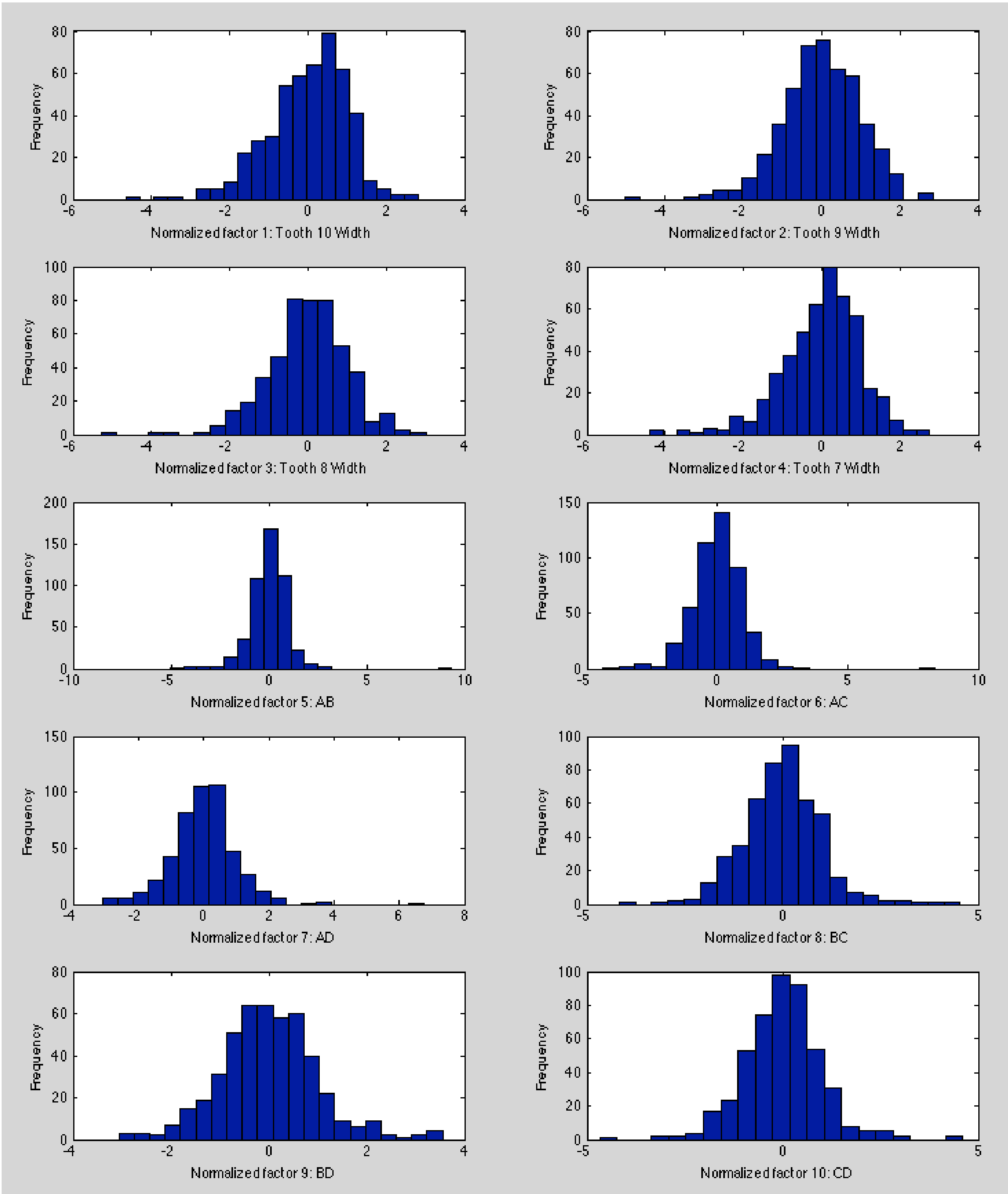

Figure 29. Histograms of ten normalized factors from upper jaw measurements by researcher 1. Distributions appear roughly bell shaped, but there are outliers.

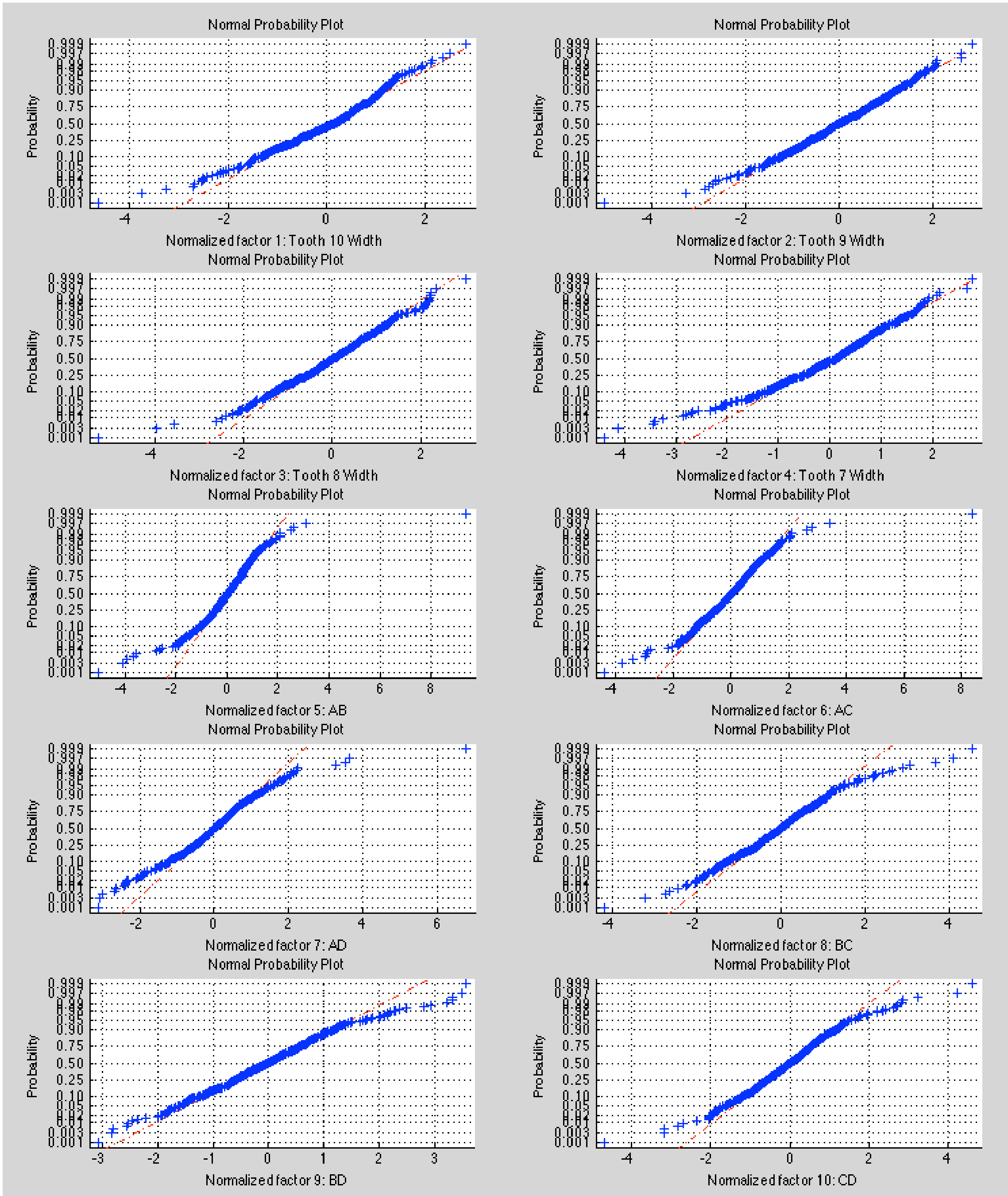

Figure 30. Normal Probability Plots of ten normalized factors from upper jaw measurements by researcher 1. If the observed distribution is normal, it follows the dashed red diagonal lines. Distributions of these factors tend to have thick tails, and some are skewed.

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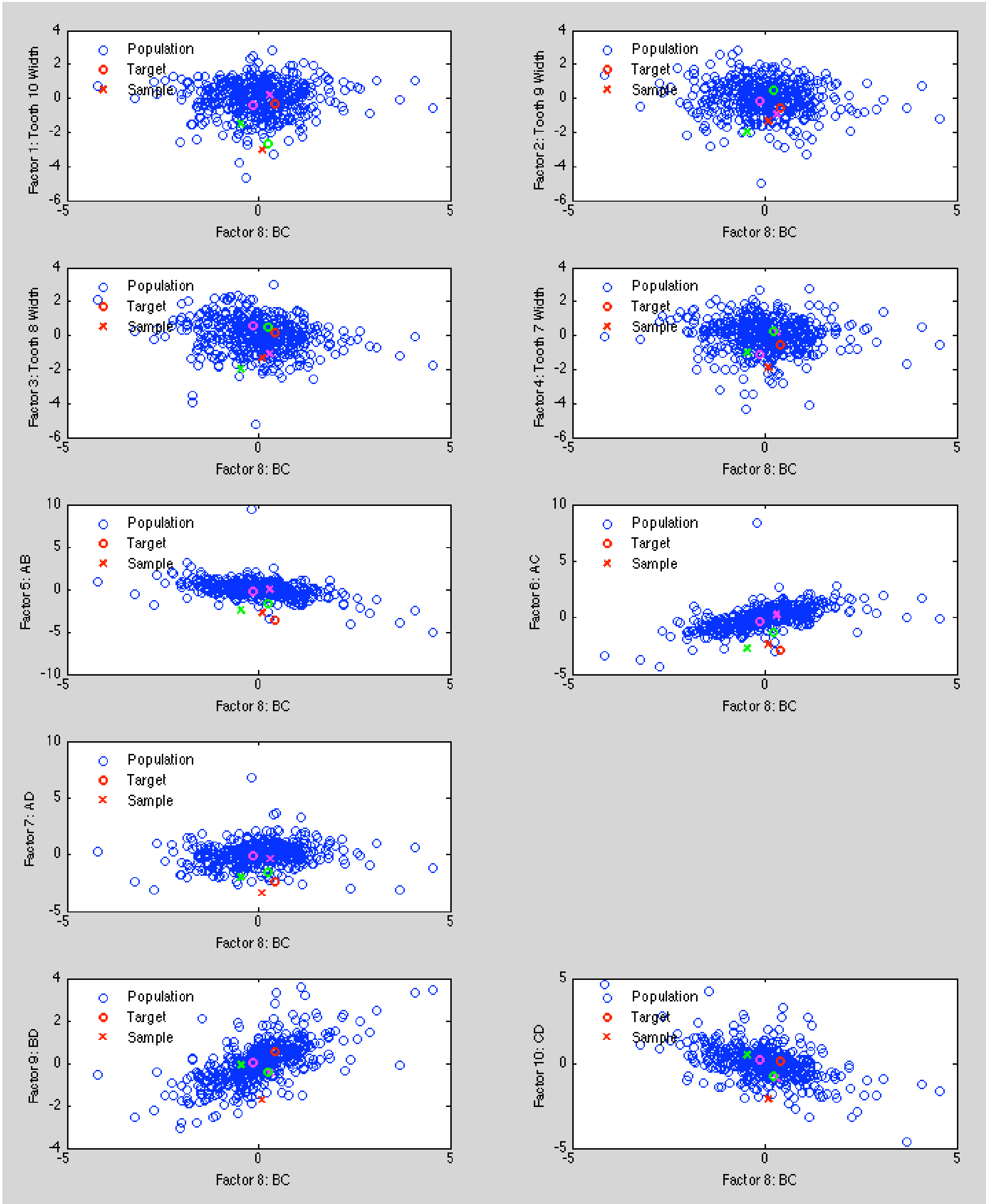

Figure 31. Scatter diagrams – Other factors vs. factor 8 (angle BC) for Population. Colored “**X**” are three Samples, with corresponding Target members of the Population marked “**O**”

For each Sample, the Distance Metric Model computes the distance (in *n*-dimensional z-score-normalized factor space) to each member of the population and

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then sorts the results in order of increasing distance. For each sample, the number of population members that lie closer to the sample than its corresponding target member of the population (the dental model that was used to create the sample image) was counted.

Figures 32 and 33 help visualize how the Distance Metric Model computes the distance between Samples and members of the Population. Figures 30 and 31 are enlargements of subfigures from Figure 29, showing scatter diagrams of factors 7 (angle AD) and 9 (angle BD), respectively, vs. factor 8 (angle BC). There are several outlier measurements, which provide good characterizations, but the choice was to focus here on more difficult Samples, marked with red, magenta, and green “X” (Samples) and “O” (Targets). The Distance Metric Model counts the number of Population members (blue “O”) that are closer to the Sample (“X”) than its corresponding Target (“O”). For these three pairs, the percentages are 4.8 %, 1.7 %, and 23% for red, green, and magenta pairs, respectively.

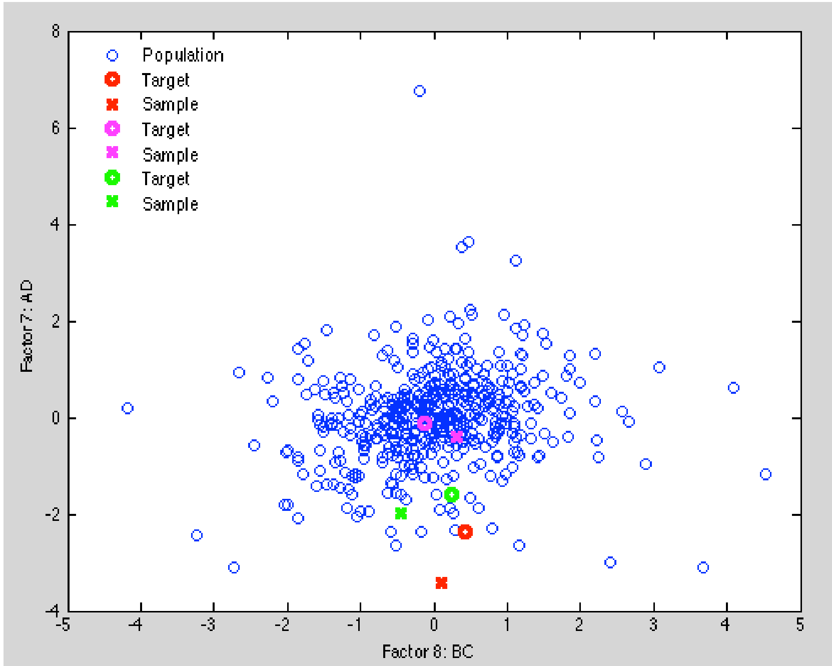

Figure 32. Factor 7 (angle AD) vs. factor 8 (angle BC) showing three Sample – Target pairs.

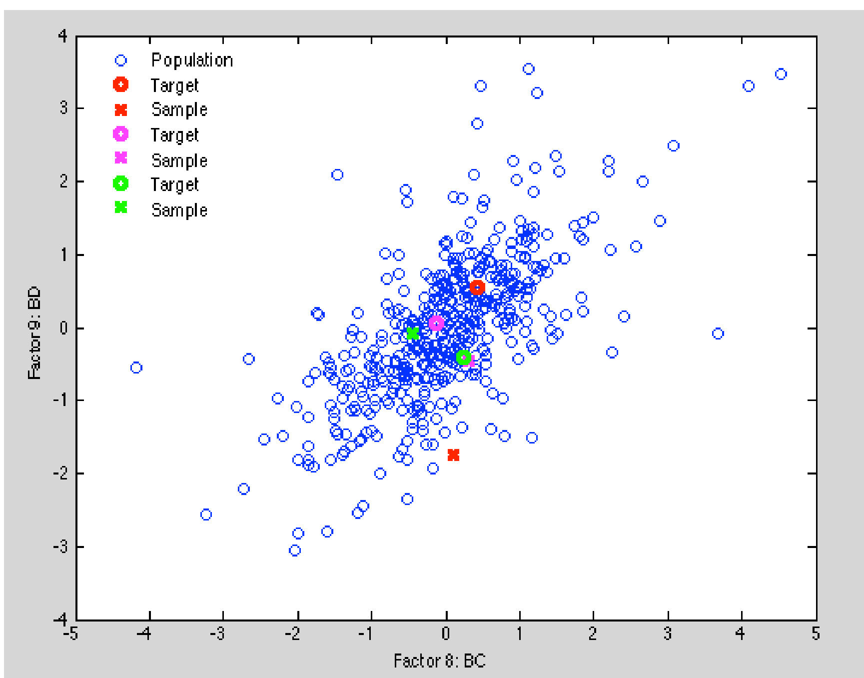

Figure 33. Factor 9 (angle BD) vs. factor 8 (angle BC) showing three Sample – Target pairs.

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These figures illustrate the effect of measuring the distance in a high-dimensional factor space, rather than in the two-dimensional spaces. One pair of dimensions alone is insufficient, but by considering all factors, one may resolve pairs that appear widely separated in a single feature pair.

By having the 10 factors provided in the data set for the upper jaw Samples measured by researcher 1, we get the results shown in Table 8. Results for lower jaws and for measurements by researcher 2 are similar.

Average target percent: 39.1

Sample count: 102

Within 1% of population: 3, 2.9 % of samples

Within 5% of population: 16, 15.7 % of samples

Within 10% of population: 23, 22.5 % of samples

Table 8. The Percent of the Population closer to selected Sample than the corresponding Target for the upper jaw. Samples were measured by Researcher 1.

Table 9 shows that for 3 (2.9 %) of the 102 sample images scored, only 1% of the population was closer to the sample than the target; 16 (15.7%) of the samples found their target within 5% of the population; and 23 (22.5 %) of the samples found their target within 10% of the population.

Figures 34 and 35 provide different views of the performance of the Distance Metric Model. Figure 34 shows a distance Cumulative Density Function for each sample. That is, each sample has a curve showing how fast the percent of the population increases with distance measured from that sample. Curves toward the left of Figure 35 correspond to Samples for which there are nearby members of the population, while curves toward the left correspond to samples for which there are very few nearby members of the population. Curves that rise sharply are including regions in which the population is dense, so a slight increase in distance includes many additional members of the population. On the other hand, curves that rise slowly are including regions in which the population is sparse, so even a relatively large increase in distance includes few additional members of the population.

In Figure 34, the blue circles represent the Target for each sample; a blue circle near the horizontal axis represents a target close to its sample, while a blue circle in the upper half of the figure represents a target far from its sample.

Figure 35 is a Cumulative Density Function, a graphical representation of the information in Table 8. It plots the percent of the Population closer to each Sample than its corresponding Target. There are 23 Samples whose Target is within 10% of the Population and 49 Samples whose Target is within 40% of the Population. Of course, the worst case Sample finds its Target within 100% of the Population. If the Distance Metric Model is performing well, the graph remains low through many Samples, jumping up to 100% only for the few Samples it finds far from their respective Targets.

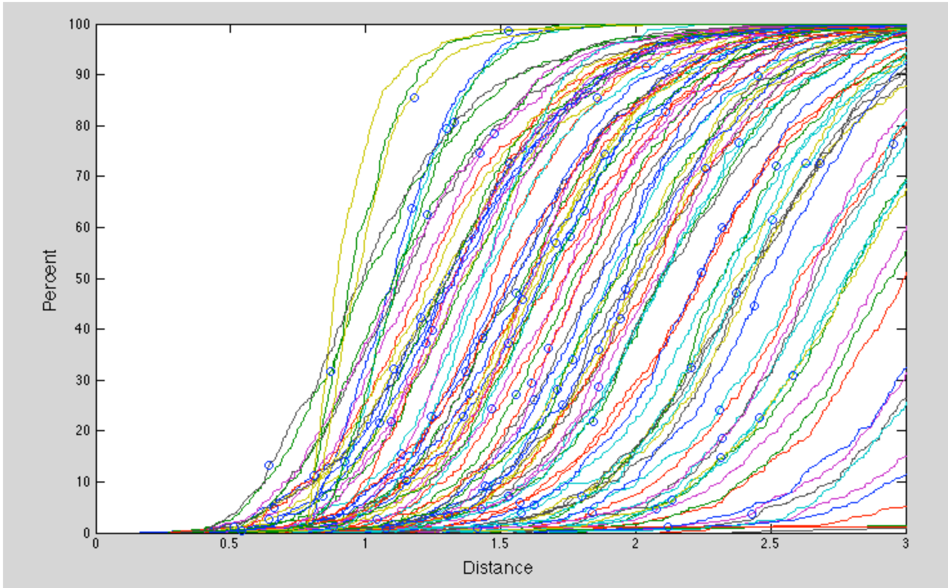

Figure 34. Proportion of Population vs. distance for each upper jaw Sample scored by researcher 1.

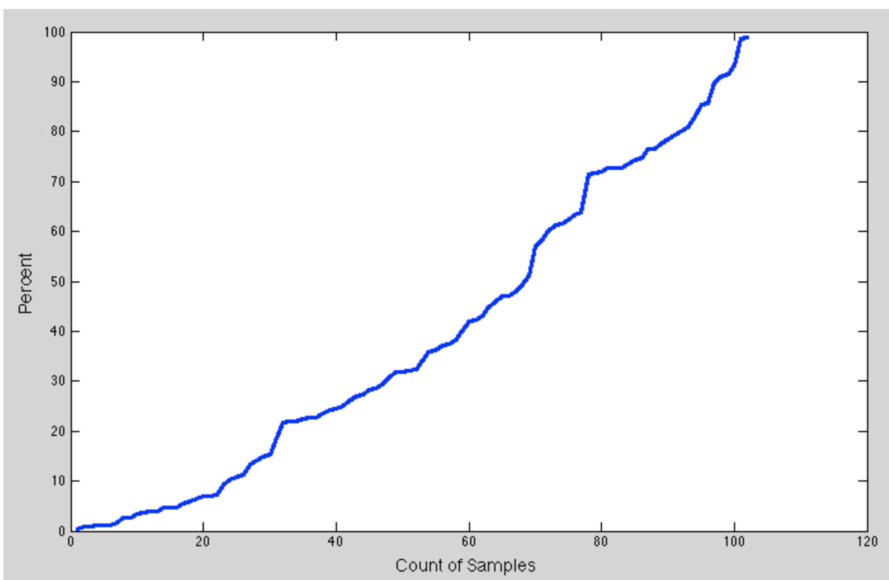

Figure 35. Cumulative Density Function, a graphical representation of the information in Table 8, the percent of the Population closer to each Sample than its corresponding Target.

In principle, the distance can be computed using any subset of the 10 factors provided in the data set. For example, if we ignore the tooth width measurements and use only the factors representing measurements of angles, we get the results shown in Table 9.

Average target percent: 26.2

Sample count: 95

Within 1% of population: 8, 8.4 % of samples

Within 5% of population: 24, 25.3 % of samples

Within 10% of population: 35, 36.8 % of samples

Table 9. The Percent of Population closer to selected Sample than the corresponding Target for upper jaw Samples measured by researcher 1, using use only the factors representing measurements of angles.

Compared with Table 8, Table 9 shows that omitting tooth width factors improved the overall performance from an average target percent of 39% to 26%, and 8%, 25%, and 37% (vs. 3 %, 16 %, and 22 %) of the Samples found their corresponding Target within 1%, 5%, and 10% of the Population, respectively. The Sample count decreases because the number of Samples with a relatively high proportion of missing information increases.

Figure 36 corresponds to Figure 34, except that the Distance Metric Model is using use only the factors representing measurements of angles. The red, magenta, and green curves are the density functions for the samples. If the magenta curve is toward the left of the figure, it indicates that the sample is in a region where the population is dense, yielding 23% of the population closer than the corresponding target, while the red curve is toward the right of the figure, indicating that the sample is in a relatively sparse region of the population, yielding only 4.8 % of the population closer than the corresponding target.

Figure 37 shows the Cumulative Density Function corresponding to Figure 36, except that the Distance Metric Model is using use only the factors representing measurements of angles. The blue curve for the smaller six-factor model remains low for more samples, indicating its improved performance.

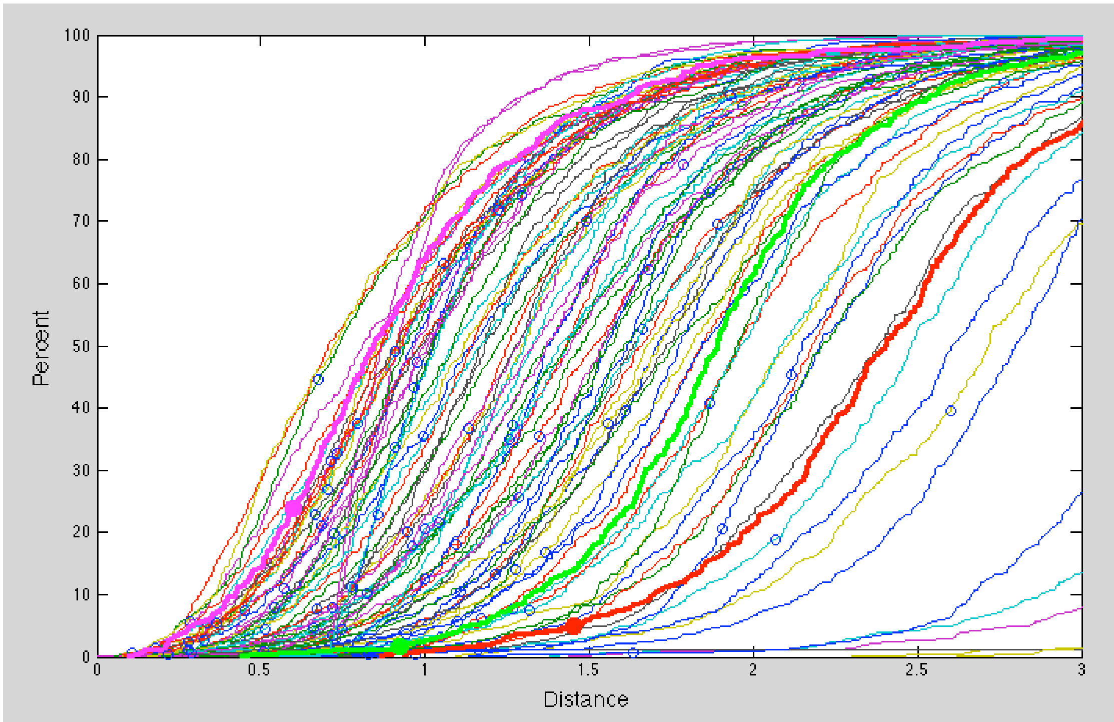

Figure 36. Proportion of Population vs. distance for each upper jaw Sample scored by researcher 1, using use only the factors representing measurements of angles.

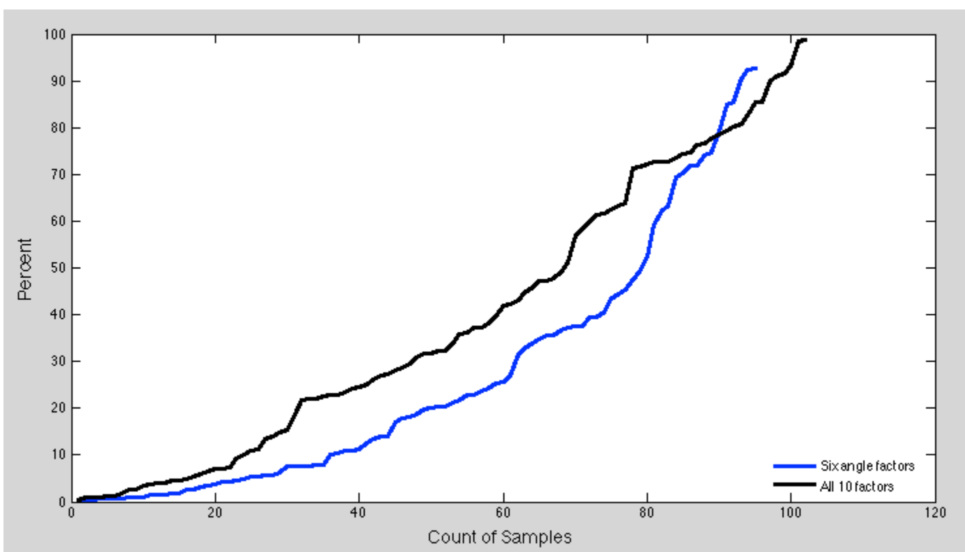

Figure 37. Cumulative Density Function, showings the percent of the Population closer to each Sample than its corresponding Target.

This presents only the results from upper jaw Samples and Populations measured by Researcher 1 to help explain the Distance Metric Model. Table 9 shows the percent of population closer to selected sample than the corresponding target, using only the factors representing measurements of angles, for both lower and upper jaws and for the measurements from both researcher 1 and researcher 2. For this data set, the Distance Metric Model performs a little better on the upper jaw samples than on the lower jaw samples, and there was no appreciable difference in performance using the sample and population measurements of each researcher.

In comparing the results in Table 9 with those in Table 10, the Distance Metric Model seemed to perform better ignoring the tooth width factors and using only the angle factors. Table 11 summarizes the performance of the Distance Metric Model using several different factor subsets:

- All ten factors, four tooth width factors and six angle factors,
- Six angle factors,
- Five angle factors, omitting the first of the six (angle AB),
- Five angle factors, omitting the second of the six (angle AC),
- Five angle factors, omitting the third of the six (angle AD),
- Five angle factors, omitting the fourth of the six (angle BC),
- Five angle factors, omitting the fifth of the six (angle BD), and
- Five angle factors, omitting the sixth of the six (angle CD).

Lower - Investigator 1			
Count samples:	125		
Samples within	1 % of the population	6	4.8 % of the samples
Samples within	5% of the population	25	20.0 % of the samples
Samples within	10 % of the populatio	36	28.8 % of the samples
Lower - Investigator 2			
Count samples	132		
Samples within	1 % of the population	5	3.8 % of the samples
Samples within	5% of the population	23	17.4 % of the samples
Samples within	10 % of the populatio	33	25.0 % of the samples
Upper - Investigator 1			
Count samples	95		
Samples within	1 % of the population	8	8.4 % of the samples
Samples within	5% of the population	24	25.3 % of the samples
Samples within	10 % of the populatio	35	36.8 % of the samples
Upper - Investigator 2			
Count samples	98		
Samples within	1 % of the population	9	9.2 % of the samples
Samples within	5% of the population	26	26.5 % of the samples
Samples within	10 % of the populatio	32	32.7% of the samples

Table10. Illustration of the percentage of Population closer to selected Sample, than the corresponding Target, use only the factors representing measurements of angles.

Each row in Table 11 summarizes performance as shown in the "In total:" portion of Table 3 for each subset of factors, across both lower and upper jaws and across both researchers For this data set, the Distance Metric Model using only the six angle factors performed better than when also using the four tooth width factors. No further improvement was observed by omitting any one of the six angle factors.

Factors	Population count within 1% (%)	Population count within 5% (%)	Population count within 10% (%)	Samples
All 10	14 (2.9)	69 (14.1)	117 (23.9)	489
Six angles	28 (6.2)	98 (21.8)	136 (30.2)	450
Omit 1st of 6	32 (7.5)	93 (21.7)	142 (33.1)	429
Omit 2nd of 6	29 (6.8)	97 (22.7)	138 (32.3)	427
Omit 3rd of 6	28 (6.4)	92 (20.9)	140 (31.8)	440
Omit 4th of 6	26 (6.2)	85 (20.4)	130 (31.2)	417
Omit 5th of 6	26 (6.0)	95 (22.1)	130 (30.2)	430
Omit 6th of 6	25 (5.8)	78 (18.2)	126 (29.4)	428

Table 11. Total performance using different factor subsets in the Distance Metric Model.

In summary, in more than 20% of the Samples in this study, the Distance Metric Model finds the Target within the closest 5% of the Population. In more than 6% of the Samples, it finds the Target within the closest 1% of the Population. This demonstrates that it is often possible to determine scientifically that a given Sample must belong to a very small (e.g., 5% or even 1%) proportion of the Population.

Results of forces applied

Using the SAS® System and incorporating the Means Procedure, the Phidgets log record for bite infliction recorded 4684 points of data during the course of the production and documentation of 200 patterns on twenty-five pigs. The mean recording for all points in which pressure was applied with the replication device was 545.62with a standard deviation of 278.78 within the range of pressures recorded for each event between 0 and 997.00on the FlexiForce® to the computer with a Phidgets device. Each of the Flexi Force® sensors was bridged to the computer with a Phidgets device. Each of

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the sensors had been bench calibrated with an Omega model LCKD-100 load cell. Force versus Time was plotted for each pig location. As an example, Pig 25 L A (left side, position A) is represented in figure 38 and the resultant bite pattern can be seen in figure 39. Each of the 200 patterns was similarly correlated to the maximum force of the device over a period of 15 seconds.

Image measurement using Tom's Toolbox© began, once the 200 highest quality images were selected and their resolution established at 300 dpi and their file format as TIFF verified. Of particular importance were the images and resultant forces producing them that lead to a high degree of inter-operator agreement. Pig 19R using blind model 659 was directly correlated to the stereolithography model from the original series represented by model number 945. The resultant pixel placement and forces used to create the bite mark are illustrated in Figure 40.

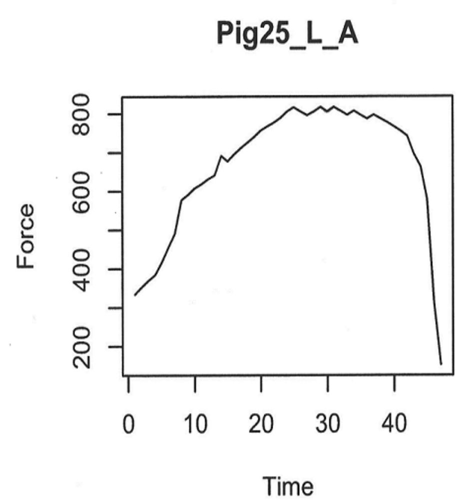

Figure 38. Analysis variable for pig number 25 left side site A, or hind limb, representing the mean force of 665.553191 Phidgets sensor reading with minimum and maximum loads over 20 second maximum load force.

Figure 39. Illustrates a replicated bite mark with a mean force of 665.553191 Phidgets sensor reading. start_side_site=Pig19_R_A.

Conclusions

Discussion of Findings

Many factors exist which can alter the value and weight that should be given to the Interpretation of a patterned injury. These include, but are not limited to, the applied force, the area of the body where the bite occurred (e.g., the skin on the human back is much thicker, as opposed to that of the female breast) Rawson [27], the underlying structures beneath the skin, whether the bite occurs ante mortem, peri mortem, or post mortem and the techniques used in the preservation and analysis. Any of these may affect the ability of the examiner to be able to correlate the patterned injury with any degree of scientific probability to a known individual.[28] [29] [30] [31] In one study, 50 volunteers were selected to inflict bite marks on each other, the patterns were analyzed by two photographic techniques that included painting and a 2D Polyline technique, measuring the arch width from cusp tip to cusp tip and the angle of rotation from this base-line along the mesial distal widths of the incisal edges of the four anterior teeth.[32] Measurements were made using the tools found in Adobe Photoshop, which required hand-eye coordination. Additionally, measurements in Adobe Photoshop are limited by the software to the nearest tenth of a decimal point. The authors' previous studies provided a methodology to standardize measurements and accuracies in both the two-dimensional and three- dimensional planes. [2] [10] Inter-operator and intra-operator error rates have been reported. Forces and stresses necessary to inflict a bite mark patterned injury have been limited to either individual pig models [16] or the use of limited number of human cadavers. [19] For a number of reasons, statistical comparisons of results from these previous studies were not possible. There was no method of comparing results to a known data set, reflecting a specific population group. In a study by Bush , a single model was physically changed by grinding away the incisal edges of existing teeth to show substantive changes in reported angles of rotation regardless of how these nine changes would have occurred, or if they were present in a given population.[30] These changes would not have involved physiologic changes such as mesial drift of the teeth that occurs with the forces of mastication nor the loading and tilting of dentitions that naturally occur when inflicting a patterned injury in vital skin. A cadaver model has its own sets of limitations such as the inelasticity of the skin, the lack of an inflammatory response that enhances patterns in vivo and the ability of tissue to maintain the patterns, when the event is coordinated with a peri-mortem period. Porcine skin has been shown to offer the best experimental model for research as a substitute for vital human skin. [18] Other investigators have noted that the dermal-epidermal ratio in the porcine model is comparable to those of human skin [33], and that the kinetics of epidermal proliferation, cell layering and the elastin deposits are remarkably similar to humans. A search of current literature did not find a study that correlates quantified human dental characteristics in a known data set to an individual bite mark pattern.

The 2009 National Academy of Science report, *Strengthening Forensic Science in the United States: A Path Forward*, has energized the field of Forensic Odontology to search for more scientific methods eliminating subjectivity, bias, and the misinterpretation of results. [1] In fact, since 1984 and long prior to the NAS 2009 recommendations, the American Board of Forensic Odontology (ABFO), has been developing guidelines. The National Academy of Science Report states that more scientific methods should be initiated in all of the comparative sciences. [1] To accomplish this objective, a series of studies was instituted to establish a methodology for constructing a dataset of dental characteristics, quantify dental characteristics in both two dimensional and three dimensional views and establishing reliability of measurements in both intra and inter operator error analysis. The initial quantifications of widths, damages, angles of rotation, missing teeth, diastema and arch width analysis, were subsequently augmented by displacement and three dimensional analyses. [2] [3] [5] [10] This study adds practical application of these data sets to replication of patterned injury in porcine skin and the interpretation of the combination of quantified characteristics of the dental arches making up the initial data set. Additionally information regarding intersecting angles formed by extending incisal lines to adjacent and cross arch teeth accounted for the ability to accurately access rotations when the native curve could not be generated. In doing so, the criticisms of past investigators regarding bias, distortion, replication and interpretations were addressed. Ball introduced the basis for errors in utilizing an acetate overlay technique in bite mark pattern analysis in which a sheet of acetate paper is used to trace the biting edges of and then comparing those visually to a patterned injury.[34] Errors in digital photography, the lack of standardized methodology, subjectivity in generating overlays, problems with accuracy and problems with reproducibility along with photographic distortions, and the reliability of computer generated overlays were among the most significant criticisms. Ball concludes that a standard was not established by this method alone. [34]

The initial portion of this study focused on creating a bite pattern in porcine skin that could be quantified. In order to accomplish this goal, a method of delivering a force that could provide a distinct pattern in skin was developed. There have been numerous studies that have reported bite forces in the anterior tooth region that range from 20-22 PSI to 122 PSI. [15] [35] [36] [37]. The forces are influenced by numerous factors. Koc et al described these influential factors as pain, gender, age morphology and the individuals existing occlusion pattern. [38] Our determination of bite force needed to create a patterned injury was based on our findings of a range between 25 and 131.1 PSI was consistent with these reports. Calibrating each device and measuring forces inflicted during the biting process added consistency and repeatability to the process of creating a bite that would closely replicate an actual event. As Koc, et.al. concluded: "….recording devices and techniques are important factors in bite force measurement Therefore, one should be careful when comparing the bite force values reported in the research." [38] The use of a Flexiforce® transducer (FlexiForce®, Tekscan Inc., South Boston, USA) has been previously reported. [21] Because the scale established thru the Phidgets device did not report in pounds per square inch, the FlexiForce® sensor imbedded in each set of the 50 pattern replication devices required calibration prior to each pig session. This insured that forces applied were within the physiologic range and consistently applied.

Porcine skin has been established as an in vivo model for human skin. [17] A number of citations in the literature point to distortions common to patterned injury evaluation in skin. [39] [40] Sheasby and MacDonald reported on a classification system. [39] They concluded that distortion can occur at various stages during the biting process. If it occurs at "the time of biting" they defined this as "primary distortion." [39] If distortion occurs subsequent to the biting, this was defined as "secondary distortion." Sheasby and MacDonald further point out that primary distortion can occur either as a dynamic or as a tissue component. Distortion is produced by the dynamics of biting and depends on the degree of movement during the process. If movement is absent or slight a static bite mark may result. With extreme movement the bite mark appears distorted and linear striations (scrape marks) may be present. Additionally they point out that the quantity of tissue is taken into the mouth may produce "tenting" of the tissue which results in dimensional changes in the skin. They also classify three categories of secondary distortion. These would be distortions that are time related, posture distortion and photographic distortion. .An exact match in arch size is fortuitous and unpredictable. Exact superimposition is only possible in bite marks exhibiting minimal distortion and size matching techniques are only applicable to bite marks exhibiting minimal distortion. The incidences of discrete morphological points of comparison or distinctive features in a bite mark are the most significant criteria in bite mark analysis since they are relatively immune to distortion. As the degree of distortion increases, bite mark analysis relies progressively more on distinctive features [39]. This project aimed at producing as little distortion as possible. Pigs 1, 2 and 3 demonstrated the distortion and lack of pattern production in a dynamic bite (see Figure 41) further evidence that, underlying tissue morphology can also impact bite mark interpretation. [27]

Figure 40. An illustration of the lack of a distinct pattern in a dynamic bite.

Kieser et al, characterized the uniqueness of the human anterior dentition. [41] The authors found uniqueness of the anterior dentition in both arches based on geometric morphometric analysis of individuals that were selected because they had similar orthodontic treatment, making their dentitions similar at the onset of the investigation. The geometric morphometric analysis focused on capturing subtle differences about

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morphology and spatial locations of the anterior teeth in both arches The study supported the findings of Rawson's initial study which concluded that certain characteristics occur that are inter related. These include, shape, number, mesio-palatal rotations and restorations. [42] These results were substantiated by our initial investigations. [2][3][5][10]. Not used in prior investigations was the concept of measuring angles formed by the intersecting extension of a line drawn on the incisal edge of each of the 4 anterior teeth in each arch. These were computed by placing markers directly opposite of each other on the mesial and distal outline of the teeth in a recognizable patterned injury. The principle of intersecting angles being that parallel lines do not cross and line segments continue past the incisal widths to intersect in a two dimensional photograph regardless of curvatures in the skin. Thus the concept of intersecting line angles is based on this incisal line, which the authors define as a straight line across the incisal edge of the teeth connecting the mesial to the distal most point on the tooth's biting (incisal) edge. This line intersects with adjacent incisal lines of the other anterior teeth at a measurable angle and is graphically represented in figures 41.


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Figure 41. Extension of the incisal lines of the anterior teeth eventually intersect with an adjacent incisal line, forming a measureable angle. The angles of intersection for the maxilla are illustrated in this image. Intersecting incisal lines forming angles AB, AC, AD, BC, BD and CD in the four maxillary incisors. Tooth 10=A, Tooth 9=B, Tooth 8=C Tooth 7=D.C (Actual photo on right is a scaled view of figure 28 for comparison)

Reliability enters into any discussion of the comparative sciences. A number of authored opinions are critical of such issues as the direct comparison methods [43], the lack of reporting of error rates [44], the claims of uniqueness [45] and the reliability of testing. [46]. In addition, photographic techniques have been questioned. The American Board of Forensic Odontology has established among their guidelines one that address distortions in photography. [48] These and SWIGIT guidelines were rigorously followed in the documenting of the photographic images used in this study. Within this study were the inter operator error rates established for the known group of data. As reported by using two methods of statistical analysis inter-operator agreement was 0.984 in the known population, using Pearson correlation and within 1% of each other when calculating the population closest to the target using distance metric analysis. Because the individual characteristics of the human dentition do not transfer equally, the authors recommend using all the characteristics previously cited in the literature in analyzing a patterned injury. The substrate in which the pattern occurs will dictate the weight given to each characteristic. In this study, widths were not transferred from the natural dentition to the porcine skin as readily as the characteristics of intersecting angles. For porcine skin, the characteristics of intersecting angulation, displacement, individual missing teeth, rotations, spacing or diastemas and angulation of teeth to the x/y axis if posterior teeth are in the pattern, visually appear to transfer well and need further analysis . Tom's Toolbox has proven to be a valuable asset in quantifying individual patterns. The authors suggest that for the imaging specialist it can serve as asset in initial evaluation of bite patterned injuries.

Implications for policy and practice.

Interest in the forensic value of patterns caused by human teeth (bite marks or tooth marks) has a long history. Anecdotal history records Agrippa recognizing the decapitated head of a rival from a peculiar tooth. Early in legal history, tooth patterns were used to authenticate a document by having the responsible official bite into the sealing wax when it was applied to the document. The literature later records the use of dental charts and radiographs in human identification. The value of patterns produced by teeth (bite marks) have long been considered by many scientists world-wide, as possible identifiers of the individual. It is assumed by most dentists, that the characteristics of the human dentition are unique to each individual. Evidence in the research literature supports this concept. [42],[43],[44],[45],[46] Disagreements exist between scientists occur over whether these unique patterns of the human dentition, if true, can be replicated in human skin. Although human tooth patterns can and have occurred in inanimate objects, those that that are present in human skin, because of its viscoelasticity, present the most difficulties in interpretation. Several variables can and do occur. Distortions, either dynamic or photographic are the most common problems. The ABFO Standard Reference Scale #2 with its three circles, was developed by George Hyzer and Thomas Krauss and provided a means of detecting and correcting moderate photographic distortion. It is broadly accepted in evidence photography [47]

The production of a legible pattern replicating the pattern of teeth in skin depends upon multiple factors in addition to the substrate and the mechanism. Firm substrates such as cheese, soap, plastic and leather, to cite several media, register dimensions best. The mechanism can be divided into two categories; dynamic and static. Dynamic distortion occurs when there is movement by either or both victim and assailant. Static distortion occurs less commonly and in the opinion of the authors occurs more often in the pattern of the lower teeth since the mandible is not fixed in position, as is the maxilla. Another variable, even in a static bite is the degree of elasticity in the skin and the inability to capture the exact dimensions of the teeth. The evidentiary value of the injury pattern can be influenced by the amount of distortion in the injury pattern. Even when agreement exists in the analysis of a pattern between all examiners, there is still a need for a scientific level of confidence for the opinion. This research is only a template for continued research. It is not the Rosetta stone. Continued research to develop this relatively new applied science of pattern analysis should not be stifled. The National Academy of Science Forensic Report in 2009, *Strengthening Forensic Science in the United States: A Path Forward*, recommended that scientific methods be initiated in all of the comparative sciences. [1]

Whether dental characteristics are reliably replicated in a bite mark in human skin and whether the replicated pattern can be correlated with a degree of probability to the source is the current challenge. Several recently published studies have demonstrated that at least seven characteristics of the human dentition can be quantified. [2] [5] [10] A data set quantifying eight dental characteristics, in both two and three-dimensions, has now been developed from research and published by the authors.

The scientific validation of the correlation of bite marks, or tooth patterns to their origin, in the opinion of the authors, predictably will be established by statistical / mathematical probability. That is, which combination of outlying characteristics demonstrated in a pattern(s) would reliably predict the probability of another individual in the population having the same combination of dental characteristics? For those images of the patterned images that include all six anterior teeth, or even several teeth that enable the investigators to insert markers, measurements were saved in Tom's Toolbox©, calculated, saved in an internal data set and an internal report function ranks the combination of characteristics in percentiles. The application also established outliers for those specific characteristics.

Prior to this report, to accomplish the frequency distribution of the dental characteristics, which make each individual's dentition individual, a series of studies were instituted to establish a methodology for quantification in both two and three-dimensions. This methodology was utilized to build a dataset of seven dental characteristics. Additional research established the reliability of the measurements, testing both intra-operator and inter-operator agreement in analysis. The initial quantification of width, damage, angles of rotation, missing teeth, diastema characteristics (spaces) and arch length were subsequently augmented by a study of displacement of the anterior teeth, either labially or lingually, from the normal physiologic dental arch form. A three- dimensional study of the width and incisal position of the anterior teeth on the horizontal (Z) plane supplemented the data. This study adds a practical application of the data set. An additional geometric approach to determining the angles of rotation of the four maxillary and mandibular incisors was developed. This concept utilizes the measurement of the angels at the intersection of the incisal lines, projected through the mesial and distal markers of each of the incisors. This geometric method of determining rotation through the measurement of the intersecting angles of the incisal lines is beneficial for several reasons. First, it eliminates subjective establishment of a base X axis. It is also more universal. One or more teeth may be missing or indistinct. If two or more anterior teeth can be identified (e.g. tooth 7 and 9), computation of the angle of intersecting lines can still be determined. This method of establishing tooth rotation also provides an expanded scope of search analysis, since it includes two additional characteristic items. In the earlier studies when an x axis could be established, we were able to determine four angles of rotation. With the alternate method of utilizing the intersecting angles formed by the incisal lines, enable the measurement of six angles of rotation.

Although the width of the teeth in injury pattern in skin may be less exact than that of the known source, the intersecting angle formed by the extension of the incisal lines remains a constant. Most significant in establishing the degree of probability of a correlation will be the presence of multiple outliers in these angles. This procedure adds four additional characteristics to enable statistically the probability of a correlation between the unknown and a known source.

The interpretation of the combination of quantified dental characteristics making up the initial two-dimension data set, also utilized the data obtained in the three-dimensional study, since the anterior teeth are not always all at the same level of eruption (Z plane). In doing so, the questions regarding whether certain teeth were present or missing in a patterned injury cited by past investigators were addressed.

In more than 20% of the Samples in this study, the Distance Metric Model found the Target within the closest 5% of the sample population. In more than 6% of the Samples, it found the Target within the closest 1% of the Population.

Implications for further research

This study demonstrates that it is sometimes possible to replicate patterns of human teeth in porcine skin and determine scientifically, that a given injury pattern (bite mark) belongs to a very small proportion of our population data set, e.g. 5%, or even 1%. Predictably, building on this template, with a sufficiently large database of samples reflecting the diverse world population, a sophisticated imaging software application requiring operators inserting parameters for measurement and additional methods of applying forces for research need further investigation. This is applied science for injury pattern analysis and is only foundational research. It should not be cited in testimony and judicial procedures. It is intended to supplement and not contradict current guidelines of the American Board of Forensic Odontology (ABFO) concerning bite mark analysis and comparisons. A much larger population data base must still be developed. This research serves as a template, refining the ability to scientifically calculate that an unknown bite mark replicated in skin can correlated with probability to a member of the population data base. This template does not limit future researchers to use specific imaging software or pattern replication apparatus. All of the research materials and records will be maintained by Marquette University for a period of three years for repeatability of the study. The authors encourage questions and challenges.

1. Marquette University School of Dentistry; 2. Medical College of Wisconsin; 3.Marquette University College of Engineering; 4.Wisconsin Department of Justice, Crime laboratory, (retired).

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Dissemination of Research Findings

1. A one hour summary of the research was presented to the Marquette University School of Dentistry faculty and students, July 16, 2013, Milwaukee Wisconsin.
2. A one hour summary of the research was presented to the graduate students and faculty in the Department of Biomedical Engineering, Marquette University, College of Engineering on November 12, 2012.

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3. A one hour PowerPoint summary of the research findings was presented at the 97th Annual Educational Conference of the International Association for Identification, on August 5, 2013 at Providence, Rhode Island.
4. A lecture capture video of the research has been recorded for dissemination via a link posted on several forensic organizations' web pages is being prepared for distribution. The Midwest Forensic Resource Center and other forensic organizations have been approached requesting that they post a link to the video on their web sites.
5. Overtures have been made to the National Association of Medical Examiners (NAME) and regional / state divisions of the International Association for Identification as possible educational presentations.

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EXHIBIT C
APPENDIX I

Bite Mark Evidence: Its Worth in the Eyes of the Expert

Pamela Zarkowski, MPH

Abstract

Comparison of bite marks at the scene of a crime or on a victim's body with the dentition of a suspect has been used as evidence to connect a suspect with a crime. Courts accepting such evidence have usually done so using the *Frye* standard for admissibility of scientific evidence. In the opinion of the author, this has led to an overdependence on expert testimony and an overestimation by the courts of the accuracy of bite mark analysis. Despite recent attempts on the part of the dental profession to standardize bite mark analysis and produce more reliable results, bite mark analysis remains somewhat subjective and equivocal. The author suggests that admissibility of bite mark evidence should be considered under the *Federal Rules of Evidence*, which provides guidelines for the admissibility of evidence and expert testimony, rather than by the *Frye* standard. (*J Law Ethics Dent* 1988;1:47–57).

Novel scientific procedures used in criminal cases take several different forms. The admissibility of identification through fingerprints, for example, was one of the earliest novel scientific procedures.[1] Bite marks, like fingerprints, fall within the category of novel scientific procedures. Bite marks are the impressions or indentations, striations or other markings left by the teeth in a softer material, such as skin, food or inanimate objects.[2] Proponents of bite mark evidence have sought to use such evidence to show that bite marks on the victim's body or elsewhere match the suspect's bite or dentition and thus connect him or her with the crime.[3]

Courts have adopted special rules for the admissibility of scientific evidence. The most common rule is known as the *Frye* standard.[4] The admissibility of bite mark evidence cannot be considered without understanding the impact of the *Frye* standard and admissibility of scientific evidence in general.

This report will begin with the *Frye* standard, since bite mark evidence may be classified as scientific evidence. Next, the gradual judicial acceptance of bite mark evidence and the current status of bite mark identification as a scientific procedure is explained. Finally, this article proposes that the admissibility of bite mark evidence not be considered under the *Frye* standard, but instead under standards in the *Federal Rules of Evidence*.

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The Frye Standard and Admissibility of Scientific Evidence

In *Frye v United States*,[4] the District of Columbia Circuit Court of Appeals originated the standard for admissibility of scientific evidence.[5] *Frye* was a murder prosecution in which the defendant unsuccessfully sought to introduce the results of a systolic blood pressure deception test, a forerunner of the modern polygraph. Prior to the trial, the defendant passed the deception test. The test was based on the theory that telling the truth is spontaneous and without conscious effort and that lying is a conscious effort reflected in the blood pressure.[6] The scientist who conducted the test was not allowed to testify as an expert witness. Defense counsel's offer to have the prospective witness conduct the test in the presence of the jury was also denied. On appeal, the defendant challenged the trial court's decision. The court of appeals rejected the defendant's challenge, holding that the test had not yet received recognition in the scientific community.[7] To justify its exclusion of the test results, the court fashioned a new rule, which came to be the standard for admissibility of novel scientific evidence. The test for admissibility of scientific evidence has three requirements: (1) the scientific principle must be recognizable; (2) the principle must be sufficiently established; and (3) the principle must have gained particular acceptance in the field to which it belongs.[8]

The importance of the *Frye* rule was not initially apparent. In 1923, the scope of *Frye* was limited to the question of the admissibility of evidence from a unique procedure, the systolic blood pressure deception test. The opinion was brief and offered no authority for the rule it announced. Initially, *Frye* was construed as limited to its own facts. Nonetheless, the rule gradually spread through state and federal courts and became the generally accepted legal test for the admissibility of all novel scientific evidence. The *Frye* test has controlled the admissibility of scientific evidence for more than half a century.[9]

Current Status of the Frye Test

Although the *Frye* standard has dominated the admissibility of scientific evidence,[9] the current status of the *Frye* test is difficult to ascertain. The *Frye* test has been rejected by some federal[10] and state[11] courts. However, considerable support remains for the *Frye* test, although it is often narrowly interpreted by the courts.[12] Courts have modified the *Frye* test, and in fact have created "*Frye* tests" to fit particular circumstances of each case.[13] Courts using *Frye* as the standard have also required proponents of scientific evidence to show the reliability of the scientific principle or technique.[14] In *People v Kelly*,[15] for example, the California Supreme Court stated that admissibility of expert testimony concerning the application of a new scientific procedure must satisfy a two-step scrutiny. The reliability of the method must first be established by expert testimony; then the witness must be properly qualified as an expert to give an opinion on the subject.[16] The *Kelly* court, although using the *Frye* test as the standard, emphasized the role of the expert witness. Proponents of the *Frye* test recognize four effects of the standard: (1) it assures uniformity in evidentiary hearings; (2) it allows appellate court decisions concerning the admissibility of new scientific developments to serve as precedent for future trials; (3) it protects against juries treating novel scientific evidence as infallible; (4) it excludes novel evidence until a pool of experts is available to evaluate it.[17]

Critics of *Frye* argue that the standard is too conservative and unduly prevents or delays the admission of relevant scientific evidence.[18] Another difficulty inheres in the "general acceptance" prong of the test.[19] Courts applying the general acceptance test must define the standard. The difficulty for the courts is in deciding who must find the procedure acceptable, the appropriate field or fields to which a particular technique belongs, and what types of evidence are subject to the *Frye* standard.[20] Despite the *Frye* test's apparent simplicity, distinguishing "scientific evidence" from other areas of expert testimony is difficult.[21]

Some commentators suggest alternatives to the *Frye* test.[22] The adoption of the *Federal Rules of Evidence* raised further questions about the need for the *Frye* standard.[23] Courts must decide whether the *Federal Rules of Evidence* replace or complement the *Frye* standard.[24] Nevertheless, the *Frye* standard remains a critical factor in the admission of bite mark evidence.

Bite Mark Cases Ignoring the Frye Standard

The evolution of bite mark evidence as an acceptable scientific procedure began slowly. The early cases either ignored or were unaware of the *Frye* standard. The first bite mark case did not appear until 1954. In *Doyle v State*,[25] the state charged the defendant with the burglary of a grocery store. The state attempted to admit as evidence a piece of the grocery store's cheese, claiming that teeth marks in the cheese matched the defendant's teeth marks. To compare bite marks in the cheese with the defendant's teeth marks, the defendant voluntarily bit into a piece of cheese while in custody. The two pieces of cheese were taken to the Department of Public Safety and a firearms examiner testified that he photographed both, took plaster of Paris impressions, and gave his opinion that, from caliper measurements, both pieces of cheese had been bitten by the same set of teeth.[26] A dentist also testified, after he examined the plaster casts and photographs, that the same man bit both pieces of cheese.[26] The court held that the evidence supported conviction.[26] The court did not state the criteria used for admissibility of the bite mark evidence or the qualifications of the experts. The defendant never questioned the expertise of the firearm expert to compare models of teeth. The question on appeal was whether the defendant failed to receive a warning that biting into the piece of cheese constituted a confession. The court saw no distinction between bite mark evidence and footprint or fingerprint evidence.[27]

Bite mark evidence gained wider acceptance and its use became somewhat more sophisticated in the 1970s. In a 1972 decision, *People v Johnson*,[28] the prosecution tried to admit into evidence a cast of the defendant's teeth and photographs of teeth marks on the victim's breast. A dentist and an oral pathologist testified as expert witnesses.[29] The oral pathologist testified that it was highly probable that the teeth marks were the defendant's. However, the court did not list the criteria for the evaluation and comparison of the cast of the defendant's teeth with the photographs.[29] On appeal, the court found no error in using the cast and photographs and did not question the integrity of the exhibit, presumably the teeth casts and photographs.[29]

Dentists began testifying as expert witnesses in the 1970s, although little forensic dentistry is taught in dental education.[30] In *Patterson v State*,[31] the defendant was found guilty of murder. The appeal raised two issues on the admissibility of bite mark evidence. The first was whether requiring the defendant to produce a mold of his teeth violated any constitutional rights, and the second was whether the testimony comparing teeth marks on the deceased's body with defendant's teeth marks and mold was properly admitted. The court held that requiring the defendant to produce a mold of his teeth did not constitute a search or seizure under the Fourth and Fourteenth Amendments.[32] The defendant also argued that evidence of testimony comparing teeth marks on the deceased's body with teeth marks on the mold were not sufficiently scientifically proven and, therefore, were not reliable. During the trial, four expert witnesses reached four different conclusions. Specifically, the issue in *Patterson* was whether a bite mark on the victim's severed left breast matched the defendant's teeth. The dentists testifying gave conflicting testimony. One dentist asserted that bite marks were as unique as fingerprints and compared the bite marks by placing a mold of the defendant's bite on the wound.[33] A second dentist said marks on the breast may have shrunk or stretched by 0.7 mm.[33] Still another dentist was unable to match the mold of the defendant's bite with the wound, but matched a mold of one of his patients;[33] and a final dentist stated that accurate measurements of the distance between marks on the breast could not be obtained.[33]

The court, however, citing *Doyle*,[26] noted that bite mark evidence had been held admissible and therefore allowed the testimony, noting that the objection went to the weight rather than admissibility of the testimony.[34] The court gave no further elaboration for its decision to allow the inconsistent and diverse testimony of the dental experts.

Bite Mark Cases Relying on the Frye Standard

The *Frye* standard's first application was in *People v Marx*.[35] There, the court admitted the testimony of three expert witnesses for the prosecution, who used different analytical techniques, but testified that the defendant's teeth matched the bite mark on the victim's nose. The experts compared a dental cast of the defendant's teeth with a cast of the bite mark on the victim's nose taken when the body was exhumed, six weeks after the autopsy.[36] The experts testified that it was possible to identify a person from his dentition, and that there were enough similarities to match the defendant's dentition with the victim's wounds and to eliminate others as suspects.[37] The court found the defendant guilty of voluntary manslaughter in the death of an elderly woman.[38]

On appeal, the defendant attacked the admissibility of evidence, which included dentists' testimony and many exhibits, questioning the experts' ability to prove identity from similarities between the defendant and the bite mark on the victim.[39] The court of appeals conceded that an established science of identifying persons from bite marks, as distinguished from identifying persons from dental records or x-rays, did not exist.[39] But the court applied the "general acceptance by recognized experts in the field" prong of the *Frye* standard.[40] After reviewing the rationale of *Frye*, the court concluded that the general acceptance standard was not determinative of the admissibility of the expert testimony as distinguished from the weight of the expert testimony.[41] The court held that, because the experts did not base their conclusions on what the court perceived as untested methods, but rather on scientific and professionally established techniques, the expert testimony was properly admitted.[42] The court of appeals noted that the trial court could observe models, photographs, x-rays and slides of the victim's wounds and defendant's teeth and concluded that this access to physical evidence maintained the court's independence and common sense in evaluating the evidence.[43]

The general acceptance prong of the *Frye* standard may or may not imply that experts must have reached unanimous agreement within their particular scientific field. The issue of whether unanimity within the field was required arose in *People v Milone*.[44] On appeal for a murder conviction, Milone argued that bite mark identification was not proven to be sufficiently reliable to permit its admission into evidence.[45] During the bench trial, over 1300 pages of dental testimony and numerous exhibits were admitted into evidence.[45] The prosecution's witnesses stated that bite marks on the victim's thigh were proof positive that the defendant orally inflicted the injury.[46] The expert witnesses for the defense, on the other hand, stated that it was easier to *exclude* a suspect through marks left by his teeth.[47]

The defendant argued that the testimony of the four forensic odontologists[47] who testified on his behalf should carry the greatest weight because it supported the defendant's argument about the unreliability of bite mark evidence. All four experts pointed out areas of inconsistency and, therefore, no certain correlation existed between the bite mark and molds of the defendant's teeth. Thus, the experts testified that a positive identification could not be made. They also specifically said the defendant was not the person responsible for the bite marks on the victim. The state's witnesses, however, steadfastly held to the contrary.[47,48]

Looking to the *Frye* standard, the defendant argued that the science of bite mark identification failed the *Frye* requirement of general acceptance in the field. The defendant offered statements by forensic odontologists who stated that bite marks can never reproduce accurately the dental features in the originator.[49] The court held, however, that a lack of unanimity in the medical profession did not mean that such testimony failed to satisfy the requirement in *Frye*.[50] The premise of the court's holding was that, unlike other scientific tests, which may involve subjective interpretation, bite mark evidence involves only a visual comparison between the wound and dentition of the defendant.[51] Expert testimony provided assistance to the trial court in interpreting physical evidence not within the average trial judge's knowledge.[51] Bite mark evidence has no intermediate stage where reliability can be questioned.[51] The court noted, although it did not offer any proof, that great care is taken to preserve and gather physical evidence, which ensures the quality of the exhibits. Bite mark evidence is more analogous to footprint, fingerprint and hair comparisons because all are made for purposes of identification.[51] The court cited other decisions allowing bite mark evidence and concluded that each person's dentition is unique. The concept of identifying a suspect by matching his dentition to a bite mark, the *Milone* court noted, is a logical extension of the principle that each person's dentition is unique.

Both the *Marx* and *Milone* courts carefully reviewed other decisions holding that bite mark evidence is admissible. In some instances, courts have admitted bite mark analysis as evidence, while recognizing its limited application.[52] However, courts have not been consistent in their application of the *Frye* standard. Whereas the *Milone* court stressed the lack of an intermediate mechanical stage which could affect the reliability of bite mark evidence, the California Court of Appeals interpreted *Frye* to guarantee the correct use of scientific procedures.

A significant contribution found in *People v Slone*[53] was the court's development of a new test for bite mark evidence. In *Slone*, the court admitted a bite mark comparison between the defendant's dentition and bite marks on the victim's thigh. The *Slone* court,[54] applying both *Frye*[55] and *Kelly*,[15] enunciated its own three-prong test for admissibility of bite mark evidence: (1) the reliability of the method must be established by expert testimony; (2) the witnesses furnishing the testimony of scientific acceptability and reliability must be properly qualified as experts; and (3) the prosecution, as proponent of the bite mark identification, must demonstrate that correct scientific procedures were used.[56]

The defendant in *Slone* argued that the comparison technique was not scientifically reliable because of lack of proof that the individual dentition is unique.[56] The court disagreed, but did note that even in the most carefully structured scientific inquiry, a probability factor is present. Therefore, the admissibility of scientific test evidence need not be predicated on 100% accuracy.[57]

A detailed description of forensic dentistry,[58] as well as an appendix of materials about bite mark evidence, is set forth in *State v Sager*.[59] According to the *Sager* court, bite mark identification is an "exact science."[60] The court outlined in detail the procedures used to obtain a cast of the defendant's teeth[61] and the methods used for comparison of the bite marks with the defendant's dentition.[62] The court stated, although two expert witnesses reached opposite conclusions, that factual and reliable evidence is important as a basis for expert testimony.[60] The appendix, the number of expert witnesses, and the dictum reflected the court's strong belief in the scientific accuracy of bite mark evidence. The court recommended that bite mark evidence be recognized as an acceptable type of scientific evidence in criminal proceedings.[63] However, questions about bite mark analysis as an exact science remained in other jurisdictions.

In *State v Kleypas*,[64] after the defendant was found guilty of murder, he requested that testimony provided by a dentist as an expert witness be removed from the record because bite mark analysis was not a recognized science. The Missouri Court of Appeals, however, relying on *State v Sager*,[58] held that the science of forensic odontology had met the *Frye* standard for admissibility of scientific evidence.[65] The *Kleypas* court studied the use of "comparison" as it applied to bite mark analysis. The court said the issue in *Kleypas* was the identification of the perpetrator of a crime by a comparison of marks or traces found at the crime with the physical characteristics of the defendant.[66] A comparison, according to the court, has two aspects. The first aspect is the means and techniques used in determining similarities or differences. If a scientific process is involved, the means and techniques must meet what has been determined as the required standard for the scientific process.[66,67] The second aspect of identification by comparison is a determination of whether the points of similarity are so unusual that the mark was obviously made by a specific object.[66] Because bite marks require a comparison, the court concluded that the identification of bite marks was similar to the identification of footprints or fingerprints.[66] The court based its decision on its somewhat philosophical discussion of comparison and held the evidence admissible.

The court of appeals saw the comparison technique used in bite mark analysis as a simple, straightforward process. Unlike other, more complicated scientific processes or techniques, bite mark evidence was compared to matching a footprint with a shoe.[66] The court, citing *Milone*,[68] again reiterated the lack of any intermediate stage that could affect reliability. The court stressed the simplicity of the concept of bite mark comparison in an almost naive way and relied on this belief in admitting evidence.

Bite mark evidence has been held admissible in most jurisdictions.[69] The number of courts accepting bite mark evidence suggests that, as an acceptable scientific procedure, it has withstood judicial scrutiny. There are no reported cases where bite mark testimony has not been allowed.

The Dental Profession's Contributions to the Reliability of Bite Mark Analysis

Although bite mark comparison appears relatively simple, it is becoming a more exact process. The dental profession has recently responded to criticisms and questions about the reliability of bite mark comparisons.

In an attempt to standardize a scientific approach to bite mark analysis, the American Board of Forensic Odontology adopted in 1984 *Guidelines for Bite Mark Analysis*,[70] which outlines information that should be collected and recorded by individuals responsible for collecting bite mark evidence. The guidelines are divided into four general categories: description of bite marks; collection of evidence from the victim; collection of evidence from the suspect; and analysis of evidence.[71]

A somewhat specific description of the *Guidelines* is given to show the extent of the information collected in each of the categories. According to the *Guidelines*, investigators should initially record the victim's demographic information including age, race and sex.[71] Also recorded is the location of the bite mark including the anatomical location, surface contour, nature of the underlying bone structure, and relative mobility of skin. The shape of the bite mark is described also.[71] The vertical and horizontal dimensions of the bite mark as well as the color of the injury are recorded.[71] Also described, for comparison purposes, is the type of injury, such as a contusion, abrasion, laceration, and whether the skin is indented or smooth.[71] Collection of evidence from the victim consists of photographs, salivary swabbing, impressions of the surface of the bite mark, and tissue samples.[71,72] Photographs are taken, black and white and color, at both distant and close-up angles. Photographs include the use of a scale so the entire field can be visualized. The information collected from the suspect includes photographs inside and outside the mouth, impressions of the teeth, and study casts, which are plaster-like models of the teeth.[72] In addition, a careful extraoral examination is performed in which biting dynamics, ability to open and close the mouth, and muscle tone and balance are observed.[72] In an intraoral examination of the suspect, saliva samples are collected, tongue deviations and periodontal status are observed, and dental charting is done.

The *Guidelines* of the American Board of Forensic Odontology do not mandate specific methods of analysis for comparison. They suggest that, as part of the analysis, findings are evaluated with consideration of gross features, such as size and shape of the arches, tooth position, and unique tooth features. To analyze data collected, a scoring guide and point system rates the number of teeth present, tooth position, and intradental features.[73] The basic premise of the *Guidelines* is that, if a uniform method of measuring the weight of evidence is achieved, it may be possible to determine the quantity of evidence that is required to consistently determine the validity of a match. Although the *Guidelines* are detailed and technical, the procedures are far more sophisticated than comparing bite marks in two pieces of cheese and are designed to improve efforts for documenting dentally related evidence on a consistent basis.

Although some commentators endorse bite mark evidence,[74] many others are critical.[75]

Studies have verified the individuality of the human dentition.[76] The methods for analyzing bite mark evidence are becoming increasingly sophisticated.[77] For those who are not dental professionals, resources explaining basic dental concepts and methods used to obtain models, records and photographs are also available.[78] The dental profession has made some progress to increase the reliability of bite mark evidence. However, most of these studies remain within the realm of the dental profession. Therefore, lawyers and medical examiners are unaware of these advances are still use outdated or limited methods for obtaining and analyzing bite mark evidence.

Bite Mark Analysis

Case law documents the progressive acceptance of bite mark comparison and brings us up to date on the status of bite mark evidence. Concurrently, the dental profession, primarily within the last ten years, is making sophisticated attempts to improve the technology associated with bite mark comparison and thus improve its accuracy and reliability. The improvements in bite mark technology are restricted to the realm of dentistry, and therefore the courts have been unaffected. Instead, the courts have continued to rely on expert testimony and presentation of evidence with little reservation.

In reviewing the legal decisions involving bite mark evidence and the dental literature, certain problems become evident. The first is a reliance by courts on the *Frye* standard and their consequent inaccurate assumption that bite mark analysis has reached a level of accuracy to warrant labeling it a novel scientific procedure. The second problem is the sole reliance on expert testimony and the experts' conclusions. Courts have given little consideration to questions about when or under what circumstances a bite mark was inflicted or in what matter and by whom the evidence was collected prior to the dental expert's analysis. To mitigate these two problems, it is proposed that bite mark evidence be considered using the *Federal Rules of Evidence* as a framework, and that the judicial system carefully scrutinize all aspects of bite mark analysis, including evidence about the circumstances in which the bite mark occurred, the information collected, and the dental expert involved.

Bite Mark Evidence: An Inaccurate Science

The acceptance of bite mark analysis as a scientific procedure evolved from a weak beginning. Although frequently categorized as a "scientific procedure" under the *Frye* standard, bite mark analysis did not progress through an experimental phase as other scientific procedures have done.[79]

At its initial acceptance in 1954 by the *Doyle* court,[24] bite mark evidence never progressed through a testing phase to measure its accuracy and reliability. Each court faced with the admissibility of bite mark evidence looked to other decisions to guide its analysis. Experiments were not conducted, nor were techniques tested, to apply the theory of bite mark analysis and evaluate the concept. The courts looked to experts for their interpretation of bite mark evidence and relied significantly on that expert testimony. In the earlier cases, the "experts" ranged from a firearms examiner in *Doyle*[24] to dentists with impressive lists of credentials in *Milone*.[80] However, although credentials varied among the experts, the bite mark evidence was held admissible. Subsequent cases admitted evidence without carefully studying the particular expert dentist involved and her or his credentials or expertise. Nor did these courts seriously question the propriety of such testimony.

The strong reliance on expert witnesses found its support in the one prong of the *Frye* standard frequently emphasized, specifically, the general acceptance standard. The emphasis on general acceptance directed courts, either by choice or because of a defendant's objection, to concentrate on bite mark analysis and its acceptability whithin the dental profession. The focus on acceptability within the profession resulted in the courts not questioning any other aspects of the technique required for bite mark analysis or comparison and therefore accepting the evidence without considering its accuracy or reliability.

In some instances, a court would state its belief that bite marks were like fingerprints and therefore were an acceptable source of identification. In offering the analogy between fingerprints and bite marks, the court offered no justification or evidence, other than the court's own discretion. The acceptance of bite mark evidence seemed to be premised on the assumption that anatomical configurations, like fingerprints, are unique to each individual, although support for this belief was not apparent. Recently, however, a study suggests that each human dentition is unique.[75] One article reports that two individuals had almost identical bite mark patterns.[81] Although the interpretation of bite mark evidence seems to have reached the level of a scientific procedure, some aspects of the analysis still raise doubts about its accuracy and reliability.

Bite Mark Evidence: Questions About Accuracy and Reliability

Bite mark evidence must be considered in light of the circumstances in which the wound(s) occurred and the manner in which the evidence about the bite mark was collected. The courts have ignored these two considerations and often relied solely on expert testimony to guide its decisions.

The courts have ignored that a bite mark can occur in different circumstances and under a variety of conditions. A bite mark on a victim can be the result of intentional abuse, rage, sexual assault or passion. The degree of force used by the perpetrator varies depending on the reason for the bite. The body part upon which the bite is inflicted also may affect the appearance of the bite. Courts have not considered that variability in skin tautness and resiliency in different parts of the body may distort the size and appearance of bite marks. The nature of the skin and its underlying structures is critical in bite mark analysis. However, few experts address this issue, relying solely on the appearance of the wound, not the conditions under which it was inflicted. For example, because a high percentage of biting activity is associated with breasts and breast morphology varies, a classification system is necessary.[82] A classification system would recognize differences related to age, position, and tissue resiliency. Although a classification system would aid in calibrating information collected by different individuals, questions arise about the regulation and responsibility for developing classification systems.

The *Guidelines* developed by the forensic odontologists are dentistry's efforts to regulate and contribute to consistency in bite mark investigations. The assumption in the *Guidelines* is that an individual familiar with teeth and other intraoral structures will be collecting the data. However, a forensic odontologist or similarly skilled individual may not always be available. The information collected or recorded can be inaccurate because of lack of appropriate personnel.

The photographs and casts taken of the wound and of the impressions of the bite mark of the defendant will all be used in the bite mark analysis. Those decisions[69] that suggest that there is no intermediate stage that could affect the reliability of bite mark analysis fail to recognize all the potential areas for mistakes or misjudgment. During the collection of evidence related to the bite mark, many situations can occur that could affect the accuracy or reliability of the evidence. Therefore, aspects of bite mark analysis raise doubts about its scientific accuracy because of human error. The *Guidelines*[80] for collection of bite mark evidence appear to be objective in nature. However, each aspect of the *Guidelines* still contains subjective judgments. For example, at what angle or angles should a photograph be taken and what system of measurement should be used? In light of questions about its reliability, bite mark analysis should not be considered as a science, falling under the *Frye* standard, but rather in the realm of expert witnesses under the *Federal Rules of Evidence*.

Bite Mark Evidence Under the Federal Rules of Evidence

Although all states do not recognize the *Federal Rules of Evidence*, the *Rules* provide a model for admissibility of evidence and expert testimony. The acceptance of the *Federal Rules* suggests to some that the *Frye* standard is no longer the governing rule. Commentators have argued that the *Frye* standard supersedes the *Federal Rules of Evidence*.[69] Rule 401 defines relevant evidence as evidence "having any tendency to make the existence of any fact more probable than it would be without the evidence." Rule 402 provides that all relevant evidence is admissible. The requirement of a general acceptance standard prior to the admission of scientific evidence, as found in *Frye*, is not stated within Rules 401 and 402. Nor does the requirement of "general acceptance" appear in the *Rules* on expert witnesses. Rule 702 specifically mentions scientific testimony, linking it with expert testimony. Rule 703 allows an expert witness to base his opinion on data that need not be admitted into evidence, but again, the elements found in the *Frye* standard are not apparent. The Advisory Committee notes to the *Federal Rules of Evidence* also do not mention the *Frye* standard. The lack of a general acceptance standard in the *Federal Rules* could reflect the drafters' belief that the *Frye* standard for the admissibility of scientific evidence is replaced by the *Federal Rules* and need not be considered.

The Expert Witness Requires Careful Scrutiny

The trend of continued admissibility of bite marks as evidence since the 1950s means it acceptability as scientific evidence is likely to continue. Courts, looking to previous decisions, will accept the evidence with little concern about its accuracy or reliability. To counteract this tendency, courts must become more critical of both the expert witness and the testimony on bite mark comparison.

The testimony of an expert witness is somewhat predictable. Each side will solicit appropriate expert testimony for or against a particular issue. Accordingly, the reputation and experience of the expert witness in dental forensics must be scrutinized. The experience of the expert both in the practice of dentistry and in forensic odontology must be considered. The expert must be familiar with evidence collection and preparation, as well as the current state of the art of bite mark analysis. The expert witness needs a working relationship with the individuals, such as the medical examiner, who are responsible for gathering information following a crime and during the preparation for a trial. A dentist can possess a dental degree and have other credentials such as continuing education courses in forensic sciences, but be unfamiliar with the techniques or protocol used by a forensic team. A critical look at the expert witness and his credentials helps to shift the emphasis to the accuracy and reliability of bite mark analysis, rather than the general acceptance standard emphasized previously.

Careful Scrutiny of Evidence by Judges

Neither attorneys nor judges are uniformly familiar with scientific concepts or, more significantly, with the practice of dentistry. The admission of bite mark analysis as evidence will require careful scrutiny by judges. Judges can easily refer to the *Federal Rules* for direction concerning the admissibility and relevancy of evidence. However, with bite mark evidence, certain issues should also automatically be considered. Judges must evaluate whether a jury can correctly interpret the information presented without giving it undue weight. The field of dentistry, its technical language, and even the concept of a bite mark on a portion of the body, can confuse or influence the jurors. The judge can base his or her decision to admit the proffered evidence on what other evidence may be presented and balance whether the bite mark analysis is necessary to aid the jurors in reaching a verdict.

If bite mark analysis is admissible, then special jury instructions would help clarify the question of the weight of such evidence. The judge, in most situations, would be required to evaluate the admission of bite mark evidence on a case-by-case basis.

Admittedly, shifting the question of admissibility of bite mark evidence onto the judge places a greater burden on her or him. However, bite mark evidence is still not a perfected scientific method. The judge has the ability to review evidence and become familiar with the methods that were used to collect the evidence. Judges should serve as a screening mechanism and use the *Federal Rules of Evidence*, specifically Rules 401 and 402, as the standard for their decisions. In addition, a series of guidelines should be developed to aid judges in their evaluation of expert witnesses and their testimony, specifically aimed at novel scientific evidence.

Conclusion

Bite mark evidence must be used with caution in criminal cases. The *Frye* standard helped to introduce bite mark evidence into the courts. However, the *Federal Rules of Evidence* are better guideposts for admissibility decisions about bite mark evidence. Ever-changing technology in dentistry and other scientific fields requires judges to develop an expertise for screening expert witnesses and testimony about novel scientific procedures.

References

1. *People v Jennings*, 252 Ill 534, 96 NE 1077 (1911) (admissiblity of fingerprint comparison).
2. *Cottone J, Standish S: Outline of Forensic Dentistry*, Chicago, Year Book Medical Pub, 1982, pp 113–114. Bite marks are often found on the victim or on the perpetrator of a crime. Typically, crimes involving bite marks are cases where bodily harm has been inflicted.
3. *Sopher I: Forensic Dentistry* Springfield, IL, CC Thomas 1976 pp 3–4, 125. Forensic dentistry applies the science of dentistry to the field of law. Forensic dentistry comprises four areas: 1) dental identification of the unknown body, 2) bite mark comparison, 3) trauma and the oral tissues, and 4) dental malpractice and negligence. For a review of bite mark analysis and technique see also *Cameron JM, Sims BG: Forensic Dentistry*. New York, Churchill Livingstone, 1974, pp 129–145, *Furuhata T, Yamamato K: Forensic Odontology*. 1967, pp 97–103, *Harvey W: Dental Identification and Forensic Odontology*. Chicago, Year Book Medical Pub, 1976, pp 88–124; *Gladfelter IA: Dental Evidence: A Handbook for Police*. Springfield, IL, CC Thomas, 1975, pp 23–182; *Gustafson G:* Forensic *Odontology*. New York, Elsevier, 1966, pp 140–165; *Kelser–Nielsen S: Person Identification by Means of Teeth: A Practical Guide*. 1980, pp 9–72.
4. *Frye v United States*, 293 F 1013 (DC Cir 1923) (evidence from systolic blood pressure deception test not admissible).
5. Id at 1014:

   Just when a scientific principle or discovery crosses the line between the experimental and demonstrable stages is difficult to define. Somewhere in this twilight zone the evidential force of the principle must be recognized, and while courts will go a long way in admitting expert testimony deduced from a well-recognized scientific principle or discovery, the thing from which the deduction is made must be sufficiently established to have gained general acceptance in the particular field in which it belongs.
6. Id at 1013.
7. Id at 1014.
8. See supra note 6.
9. The *Frye* standard applies to many areas of scientific evidence See, eg, *United States v Tronowski*, 659 F2d 750, 757 (7th Cir 1981) (astronomical calculations of photograph supporting

alibi incorrectly admitted because of lack of general acceptance in the field); *Hughes v Matthew*, 576 F2d 1250, 1258 (7th Cir), cert denied, 99 US 43 (1978) (psychiatric testimony satisfies general test for admissibility of scientific evidence because sufficiently established and generally accepted); *Lindsey v United States*, 237 F2d 893, 896 (9th Cir 1956) (sodium pentothal, though generally accepted in field, not supported by scientific authority); *State v Smith*, 50 Ohio App 2d 183, 193, 362 NE2d 1239, 1246 (1976) (gunshot residue test not based on sound principles, nor accepted in field); *State v Thomas*, 66 Ohio St 2d 518, 521–22, 423 NE2d 137, 140 (1981) (no general acceptance of expert's methodology for battered wife syndrome established).

10. See, eg, *United States v Williams*, 583 F2d 1194, 1198 (2d Cir 1978), cert denied, 96 US 456 (1976) (spectrographic voice analysis reliable to warrant use in courtroom; *Frye* rejected).
11. See, eg, *Harper v State*, 249 Ga 519, 292 SE2d 389, 395 (1982) (sodium amytal; the *Frye* rule of counting heads in scientific community not appropriate to determine admissibility; not a test of general acceptance, but a stage of verifiable certainty); *State v Williams*, 4 Ohio St 3d 53, 446 NE2d 444 (1983) (voiceprints; admissibility of scientific principles based on *Fed R of Evid* 402, 403, 702); *State v Kersting* 50 Or App 461, 470–471, 623 P2d 1095, 1101–1102 (1981) (for acceptance of microscopic hair analysis, test must be reasonably reliable).
12. For a vigorous defense of *Frye*, see *Reed v State*, 283 Md 374, 391 A2d 364 (1978); *People v Kelly*, 17 Cal 3d 24, 549 P2d 1240, 130 Cal Rptr 144 (1976); *State v Addison*, 498 F2d 741 (DC Cir 1974). For examples of cases which still apply *Frye*, see, eg, *Commonwealth v Nazarovitch*, 496 Pa 97, 110 436 A2d 170, 177 (1981) (process of refreshing recollection by hypnosis not sufficiently accepted in field); *State v Canaday*, 90 Wash 2d 808, 813, 585 P2d 1185, 1188 (1978) (*Frye* applicable to determine breathalyzer test ampule admissibility). But see *United States v Rummell*, 642 F2d 213, 215 (7th Cir 1981) (no error in refusing polygraphs); *United States v Marshall*, 526 F2d 1349, 1360 (9th Cir 1975), cert denied, 426 US 923 (1976) (admissibility of polygraph tests using traditional analysis under the *Fed R of Evid*.
13. See *People v Williams*, 164 Cal App 2d Supp 858, 862, 331 P2d 251, 254 (App Dept Super Ct 1985) (upheld admission of Nalline test for detecting narcotic use because test generally accepted by those expected to be familiar with its use).
14. See eg, *Pulakis v State*, 476 P2d 474, 479 (Alaska 1970), *State v Saia*, 172 Conn 37, 42, 372 A2d 144, 147 (1975); *Marshall v State* 620 P2d 443, 445 (Okla Crim App 1980); *Greenfield v Commonwealth*, 214 Va 710, 715, 204 SE2d 414, 419 (1974)
15. *People v Kelly*, supra note 12.
16. Id at 26, 549 P2d at 1241, 130 Cal Rptr. at 146.
17. McCormick: Scientific evidence: Defining a new approach to admissibility, *Iowa L Rev* 1982;67:879, 905
18. See eg, *Jackson v Garrison*, 495 F Supp 9, 10 (WDNC 1979) ("The old standby test for the admissibility of scientific evidence laid down in *Frye v United States* . . is out of date and has met increasing rejection among the courts."), *United States v Sample*, 378 F Supp 44, 53 (ED Pa 1974).
19. *State v Hall*, 297 NW2d 80, 84–85 (Iowa, 1980), cert denied, *Hall v Iowa*, 450 US 927 (1981) (held admissible blood stain analysis evidence) The Supreme Court criticized the "general scientific acceptance" as a separate prerequisite for admission of scientific evidence if the reliability of the evidence is established. The court observed that a general scientific acceptance rule imposes a standard for admissibility that is not required of other areas of expert testimony. The court also noted the inconsistency with modern concepts of evidence specifically *Federal Rule of Evidence* 702 which states, "[if] scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine the fact in issue, a witness may testify . . in the form of an opinion or otherwise." Finally, the court questioned the difficulty in differentiating scientific evidence from other areas of expert testimony and the acceptance in scientific community as a nebulous concept.
20. Gianelli: The admissibility of novel scientific evidence: Frye v United States, a half century later. *Colum L Rev* 1980;80 1197, 1208.
21. *State v Hall*, supra note 19 at 85.
22. See generally Berger: A relevancy approach to novel scientific evidence. *Jurimetrics J* 1986; Spring: 237, 245 (recent issue of *Jurimetrics Journal* proposed alternatives to the *Frye* standard through amendments of the *Federal Rules of Evidence*) Amendment to *Federal Rule of Evidence* 702 would read:

> If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise. *When the witness seeks to testify about a scientific principle or technique that has not previously been accorded judicial recognition, the testimony shall be admitted if the court determines that its probative value outweighs the dangers specified in Rule 403.* [Emphasis added.]

See also Gianelli, supra note 20. *Frye* standard is reviewed from a historical perspective to its current status in light of the *Federal Rules of Evidence*. An alternative approach suggested by the author is an independent commission or tribunal consisting of bodies of experts who would review novel scientific techniques. Another alternative—a traditional approach suggested by another commentator—is a return to relevancy using the *Federal Rules of Evidence* as a basis, Gianelli: Scientific evidence: a proposed amendment to Federal Rule 702. *Jurimetrics J* 1980; Spring: 237, 260. The proposed amendment to 702 would have the addition of a second sentence which would read: "Expert testimony is not admissible unless the proponent gives the adverse party sufficient advance written notice of intent to use such evidence, including the nature of the expected testimony, the tests used, and the qualifications of the person who will testify." Lederer: Resolving the Frye dilemma—A reliability approach. *Jurimetrics J* 1986; Spring: 237, 240. Author suggests adding the word reliable to Rule 702 so it reads: If *reliable* scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise. McCormick, supra note 17. (suggesting factors for determining admissibility of scientific evidence, such as error rate, technique standards and safeguards, and acceptability. These factors provide a unified framework for admissibility decisions equally applicable to all evidence); Moenssens: Admissibility of scientific evidence: An alternative to the Frye Rule. *Wm & Mary L Rev* 1984;25:545. The *Frye* standard is inadequate because: it is difficult in some instances to determine the appropriate field for the evidence; it contributes to false general acceptance on the part of judges; it encourages acceptance of scientific techniques which have not undergone serious scientific testing; and it places excessive reliance on a single expert. Professor Moenssens suggests a new procedure rather than a new test for admitting scientific evidence. The reliability determination of the scientific evidence occurs at three separate stages of the litigation process: the discovery stage, the pretrial hearing stage, and the decision-making stage. Starrs: Frye v United States restructured and revitalized: A Proposal to Amend federal evidence Rule 702. *Jurimetrics J* 1986; Spring: 237, 249.

23. *Fed R of Evid* 401, 403, 702.
24. See eg, *State v Williams*, 388 A2d 500, 502–503 (Me 1978); cf *State v Dorsey*, 88 NM 184, 539 P2d 204 (1975) (applying rules of evidence without mentioning *Frye*).
25. *Doyle v State*, 159 Tex Crim 310, 263 SW2d 779 (1954).
26. Id at 311, 263 SW2d 779.
27. Id at 312, 263 SW2d 780.
28. *People v Johnson*, 18 Ill App 3d 457, 289 NE2d 722 (1972).
29. Id at 461, 289 NE2d 726 (1972).
30. Herschaft EE, Rasmussen RH: The teaching of forensic dentistry: A status report. *Dent Educ J* 1978;42:532 (survey of 60 dental schools indicates that 42% of respondents do not offer formal courses in forensic dentistry at any level of dental education).
31. *Patterson v State*, 509 SW2d 857 (Tex Crim App 1974).
32. Id at 862–863.
33. Id at 862.
34. 509 SW2d at 863.
35. *People v Marx*, 54 Cal App 3d 100, 126 Cal Rptr 350 (1975).
36. Id at 105–106, 126 Cal Rptr at 352.
37. Id at 106, 126 Cal Rptr at 353. The three prosecution witnesses summarized their findings as follows:

    ...I am compelled to draw the conclusion that the bite marks observed on the victim are in complete harmony with the anatomical configuration of the teeth of the suspect.... And, consequently, I must conclude that the possessor of the teeth from whom these casts were made must have made these marks in the skin of the victim. [Dr Sognnaes]

    My basic opinion and conclusions are that the bite marks that I studied [were], in fact, made by the teeth that were reproduced in the models labeled 'Suspect W. Marx.' That is my basic conclusion: That the bite mark matches the teeth reproduced in the model. [Dr Vale]

    ...Without a doubt.. the suspect's teeth did make the bite mark. [Dr Felando]
38. Id at 103, 126 Cal Rptr at 350.
39. Id at 107, 126 Cal Rptr at 353.
40. *Frye v United States*, supra note 4 at 1014.
41. *People v Marx*, supra note 35 at 110, 126 Cal Rptr at 355.
42. Id at 112, 126 Cal Rptr at 356.
43. Id at 111, 126 Cal Rptr at 356.
44. *People v Milone*, 43 Ill App 3d 385, 356 NE2d 1350 (1976).
45. Id at 392, 356 NE2d at 1355.
46. Id at 393, 356 NE2d at 1356.
47. Id at 395, 356 NE2d at 1356. Defendant contended that "[a]ll authors are unanimous that it is easier to state with assurance that bite marks were not made by a suspect than it is to show they were," citing *Gustafson*, supra note 3 at 140–165.
48. See Levine: Forensic dentistry, our most controversial case. *Legal Medicine Annual* 1978, pp 73–101. Levine states that in *People v Milone*, bite marks were not caused by defendant but by another individual, Richard Macek. Levine reviews the evidence and points out discrepancies in the state's expert testimony against Milone, including incorrect comparison of a tooth and bite mark. Levine illustrates through photographic proof that Richard Macek, not the individual accused, most likely bit the victim in the Milone case.
49. *People v. Milone*, supra note 44 at 394, 356 NE2d at 1357.
50. Id at 395, 356 NE2d at 1357.
51. Id at 396, 356 NE2d at 1358.
52. *Niehaus v State*, 256 Ind 655, 359 NE2d 513, 516, cert denied 434 US 902 (1977) (in murder trial, although bite mark evidence had limited application, simplicity of comparison of physical items and scientific methods used allowed evidence to be admitted) (dentist testifying as expert was doing so for first time).
53. *People v Slone*, 76 Cal App 3d 611, 143 Cal Rptr 61 (1978).
54. Id at 623, 143 Cal Rptr at 69.
55. *Frye v United States*, supra note 4.
56. *People v Slone*, supra note 53 at 623–624, 143 Cal Rptr at 69.
57. Id at 625, 143 Cal Rptr at 71.
58. Forensic dentistry, which is often referred to as forensic odontology, is a branch of dentistry concerned with the proper handling and examination of dental evidence, and the proper evaluation and presentation of dental findings in the courtroom setting. Cottone, supra note 2 at 16.
59. *State v Sager*, 600 SW2d 541 (Mo App 1980), cert denied. 450 US 910 (1981).
60. Id at 569.
61. Id at 562.
62. Id at 562–567.
63. Id at 600. In dicta, the Missouri court of appeals in *Sager* stated a strong support for the use of bite mark evidence
64. *State v Kleypas*, 602 SW2d 863 (Mo App 1980).
65. Id at 868.
66. Id at 869.
67. See eg, *State v Jackson*, 566 SW2d 227 (Mo App 1978); *State v Stevens*, 467 SW2d 10 (Mo 1971).
68. See, *People v Marx*, supra note 54
69. See *United States v Holland*, 378 F Supp 144 (EDPa 1974) aff'd sub nom *Appeal of Ehly*, 506 F2d 105, cert denied, 420 US 994 (1974), *United States v Martin*, 9 MJ 731 (NCMR 1979), *Aguilar v State*, 98 Nev 18, 639 P2d 533 (1982), *People v Allah*, 84 Misc 2d 500, 376 NY2d 399 (1975); *State v Asherman*, 193 Conn 695, 478 A2d 227 (Conn 1984), cert denied, 470 US 1050 (1985); *State v Garrison*, 120 Ariz 255, 585 P2d 563 (1978); *State v Green*, 305 NC 463, 290 SE2d 625 (1982); *State v Jones*, 259 SE2d 120 (SC 1979), *Kennedy v State*, 640 P2d 971 (Okla Crim 1982), *People v Middleton*, 54 NY2d 42, 429 NE2d 100 (1981), *State v Routh*, 30 Or App 901, 568 P2d 704 (1977), *State v Temple*, 302 NC 1, 273 SE2d 273 (1981); *State v Turner*, 633 SW2d 421 (Mo App 1982); *People v Watson*, 75 Cal App 3d 384, 142 Cal Rptr 134 (1977); *People v William*, 128 Ill App 3d 384, 470 NE2d 1140 (1984).
70. American Board of Forensic Odontology Guidelines for Bite Mark Analysis. *J Am Dent Assoc* 1986;112:383–386.
71. Id at 384.
72. Id at 385.
73. Id at 386
74. Note: Bite mark evidence: Hocus pocus or science? *Cum L Rev* 1986;16:126.
75. See generally, Wilkinson A, Gerughy R Bite mark evidence: Its admissibility is hard to swallow. *W St L Rev* 1985;12:519. Note: The admissibility of bite mark evidence. *S Cal L Rev* 1978;51:309.
76. See Sognnaes RF, Rawson RD, Gratt BM, Nguyen NBT.

Computer comparison of bite mark patterns in identical twins. *J Am Dent Assoc* 1982; 105: 449; Rawson RD, Ommen RK, Kinard G, et al: Statistical evidence for the individuality of the human dentition. *J Forensic Sci* 1984;29:245.

77. Berkstead J, Rawson R, Giles W: Review of bite mark evidence. *J Am Dent Assoc* 1986;99:69. Videotape analysis, first introduced in 1977, views two separate images at one time followed by superimposing or comparing images with one another. Images utilized are photographic prints, models of teeth, simulated bites and other evidence presented on videotape. Computerized, electronic image enhancement aids the rapid and precise interpretation of a photographic transparency. The technique allows a three-dimensional perspective, which can include density levels and further enhances areas to be analyzed, and thus improves comparison. The computerized image is also used for tooth edge enhancement. The borders of the bite mark are displayed allowing hidden discrepancies, scratches, and perforations to become evident. See generally David T: Adjunctive use of scanning electron microscopy in bite mark analysis: a three-dimensional study. *J Forensic Sci* 1986;31:1126–1134; Rao V, Souviron R: Dusting and lifting the biteprint: A new technique. *J Forensic Sci* 1984;19:326 (powder and brush method employed in lifting fingerprints can also lift toothprints); Webster G: A suggested classification of bite marks in foodstuffs in forensic dental analysis. *Forensic Sci Int* 1982;20:45 (teeth penetrate food differently than flesh; guidelines suggested for uniformity in classifying foodstuffs).

78. See supra note 4; see also Havel D: The role of photography in the presentation of bite mark evidence. *J Biol Photogr* 1985;53:59. See generally Dorion R: Bite mark evidence *Can Dent Assoc J* 1982;48:795–798 (guidelines for separating human from animal bites); Drinnan A, Melton M: Court presentation of bite mark evidence. *Int Dent J* 1985;35:316; Furness J: A general review of bite mark evidence. *Am Forensic Med Path* 1981;2:49; Vale G: Bite mark evidence in the investigation of crime. *Can Dent Assoc J* 1986;14:36.

79. See Moenssens, supra note 22 at 556. Most scientific inquiry or testing follows a logical progression to guarantee accuracy and reliability. Stages or steps include:

    Stage 1: A theory is postulated.

    Stage 2: Experiments are designed to verify the validity of the theory.

    Stage 3: If not disproven, it is valid and a court may take judicial notice of the theory.

    Stage 4: A technique or an instrument is designed and built to permit the theory to be applied practically in a forensic setting.

    Stage 5: After devising a methodology, further tests must demonstrate a positive correlation between results and underlying theory.

    Stage 6: After a test has been shown to yield reliable results relevant to disputed issues in a law suit, a court may admit these results into evidence and a qualified expert may interpret the results before the jury.

80. See *People v Marx*, supra note 35.

81. Levine, supra note 48.

82. Rawson R, Brooks S: Classification of human breast morphology important to bite mark investigation. *Am J Forensic Med Path* 1984;5:20.

83. *Symposium on Science and Rules of Evidence*. FRD 1983;99:188, 192–193.

EXHIBIT C
APPENDIX J

REALITY BITES: THE ILLUSION OF SCIENCE IN BITE-MARK EVIDENCE

Erica Beecher-Monas[*]

ABSTRACT

More than a decade after Daubert*, years after the amendments to the Federal Rules of Evidence, and long after the courts in* Frye *jurisdictions started examining the empirical basis for expert claims before permitting such testimony in their courtrooms, judges are still evading their gatekeeping duties when it comes to criminal cases. A prime example of this can be found in bite-mark testimony. Although it comes dressed in the illusion of science, having experts with advanced degrees, a fancy name (forensic odontology), professional associations, and professional journals, that illusion belies the reality that bite-mark evidence utterly lacks empirical support for its claims. This Article examines the claims made for bite-mark testimony, and the empirical support for those claims. It discusses the avoidance techniques used by the courts which permit this testimony into evidence despite the experts' inability to provide empirical support. It analyzes the threshold relevance requirement as basic to a rational system of adjudication, the concept of reliability as an inextricable component of this analysis, and why cross-examination, engine of truth though it may be, cannot resolve the problem of bogus expertise. This matters, because the result of admitting such flawed testimony is not only an injustice to the individual; it also undermines the legitimacy of the justice system.*

INTRODUCTION

Accurate fact-finding is supposed to be the key to the structure of adjudication, whether in civil or criminal cases, with the ultimate goal of discovering the truth through a rational process.[1] While trials may be

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[1] Scott Brewer, *Exemplary Reasoning: Semantics, Pragmatics, and the Rational Force of Reasoning by Analogy*, 109 HARV. L. REV. 923, 929 (1996) ("[N]ormative order constituted by

imperfect mechanisms for achieving that goal, admitting bunkum into evidence cannot help. Nonsense masquerading as science has no place in being admitted into evidence to prove an issue disputed at trial. Half-baked theories and expert *ipse dixit* without empirical support have no place in this process. That is the basis for rules about the admissibility of expert evidence, including the *Daubert*[2] decision, its progeny, and the ensuing amendment to the Federal Rules of Evidence.[3] It was also the basis for the *Frye*[4] rule, although there the emphasis was entirely placed on general acceptance by the scientific community as a proxy for validity.[5]

This goal of accuracy applies to both civil and criminal cases, and the same rules governing admissibility of expert testimony apply to both contexts.[6] If anything, accurate fact-finding is even more important in criminal justice, because the legitimacy of the justice system depends on it.[7] In practice, however, despite the common goal of accurate factfinding and the common threshold of relevance and reliability, judicial application of gate-keeping standards in civil and criminal trials could not be more different.[8]

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the legal system, informed by 'rule of law' principles as well as by many others, aspires to be rational in significant ways."). As philosopher and legal scholar Susan Haack explains, "intellectual integrity requires a willingness to seek out evidence, and assess it, honestly." Susan Haack, *The Ideal of Intellectual Integrity, in Life and Literature*, 36 NEW LITERARY HIST. 359, 364 (2005). There are other goals, of course, and sometimes policy considerations trump accuracy (spousal privilege rules, for example, which promote conjugal harmony at the expense of truth). But no one contends that rules should promote false information. Yet that is exactly what is being promulgated with bite-mark evidence.

2 Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579 (1993).

3 FED. R. EVID. 702.

4 Frye v. United States, 293 F. 1013 (D.C. Cir. 1923) (excluding polygraph testimony in a criminal case).

5 For a discussion of the epistemological underpinnings of *Frye* and *Daubert*, and an explanation for the author's preference of *Daubert* over *Frye*, see ERICA BEECHER-MONAS, EVALUATING SCIENTIFIC EVIDENCE: AN INTERDISCIPLINARY FRAMEWORK FOR INTELLECTUAL DUE PROCESS 4-16 (2007). The point that I wish to make here, however, is that the courts are failing to engage in any analysis—neither *Frye* nor *Daubert*—when it comes to expert testimony in criminal cases.

6 An exception to this is Georgia, whose Supreme Court recently ruled that civil rules of evidence require reliability, but criminal rules do not. *See, e.g.*, Mason v. Home Depot U.S.A., Inc., 658 S.E.2d 603, 607 (Ga. 2008) (ruling that the Georgia Tort Reform Act of 2005, which affected the admissibility of expert testimony in tort actions but not criminal cases, violated neither the U.S. nor the Georgia constitutions, holding that "for purposes of evidentiary standards . . . the parties to civil cases are not similarly situated to those engaged in criminal prosecutions"). The effect of this ruling is that in Georgia, expert evidence affecting life and liberty is subjected to a far less stringent standard than that affecting property interests.

7 LARRY LAUDAN, TRUTH, ERROR, AND CRIMINAL LAW: AN ESSAY IN LEGAL EPISTEMOLOGY 2 (2006) ("Public legitimacy, as much as justice, demands accuracy in verdicts.").

8 *See* D. Michael Risinger, *Navigating Expert Reliability: Are Criminal Standards of Certainty Being Left on the Dock?*, 64 ALB. L. REV. 99 (2000) (demonstrating that, in the post-*Daubert* period studied, civil defendants won their reliability challenges to plaintiffs' proffers most of the time, while criminal defendants virtually always lost their challenges to prosecution

In post-*Daubert* civil trials, judges routinely hold hearings to examine the scientific validity of expert testimony proffered in their courts, even in *Frye* jurisdictions.[9] These judges have no compunction about excluding expert testimony that they deem shaky.[10] But, in contrast to the routine and extensive challenges to expert testimony in civil cases, especially in toxic torts, the validity of expert testimony is rarely challenged in criminal cases.[11] Moreover, when criminal defendants do challenge the scientific basis of the evidence against them, they nearly always lose.[12] The reasons for this disparity are puzzling. Factual accuracy can hardly be less important in criminal trials. The purpose of criminal proceedings is to correctly identify the perpetrator of the crime so that the perpetrator can be punished.[13] Yet, while ostensibly using the same standards to evaluate scientific evidence (*Daubert* or *Frye*, depending on the jurisdiction), judges in criminal cases overwhelmingly circumvent their gatekeeping responsibilities. A prime example of this phenomenon can be found in bite-mark testimony.

The science behind bite-mark testimony is murky at best. The underlying theory, that a mark found on a dead victim can be traced to the dentition of the perpetrator, is dubious. The uniqueness of human dentition is questionable, and there is little empirical support for such a proposition. Moreover, unlike dental casts of all the teeth, skin injuries to dead victims tend to be fragmentary and diffuse. The bite-marks consist at most of the anterior teeth, and usually not all of those teeth.[14]

evidence; and when plaintiffs challenged civil defendants' expert evidence, the defendants usually won, but when criminal defendants challenged prosecution evidence, they seldom won).

9 *See, e.g.*, Haggerty v. Upjohn Co., 950 F. Supp. 1160, 1165 (S.D. Fla. 1996) (excluding testimony based on case reports because "they are no substitute for a scientifically designed and conducted inquiry"), *aff'd* 158 F.3d 588 (11th Cir. 1998); Shepard v. Barnard, 949 So. 2d 232 (Fla. Dist. Ct. App. 2007) (while ostensibly applying *Frye* to exclude plaintiff's causation testimony, the court examined the scientific basis of the expert opinion); Bouley v. Windschilt, No. A06-2145, 2008 WL 73297 (Minn. Ct. App. Jan. 8, 2008) (upholding exclusion of expert testimony as unreliable); Coratti v. Wella Corp., 831 N.Y.S.2d 358 (2006) (examining basis of expert causation opinion and finding case reports scientifically unreliable).

10 *See, e.g.*, *In re* Vioxx Prods. Liab. Litig., MDL No. 1657, 05-4046, 2005 WL 3541045 (E.D. La. Dec. 6, 2005) (refusing to allow expert cardiologist to testify about any connection between vioxx and the decedent's heart attack on defendant's objection); *In re* Vioxx Prods. Liab. Litig., 401 F. Supp. 2d 565, 593 (E.D. La. 2005) (limiting plaintiff's expert cardiologist to testifying about the decedent's heart condition after an extensive *Daubert* hearing).

11 Interestingly, in both *Daubert* and *Frye* jurisdictions, the exception to this is DNA testimony, where courts appear to routinely examine validity. *See* Brim v. State, 695 So. 2d 268 (Fla. 1997) (scrutinizing each step of DNA evidence for its scientific validity under *Frye*).

12 *See* Risinger, *supra* note 8, at 99 ("[C]ivil defendants win their *Daubert* reliability challenges to plaintiffs' proffers most of the time, and . . . criminal defendants virtually always lose their reliability challenges to government proffers.").

13 *See* PAUL ROBERTS & ADRIAN ZUCKERMAN, CRIMINAL EVIDENCE 101 (2004) (discussing legal relevance and the importance of accuracy in criminal adjudication).

14 *See* C. Michael Bowers, *The Scientific Status of Bitemark Comparisons*, *in* SCIENCE IN THE LAW: FORENSIC SCIENCE ISSUES 246 (David L. Faigman et al. eds., 2002) (noting the "fragile

No population databases establish the frequency of bite-mark patterns. Nor is there any system of blind, external proficiency testing using realistic models. Error rates are unknown. The few tests that have been attempted demonstrate a disturbingly high level of false positives.[15]

Remarkably, most of this questionable testimony is admitted without challenge.[16] Perhaps this is because, despite the dubious science behind bite-mark expertise, it is a field replete with the trappings, if not the substance, of science. The testifying experts have advanced degrees, and often board certification. They have two professional associations, with impressive names. They publish in their own professional journals. They use the statistical product rule[17] to come up with remote-sounding probability statements. But those trappings do not make it science.

Nevertheless, these trappings of science seem to be persuasive to lawyers, judges and juries. In the few post-*Daubert* challenges to bite-mark evidence, courts focused on the credentials of the experts and avoided the question of scientific foundations, predominantly by citing to legal precedent. Courts frequently admit bite-mark testimony simply because other courts have done so.[18] They find that it is "not novel"[19]

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foundation of minimally relevant empirical research" on which bite-mark testimony is based).

15 *See* C. Michael Bowers, *Problem-Based Analysis of Bitemark Misidentifications: The Role of DNA*, 159S FORENSIC SCI. INT'L S104, S107 (2006) (noting that bite-mark proficiency testing "shows a disturbingly high false-positive error rate").

16 Keith A. Findlay, *Innocents at Risk: Adversary Imbalance, Forensic Science, and the Search for Trust*, 38 SETON HALL L. REV. 893, 931 (2008) ("[T]he defense bar as a whole is generally unprepared to utilize or challenge scientific evidence adequately."). The failure of defense counsel to object to bite-mark evidence is astounding, considering the shaky basis of such testimony.

17 The statistical product rule is frequently used in DNA testimony and is defined by Hans Zeisel and David Kaye as follows:

> When alleles occur independently at each locus . . . and across loci . . . the proportion of the population with a given genotype is the product of the proportion of each allele at each locus, times factors of two for heterozygous loci.

HANS ZEISEL & DAVID KAYE, PROVE IT WITH FIGURES: EMPIRICAL METHODS IN LAW AND LITIGATION 322 (1997). Note the requirement that the variables (alleles in this instance) be independent. This is something that forensic odontologists have never been able to establish.

18 *See, e.g.*, People v. Wright, No. 179564, 1999 WL 33446496 (Mich. Ct. App. Apr. 23, 1999) (remanding for reconsideration of whether it was an error to admit testimony of forensic odontologist in rape-murder in which bite marks were all that linked defendant to crime scene). The appellate court concluded that any error was harmless in light of bite-mark testimony being admissible in 35 states.

19 *See, e.g.*, Verdict v. State, 868 S.W.2d 443, 447 (Ark. 1993) (no error in admitting bite-mark testimony of Dr. West because "evidence on human bite marks is widely accepted by the courts"); Carter v. State, 766 N.E.2d 377, 280 (Ind. 2002) (admitting bite-mark testimony because "defendant does not argue that it has become less reliable" than it was in 1977 when Indiana first admitted bite-mark testimony); State v. Timmendequas, 737 A.2d 55, 114 (N.J. 1999) (finding bite-mark testimony in a capital case reliable because "thirty states considering such evidence have found it admissible"); State v. Blamer, No. 00CA07, 2001 WL 109130 (Ohio Ct. App. Feb. 6, 2001) (holding, without analysis, that the challenged testimony was admissible); Seivewright v. State, 7 P.3d 24, 30 (Wyo. 2000) (holding it was no abuse of discretion for trial court to refuse to

or they let in this shaky testimony precisely because it is "not science."[20] One court, holding bite-mark testimony admissible, remarked that expert testimony is "often speculative" and left it at that.[21] This is a far cry from the exacting standards that the civil courts demand of expert evidence.

Nor can the federal courts be counted on to mop up the mistakes of the state courts in habeas relief by finding trials fundamentally unfair or by finding ineffective assistance when defense counsel fails to retain its own experts or challenge the prosecution's. The federal courts are no more willing than the state courts to engage in any analysis of the scientific grounds for bite-mark testimony. [22]

This is not because the evidence has been overwhelmingly correct and has therefore withstood the test of time (as is often argued in fingerprint cases[23]). A number of capital DNA exoneration cases have involved bite-mark testimony. In *State v. Krone*,[24] for example, a capital conviction involving expert testimony that the defendant was the source of a bite-mark found on the victim's body, the defendant was later exonerated through DNA analysis.[25] The cases of Roy Brown,[26] and Willie Jackson[27] also involved bite-mark testimony and post-conviction DNA exonerations.[28] Subsequent DNA tests also starred in the release of Dan Young, Jr., after twelve years in jail following a trial for rape and murder in which a forensic dentist had testified that his bite matched the marks on the victim's body.[29] In *Brewer*, a DNA

hold a *Daubert* hearing, "[g]iven the wide acceptance of bite mark identification testimony and [defendant's] failure to present evidence challenging the methodology").

20 *See, e.g.*, *Carter*, 766 N.E.2d at 377 (admitting bite-mark testimony because it was not science).

21 State v. Cazes, 875 S.W.2d 253 (Tenn. 1994).

22 In a typical example, *Kunco v. Att'y Gen. of Pa*., 85 Fed. App'x 819 (3d Cir. 2003), where the petitioner claimed that admitting bite-mark testimony employing an ultraviolet light technique that even other odontologists had castigated as unreliable, unethical, and incredible, the court held that this was not enough to show the necessary violation of due process.

23 *See, e.g.*, United States v. Joseph, No. CR. A. 99-238, 2001 WL 515213 (E.D. La. May 14, 2001) (admitting fingerprint evidence because it had "proven to be a reliable science over decades of use"). As Simon Cole points out, however, the "test of time" is not an appropriate validation mechanism for fingerprints either. *See* Simon A. Cole, *"Implicit Testing": Can Casework Validate Forensic Techniques?*, 46 JURIMETRICS J. 117, 125 n.43, 124-26 (2006) (discussing the fallacy of relying on the adversarial process to exposes latent fingerprint misattributions).

24 182 Ariz. 319 (1995).

25 Michael J. Saks & Jonathan J. Koehler, *The Coming Paradigm Shift in Forensic Identification Science*, 309 SCI. 892, 893, 893 fig.2 (2005) (showing the bite-mark evidence exhibit from *Krone*).

26 People v. Brown, 618 N.Y.S.2d 188 (N.Y. County Ct. 1994), *aff'd*, 600 N.Y.S.2d 593 (N.Y. App. Div. 1993).

27 Jackson v. Day, 121 F.3d 705 (5th Cir. 1997).

28 The stories behind these cases are presented more fully in Craig M. Cooley & Gabriel S. Oberfield, *Increasing Forensic Evidence's Reliability and Minimizing Wrongful Convictions: Applying Daubert Isn't the Only Problem*, 43 TULSA L. REV. 285, 358-59 (2007).

29 Steve Mills & Jeff Coen, *12 Years Behind Bars, Now Justice at Last*, CHI. TRIB., Feb. 1,

exoneration case involving bite-mark testimony, the court ordered a new trial, but refused to vacate the defendant's capital conviction.[30] In yet another case involving charges that were ultimately dropped, the expert had testified that the only person who could have made the bite found on the victim was the defendant; that same defendant was subsequently exonerated by DNA analysis.[31]

This Article argues that admitting expert evidence that has never been able to demonstrate its validity (and is thus irrelevant) into criminal cases tears a gaping hole in the fabric of a justice system that values accuracy in adjudication. In Part II, this Article examines the science behind forensic expert bite-mark identification testimony. It examines the espoused theory of forensic odontologists, the assumptions made and the data supporting the theory, and the methodology, to conclude that the evidence is simply not supported. Despite the apparent existence of many of the *Daubert* factors, a closer examination reveals that there is no substance to the claims that forensic odontology is a science. Part III examines how post-*Daubert* courts have addressed the admissibility question and finds that despite the myriad weaknesses of the evidence, it is rarely challenged, and when it is challenged it is nearly always found to be admissible, and admissibility is almost always upheld on appeal. This is not because the courts are actually examining whether the evidence could meet *Daubert* or *Frye*. Instead, once the expert is qualified, courts tend to simply cite to precedent, or declare that the evidence is not science, so it does not have to meet *Daubert* or *Frye*.[32] At most, and infrequently, the courts glance at the *Daubert* factors, and check them off their list. Part IV asserts that relying on the trappings of science rather than examining the basis for the expert's assertions is a dereliction of judicial gate-keeping duties, whatever standard of admissibility the court uses. It discusses the flaws underlying the notion that cross-examination and the presentation of contrary evidence will solve the problem. This article

2005, at 1.

[30] Brewer v. State, 819 So. 2d 1169 (Miss. 2002). In 2007, Brewer was finally released on bail pending retrial. Not until 2008 was Brewer exonerated, following the databank identification and subsequent confession of another inmate. For further details of this saga, see Cooley & Oberfield, *supra* note 28, at 358-59.

[31] Otero v. Warwick, 614 N.W.2d 177, 178 (Mich. Ct. App. 2000) (negligence action against testifying prosecution expert); *see also* Cooley & Oberfield, *supra* note 28, at 300-01 (discussing the cases of Edmund Burke and Dale Morris, both involving bite-mark identifications of suspects against whom the charges ultimately had to be dropped because of conflicting DNA evidence).

[32] This loophole should have been closed by the Supreme Court's decision in *Kumho Tire*, but many courts persist in admitting expert testimony that cannot demonstrate its empirical validity as "nonscience." *See* D. Michael Risinger, *Goodbye to All That, or a Fool's Errand, By One of the Fools: How I Stopped Worrying About Court Responses to Handwriting Identification (And "Forensic Science" in General) and Learned to Love Misinterpretations of* Kumho Tire v. Carmichael, 43 TULSA L. REV. 447, 460 (2008) (discussing the courts' evasion of their gatekeeping duties in the context of handwriting analyses).

concludes that gate-keeping matters and offers some suggestions for implementing more rigorous gate-keeping in the criminal context. It acknowledges that in order for the adversary system to work in criminal cases, defense lawyers must challenge questionable expertise, like bite-mark evidence. But when they do, judges must do more than superficially examine credentials and cite to precedent before deciding on admissibility. Expert evidence that has no empirical basis has no relevance to any issue before the court. It cannot possibly help the jury to decide any disputed issue of fact.

I. DOES BITE-MARK TESTIMONY PASS *DAUBERT* (OR *FRYE*) MUSTER?

Interpreting Rule 702 of the Federal Rules of Evidence, which permits experts to testify "[i]f scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue,"[33] the Supreme Court in *Daubert* explained that the rule "clearly contemplates some degree of regulation of the subjects and theories about which an expert may testify" and placed judges squarely in the gate-keeping role.[34] In response to *Daubert* and its progeny,[35] Rule 702 was amended to require that expert testimony be based upon "sufficient facts or data," be the "product of reliable principles and methods," and that those principles and methods be reliably applied to the facts of the case.[36] Although not defined by the rule, reliability, in a case involving scientific evidence, "will be based upon scientific validity."[37] To guide this inquiry, the *Daubert* Court outlined four non-definitive factors (explicitly not to be used as a checklist): whether the theory can be and has been tested; its error rate; whether it has been subjected to peer review and publication; and whether it has met with general acceptance in the scientific community.[38]

A superficial application of these factors might give a judge the impression that bite-mark testimony meets these standards. It has after all, a theory that perhaps might be testable: that bite-marks are uniquely

33 FED. R. EVID. 702.

34 Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 589 (1993).

35 FED. R. EVID. 702 advisory committee's note (noting that it applies to all expert testimony).

36 FED. R. EVID. 702.

37 *Daubert*, 509 U.S. at 590.

38 *Id.* at 593. The Court did far more than simply list factors; it explained why they were important and discussed their limitations in an attempt to get gatekeepers to actually think about the expertise they were letting in or keeping out. For an article remarking upon the distressing habit of post-*Daubert* trial courts to use these factors as a "mechanical checklist, woodenly applied," see Risinger, *supra* note 32, at 460.

identifying. The testifying experts claim that there are studies to support this theory. These studies are published in peer-reviewed publications put out by their professional associations. The experts also claim a vanishingly small error rate (although they rarely explain what the error rate refers to). Bite-mark identification testimony is generally accepted by forensic odontologists. But any examination beneath the surface of these factors demonstrates the utter lack of science behind bite-mark testimony.

Not all the states have adopted the amended Rule 702. Some states prefer the general acceptance standard first enunciated by *Frye*.[39] But under either standard for scrutinizing expert testimony, the judge has the primary duty to decide whether the evidence is relevant.[40] And evidence that is based on nothing more than the illusion of science and the *ipse dixit* of the expert cannot have any tendency to make a fact of consequence more or less probable than it would be without the evidence.[41]

Simply put, bite-mark testimony cannot meet this standard. It has no empirical support. None of the trappings of science, the scientific sounding titles, group "certification" and publication in journals put out and reviewed by other members of the group, can serve to make bite-mark evidence helpful in deciding the perpetrator's identity unless the theory and assumptions on which the identification is based, the data supporting the theory, and the methodology used are sound.[42] Bite-mark testimony fails on each of these fronts: the theory is based on unsupportable assumptions, the data is absent and what we do have demonstrates the invalidity of the theory, and the methodology lacks professional guidelines or standards, and is entirely subjective. Absent empirical support, the testimony can have no tendency to make a disputed issue of identity more or less probable.

39 Frye v. United States, 293 F. 1013 (D.C. Cir. 1923) (excluding polygraph testimony in a criminal case). Notably, the operative question in *Frye* is whether the testimony at issue has achieved general acceptance in the scientific community. This standard is frequently misapplied in bite-mark evidence, where courts seem to believe that what counts is general acceptance by the courts. *See, e.g.*, State v. Swinton, 847 A.2d 921 (Conn. 2004) (citing other cases in upholding admissibility of bite-mark evidence); State v. Blamer, No. 00CA07, 2001 WL 109130 (Ohio Ct. App. Feb. 6, 2001) (holding that bite-mark evidence was admissible).

40 As the *Daubert* Court explained, the requirement that expert testimony assist the trier of fact "goes primarily to relevance." *Daubert*, 509 U.S. at 591.

41 *See* Gen. Elec. Co. v. Joiner, 522 U.S. 136, 146 (1997) ("[N]othing in either *Daubert* or the Federal Rules of Evidence requires a district court to admit opinion evidence that is connected to existing data only by the *ipse dixit* of the expert.").

42 *Daubert*, 509 U.S. at 590 (requiring expert scientific testimony to be grounded in scientific method).

A. *What are These "Trappings of Science"?*

Qualifying a witness as an expert is generally the first step in determing whether expert testimony is admissible. In the majority of bite-mark cases, it tends to be the only step courts engage in, and the courts usually find these experts qualified in their field.[43] Most of the experts testifying about bite-mark identification (whether for the prosecution or defense) in criminal cases are dentists. In addition, most testifying experts are members of the American Board of Forensic Odontology ("ABFO"). Another professional association that many bite-mark experts belong to is the American Society for Forensic Odontology. These organizations have publications, and the articles published in them are peer-reviewed. Some of the articles published attempt to perform studies of various kinds that are later cited by experts in testimony.

So why is that not enough? First, the theory that bite-marks are unique has never been adequately tested—and may be untestable—so rather than even attempting to support it with data, testifying experts simply assert that it is so. Second, the few studies that have been attempted are so riddled with flaws that they cannot support the claims that their authors make, and would never be accepted into a mainstream scientific journal. This is at least partly attributable to the fact that there is no formal academic post-graduate training in the U.S. in forensic odontology. There is little funding for odontology research.[44]

Third, the methodology employed by forensic odontologists in making bite-mark identifications is entirely subjective. There are no objective standards by which to determine the minimal criteria for declaring a "match." ABFO attempted in 1984 to issue Guidelines to develop a scoring protocol that was supposed to achieve a reliable and objective method of quantifying similarities and differences between the marks and the questioned dentition.[45] This was supposed to be a more scientific approach,[46] but the authors soon retracted and advised "all

43 Even when serious questions about the experts' credentials have arisen, such as in the case of Michael West, who was expelled from one professional association and asked to resign from another, and had been the subject of a critical expose on CNN, courts managed to find him qualified. *See* Howard v. State, 945 So. 2d 326, 352 (Miss. 2006) (holding that there was no error in admitting Dr. West's testimony since the court had previously admitted his testimony and remarking that "[j]ust because Dr. West has been wrong a lot does not mean, without something more, that he was wrong here").

44 *See* Iain A. Pretty, *The Barriers to Achieving an Evidence Base for Bitemark Analysis*, 159S FORENSIC SCI. INT'L S110, S119 (2006) (noting the absence of post-graduate programs in forensic odontology and the dearth of research funding).

45 Am Bd. of Forensic Odontology, Inc., *Guidelines for Bite Mark Analysis*, 112 J. AM. DENTAL ASS'N 383 (1986).

46 *See* Raymond D. Rawson et al., *Reliability of the Scoring System of the American Board of*

odontologists [to] await the results of further research" rather than rely on the Guidelines.[47] The world is still waiting.

B. *What is the Theory Underlying Bite-Mark Testimony?*

Bite-mark testimony is primarily offered by the prosecution as identification testimony. Occasionally, it is also offered to demonstrate the heinousness of the crime. While the latter use may be problematic with respect to whether the marks are actually bite-marks rather than bruises or abrasions, it is the first use, as identification evidence, that is the most troubling.

Prosecutors presumably have turned to bite-mark testimony because they were not able to obtain the far more scientific DNA evidence from the crime scene, or because the DNA evidence was degraded, contaminated in some way, or (for some other reason) the test results were equivocal. Typically, the prosecution expert purports to be able to identify the biter from the bruises left on the corpse of a victim (or, occasionally, from food left at the crime scene).[48] The theory behind the testimony is that each person has a unique bite-mark, and that the biter can be identified from the marks left on the skin of a dead victim.[49] This theory of uniqueness has grave underlying statistical and logical flaws, which have never been addressed by bite-mark experts.[50] Further, even if tooth morphology is a result of random processes (such as growth, disease, environmental insults, diet, etc.) rather than being genetically determined, coincidental matches between people may still be possible—a question that a database would be necessary to address.[51]

Forensic Odontology for Human Bite Marks, 31 J. FORENSIC SCI. 1235, 1259 (1986) (praising the guidelines as "a truly scientific approach").

47 Gerald L. Vale et al., Letter, *Discussion of "Reliability of the Scoring System of the American Board of Forensic Odontology for Human Bite Marks,"* 33 J. FORENSIC SCI. 20 (1988).

48 *See, e.g.*, State v. Ortiz, 502 A.2d 400 (Conn. 1985) (finding admissible forensic odontologist's testimony that defendant made the bites in apple found at crime scene); Banks v. State, 725 So. 2d 711, 716 (Miss. 1997) (expert witness matched the bite marks on a bologna sandwich left at the crime scene to the capital defendant's dentition); Doyle v. State, 263 S.W.2d 779 (Tex. Crim. App. 1954) (allowing identification of burglary suspect from bite-mark left in cheese at the crime scene); Seivewright v. State, 7 P.3d 24, 26 (Wyo. 2000) (comparing suspect's dentition with marks left on cheese at crime scene).

49 *See, e.g.*, State v. Sager, 600 S.W.2d 541, 561 (Mo. Ct. App. 1980) (substantiating the admissibility of bite-mark identification testimony through the use of forensic odontology to identify unknown victims through dental records).

50 For an explanation of the uniqueness fallacy, see Michael J. Saks & Jonathan J. Koehler, *The Individualization Fallacy in Forensic Science Evidence*, 61 VAND. L. REV. 199, 204-05 (2008) (explaining why it is a fallacy to assert that even snowflakes are unique simply because of the number of ways that water molecules can be arranged, and discussing the "faulty logic that equates infrequency with uniqueness").

51 *See* David L. Faigman, *Identification from Bitemarks*, *in* SCIENCE IN THE LAW: FORENSIC SCIENCE ISSUES 256, 257 (David L. Faigman et al. eds., 2002) (discussing the study of identical

When asked about the foundation of bite-mark evidence, experts generally cite to the ability of forensic odontologists to identify victims of disaster or homicide.[52] With this kind of identification, an unknown victim is examined, and the dental records of a known person are compared to the dentition of the victim. A dentist armed with a full set of dental records can probably identify a corpse with a fair degree of certainty (although just how much certainty has never been studied, and is therefore still unknown). Using this technique, the dentist examines the (nominally) thirty-two teeth, with five surfaces each, making 160 possible surfaces which can each contain specific characteristics, and any fillings, decay, lost teeth, and mis-positioning. In addition, the forensic odontologist examines number, shape, type and placement of dental restorations, root morphology, bone patterns, and sinus morphology. Because each of these factors provides some individual characteristics, there is little controversy about the ability of a dentist to put them together to identify a dead person from a complete set of dental records, especially if there are anomalies in the teeth.[53]

Thirty-two teeth are not used in bite-mark comparisons, however, since at most, four to eight teeth are visible in bite-marks.[54] Unlike the identification of catastrophe victims from a full set of dental records, bite-mark identification consists of "matching" a mark on the victim with the anterior teeth of a suspect. Bite-mark experts only look at marks that are essentially bruises on a victim, and compare them with a model (or tracing of a model) of the suspect's teeth.[55] So although the use of dental records in identifying catastrophe victims is often cited in validation, bite-mark comparison bears little resemblance to identifying an unknown victim using a complete set of dental records.

The underlying theory for bite-mark comparisons thus depends on three assertions: first, that "the dental characteristics of anterior teeth involved in biting are unique among individuals;"[56] second, that this "asserted uniqueness is transferred and recorded in the injury;"[57] third, that human skin can maintain the accuracy of the marks over time, after

twins).

52 *See, e.g.*, People v. Mattox, 237 N.E.2d 845, 846 (Ill. App. Ct. 1968) (identifying homicide victim from dental records).

53 *See* Paul C. Giannelli, *Bite Mark Analysis*, 43 CRIM. L. BULL. 5, 5 (2007) (discussing the difference between use of forensic odontology to identify the deceased and its use to identify suspects in homicide cases).

54 *See* Iain A. Pretty & David J. Sweet, *The Scientific Basis for Human Bitemark Analyses—A Critical Review*, 41 SCI. & JUST. 85, 89 (2001).

55 *See* Iain A. Pretty, *Unresolved Issues in Bitemark Analysis*, *in* BITEMARK EVIDENCE 554, 557 (Robert B.J. Dorian ed., 2005) (discussing methods of comparison and the difference between dental identification and bite-mark comparison).

56 *Id.* at 557.

57 *Id.*

the death of the victim.[58]

All three are highly questionable assertions.[59] There is a great deal of controversy about the ability of forensic odontologists to identify marks left on a victim's body as bite-marks at all.[60] In one of the first bite-mark cases, *People v. Marx*,[61] the court concluded that "there is no established science of identifying persons from bite marks as distinguished from, say, dental records and X-rays."[62] There is no evidence that things have changed in this regard.

C. *What Data Support the Theory That Bite-Marks are Identifying?*

Testifying experts surmount the problems underlying the theory of uniqueness by simply assuming that the theory is valid. Rather than offering data to support the theory of uniqueness, testifying experts simply state that bite-marks are unique. Few empirical studies have even attempted to demonstrate the asserted uniqueness of bite-marks, and those few have critical flaws.[63] One study attempting to compare bites of identical twins, and concluding that each was unique, was flawed by being extremely small (five sets of twins), and failing to set

58 *Id.* at 549-50 (discussing as "unresolved issues" the "highly viscoelastic" properties of human skin and citing studies demonstrating that "changes in bitemark appearance are likely to be greater as the injury grows older" in both living and dead victims).

59 *See, e.g.*, Bowers, *supra* note 15, at S106 (2006) (castigating the linkage between injuries and a specific person as not being arrived at with scientific rigor and noting that the "dental literature . . . is surprisingly thin and sorely lacking in rigorous scientific testing"); Duane T. DeVore, *Bite Marks for Identification?—A Preliminary Report*, 11 MED. SCI. & L. 144 (1971) (questioning the accuracy of skin as a substrate for bite-mark impressions and the lack of a population database); Iain A. Pretty & Malcolm D. Turnbull, *Lack of Dental Uniqueness Between Two Bite Mark Suspects*, 46 J. FORENSIC SCI. 1487, 1487 (2001) (challenging the "central dogma" that human teeth are unique and that sufficient detail is rendered during biting to enable identification of the biter).

60 *See, e.g.*, Ege v. Yukins, 380 F. Supp. 2d 852, 878 (E.D. Mich. 2005) (defense expert contended marks were the result of livor mortis rather than bite-marks), *aff'd in part, rev'd in part*, 485 F.3d 364, 366 (6th Cir. 2007) (holding that trial court's admission of expert's probability statement substantially prejudiced trial and that defense counsel's failure to object constituted ineffective assistance); Kinney v. State, 868 S.W.2d 463, 464-65 (Ark. 1994) (battling experts disagreed about whether the marks were bite marks at all); State v. Duncan, 802 So. 2d 533, 553 (La. 2001) (battling experts disagreed over whether marks were bites); Stubbs v. State, 845 So. 2d 656, 668 (Miss. 2003) (same); Brewer v. State, 725 So. 2d 106, 116 (Miss. 1998) (same).

61 126 Cal. Rptr. 350 (1975).

62 *Id.* at 353. Remarkably enough, despite this concession, the testimony was admitted. But in that case, the defendant had distinctive irregularities in his teeth, and the mark was in skin overlying cartilage on the victim's nose, which resulted in one of the most distinct and deepest bite marks on record in human skin. *Id.* at 354 (explaining that most bite marks are on softer tissue and not very deep). These conditions are rarely met, and yet courts routinely continue to admit bite-mark testimony, often citing *Marx* as precedent.

63 *See* Giannelli, *supra* note 53, at 4.

out a detailed methodology.[64] Because much of the variation observed could have been caused by the technique used to produce the comparisons, its results are suspect.[65] Moreover, whether the differences the study found in the twins' dentition would be observed in a bite-mark was not addressed.

Similarly flawed was a 1984 study attempting to apply a statistical probability theory to 397 bites chosen for their clarity, but without randomization.[66] Again, details of methodology were omitted, and techniques were combined.[67] Even worse, the study's conclusions were based on the flawed premise that the position of each tooth was independent of the position of the others, an assumption that has been shown to be incorrect.[68]

As noted above, armed with a full set of dental records (that is, records of all thirty-two teeth, present or absent, filled or broken) and a corpse, forensic odontologists have been able to identify catastrophic victims (usually from a finite list) with some degree of success. Whether the biting teeth are unique from person to person is the subject of a single study of fifty young adults.[69] First, the design is flawed: it is far to small to establish what it purports to establish. Moreover, the study examined only the question of whether "the occlusal surfaces of the upper and lower anterior teeth are specific to each individual" rather than the more salient question of "the probability of finding a sufficiently similar set of occlusal surfaces in a target population" which the authors acknowledge would require the development of a statistical database.[70] Nor did the study suggest that the features of the anterior teeth would be transferred to a bitten surface.[71] Or that the transfer would remain accurate over time.

But even if there were support for the theory that each person's mouthful of teeth is unique, that does not address the question of how unique are the marks made by those teeth.[72] And of that question, no

[64] Reidar F. Sognnaes, Raymond D. Rawson et al., *Computer Comparison of Bitemark Patterns in Identical Twins*, 105 J. AM. DENTAL ASS'N 449 (1982).

[65] *See* Iain A. Pretty, *The Barriers to Achieving an Evidence Base for Bitemark Analysis*, 159S FORENSIC SCI. INT'L S110 (2006) (noting flaws in twin study).

[66] Raymond D. Rawson et al., *Statistical Evidence for the Individuality of the Human Dentition*, 29 J. FORENSIC SCI. 245 (1984).

[67] *See* Pretty, *supra* note 44, at S115-16 (noting flaws in Rawson study).

[68] *See id.*

[69] Jules A. Kieser et al., *The Uniqueness of the Human Anterior Dentition: A Geometric Morphometric Analysis*, 52 J. FORENSIC SCI. 671 (2007). Earlier studies attempting to demonstrate uniqueness had been fatally flawed. One study failed to consider the registration of the features examined on human skin, and additionally concluded that it had not confirmed the uniqueness of the anterior teeth. T.W. MacFarlane et al., *Statistical Problems in Dental Identification*, 14 J. FORENSIC SCI. SOC. 247-52 (1974).

[70] Kieser, *supra* note 69, at 675.

[71] *Id.*

[72] *See, e.g.*, DAVID J. BALDING, WEIGHT-OF-EVIDENCE FOR FORENSIC DNA PROFILES 54

systematic study has been made. There is, however, anecdotal evidence that demonstrates just the opposite.[73]

Although some bite-mark experts in criminal cases purport to quantify the chance of a coincidental match, they are doing so without an underlying database, which makes their numbers meaningless.[74] The problem with using the product rule to determine the likelihood of coincidental match in bite-mark cases is that, unlike DNA testing, there is no supporting database. Nor (again, unlike DNA evidence) is there any evidence that the factors being measured in bite-marks are independent, which is another requirement in using the product rule to determine the likelihood of coincidental matches.[75]

Even if bite-marks were not unique, they might be useful in identification, as long as the frequency of a particular bite-mark were known. For example, before the advent of DNA typing, blood groups were used as a fairly imprecise method of identification.[76] If blood found at the crime scene was not the same blood group as that of the defendant, it would make it less likely that the defendant was there. On the other hand, if the blood at the crime scene "matched" the type of the defendant, it did not mean very much, because it could also "match" many other people.[77] But by making the unsupported assumption that

(2005) (explaining that with respect to fingerprints, although "the suggestion that recorded fingerprints are unique has never been rigorously checked," the question before the court is whether the imperfect impression taken from a crime scene is "enough to establish the defendant and nobody else could have left it"). To answer that question one would need to know the frequency of those particular marks in the relevant population.

73 *See, e.g.*, C. Michael Bowers, *supra* note 14 (demonstrating that two different people "matched" the same set of bite-marks); Bruce R. Rothwell, *Bite Marks in Forensic Dentistry: A Review of Legal, Scientific Issues*, 126 J. AM. DENTAL ASS'N 223, 230 (1995) (recounting the saga of the 1976 Milone murder trial, in which one defendant was convicted on the basis of bite-mark testimony, someone else later confessed, and his teeth also "matched" the marks).

74 A similar problem in microscopic hair analysis caused the F.B.I. to reject it. *See* ERICA BEECHER-MONAS, *supra* note 5, at 115 (discussing the F.B.I.'s acknowledgment that microscopic hair analysis cannot be used as the basis for personal identification). In microscopic hair analysis testimony, experts often couch their conclusions in the form of a statistical likelihood so high that it suggests a very low probability of error. For example, if the hairs match eight characteristics out of twenty-six, there is a 1-in-4500 chance that the same characteristics would be found to match if the hairs came from different individuals. These are called Gaudette statistics. Although this may sound impressive, even the progenitor of this method acknowledges its subjectivity. *See id.* The real question is, assuming a match, what is the probability that the unknown and known hairs came from the same person? This question cannot be answered without knowing the size of the population from which the defendant came, something the Gaudette statistics cannot answer. The next most useful question is the probability of misinformation: Given a match, what is the probability that the crime scene hair came from someone other than the defendant? The Gaudette statistics do not answer that question either.

75 See *id.*

76 *See, e.g.*, WILSON J. WALL, GENETICS & DNA TECHNOLOGY: LEGAL ASPECTS 29-41 (2d ed. 2004) (discussing blood group identification and contrasting it with DNA profiling).

77 *See, e.g.*, Cherry v. State, 959 So. 2d 702 (Fla. 2007) (finding that testimony that blood found at the crime scene matched the defendant's blood group typing, which was found in approximately 1.9% of the population). Notably, however, many of the DNA exonerations

bite-marks are unique, forensic odontologists give a specious illusion of accuracy.

D. *What Data Support the Theory that Human Skin Registers Bites?*

The second postulate upon which the theory of bite-mark identification rests is that human skin can accurately register bites. Two studies have attempted to demonstrate the validity of matching marks made on pigskin (which is said to be similar to human skin) to human dentition. In the first of these studies, the percentage of incorrect identifications ranged from 24% under ideal laboratory conditions immediately after biting, to 91% incorrect identifications after 24 hours.[78] In a later study, matching dental casts to marks in pig skin, incorrect identifications ranged from 12% to 22%.[79] With such a high error rate, the studies cannot purport to be measuring anything reliably.[80]

Further complicating this issue is the tendency of living human skin to distort marks made upon it. The third postulate of bite-mark identification theory requires that marks made upon the (presumably living) victim remain unchanged over time (and after death). On its face, this assertion seems dubious. Bite-marks are essentially bruising, blood tends to pool in various parts of the corpse (livor mortis), and human skin is highly malleable.[81] Skin responds to trauma differently in

involved faulty serology testimony. *See* Brandon L. Garrett, *Judging Innocence*, 108 COLUM. L. REV. 55, 82 (2008) (discussing the high percentage of faulty serology testimony involved in DNA exoneration cases).

78 David A. Whittaker, *Some Laboratory Studies on the Accuracy of Bite Mark Comparison*, 25 INT'L DENTAL J. 166 (1975) ("[T]he inability of examiners to correctly identify bitemarks in skin . . . under ideal laboratory conditions and when examined immediately after biting suggests that under sometimes adverse conditions found in an actual forensic investigation it is unlikely that a greater degree of accuracy will be achieved.").

79 Iain A. Pretty & David Sweet, *Digital Bite Mark Overlays—An Analysis of Effectiveness*, 46 J. FORENSIC SCI. 1385, 1390 (2001) (concluding that this "[p]oor performance" has "very serious implications for the accused, the discipline, and society").

80 Contrast these results with the requirements for statistical significance levels of p=0.05, or confidence intervals of 95%, without which judges routinely exclude expert testimony in toxic torts. *See, e.g.*, Knight v. Kirby Inland Marine, Inc., 482 F.3d 347 (5th Cir. 2007) (affirming exclusion of plaintiffs' expert testimony in toxic tort action for failure to meet statistical significance levels); Vanderwerf v. SmithKlineBeecham Corp., 529 F. Supp. 2d 1298 (D. Kan. 2008) (excluding plaintiff's testimony of link between paxil and suicidal ideation). These concepts of statistical significance are important in scientific studies because they reflect the scientific preference for false negatives over false positives, and therefore express the results of hypothesis testing as the chance of obtaining the observed data if the null hypothesis was correct. For an explanation of statistical significance, confidence intervals, and relative risk, see BEECHER-MONAS, *supra* note 5, at 60-62.

81 *See, e.g.*, Ege v. Yukins, 380 F. Supp. 2d 852, 878 (E.D. Mich. 2005) (defense experts testified that the marks on victim were livor mortis rather than a bite-mark).

different people, and at different times.[82] It is also highly elastic, so that it stretches when bitten and when evidence is collected.[83] Any bite-mark on skin may be distorted.[84] Areas with more underlying fat, or more prone to movement, are especially prone to distortion, and this may be compounded by the force of the bite.[85] The older the bite, the more distortions can be expected.[86] The inevitable distortions of a mark made on human skin are further compounded by movement of the victim's body, before and after death. Given the inevitability of distortions, comparisons of marks on skin with dentition are highly suspect.

E. *Unsupported Assumptions Bolstered by Unfounded Certainty: The Illusion of Statistical Support for Expert Conclusions*

Forensic odontologists generally bolster their conclusions of a "match" with impressive sounding certainty. The basis for this certainty originated in the statistical product rule.[87] For example, in an early case, the Arizona Supreme Court upheld the admissibility of bite-mark testimony finding "that there is an eight in one million probability that the teeth marks found on the [victim] . . . were not those of the [defendant]."[88] The expert based these figures on several points of comparison, citing two books and several articles employing the product rule for its use.[89] Although this use was upheld on appeal, subsequent cases have made experts more leery of using quantitative assertions, or even attempting to explain the product rule.[90]

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82 *See* DeVore, *supra* note 59 (noting distortions in human arm skin of live subjects).

83 *See* D. R. Sheasby & D. G. MacDonald, *A Forensic Classification of Distortion in Human Bite Marks*, 122 FORENSIC SCI. INT'L 75 (2001) (noting that the same biter may leave differing marks on the same victim).

84 DeVore, *supra* note 59 (noting distortions in human arm skin of live subjects).

85 *See* J. C. Barbenel & J. H. Evans, *Bite-Marks in the Skin—Mechanical Factors*, 14 J. FORENSIC SCI. SOC. 235 (1974) (studying distortions during and after biting).

86 *Id.*

87 *See, e.g.*, State v. Garrison, 585 P.2d 563 (Ariz. 1978) (upholding expert bite-mark testimony based on the product rule).

88 *Id.* at 566.

89 *Id.*

90 Professors Saks and Koehler give an elegant explanation of the product rule:

> According to the rule, the probability that each of a series of independent events will occur is given by the product of their unconditional probabilities. Attempts to use the product rule to support individualization run into several problems. First, proper application of the rule requires a set of reliable frequency estimates for the relevant set of forensic characteristics. Second, the characteristics must be independent of each other. Third, even if the first two problems are overcome, application of the product rule necessarily falls short of establishing unique individualization. The product of probabilities greater than zero always yields a value greater than zero. The probabilistic approach, therefore, always leads to the conclusion that a source other than the suspected individual or object might exist.

An example of this is found in *Ege v. Yukins*,[91] where the bite-mark expert, having first opined that the defendant's dentition was "highly consistent" with the marks on the victim, responded to the prosecutor's question by answering that no one else in a city of 3.5 million people (like Detroit, where the murder took place) would "match up."[92] Defense counsel did not object, instead proffering experts who opined that the marks were livor mortis rather than bite-marks, and even if they were bite-marks, they did not match the defendant's dentition.[93] Although the prosecution expert's figures were undoubtedly based on the product rule, the expert neither referred to it, nor explained it. Because the expert's probability statement was not supported by anything other than the size of the Detroit metropolitan area, where the murder took place, it was ultimately the basis for the Sixth Circuit's grant of habeas.[94]

The same prosecution expert who testified in *Ege* had testified previously in numerous cases, among them *People v. Wright*.[95] There, the expert explicitly based his statistics on an article published in the Journal of Forensic Science,[96] and opined that "if you have five unique points, . . . the chance of another individual making that same mark is 4.1 billion to one" and concluding that no one in the world "would have this unique dentition."[97]

The article on which Dr. Warnick based his testimony, however, is deeply flawed; the study design and execution are faulty and the statistical assumptions unsupportable.[98] In a nutshell, the author, using the product rule, and based on a determination that there were 150

Michael J. Saks & Jonathan J. Koehler, *The Individualization Fallacy in Forensic Science Evidence*, 61 VAND. L. REV. 199, 209 (2008).

91 485 F.3d 364 (6th Cir. 2007).

92 *Id.* at 368.

93 *Id.*

94 *See id.* at 373 (finding that although Ege's ineffective assistance claim for her counsel's failure to object was time-barred, because "it should have been obvious . . . that the *manner* in which this physical evidence was presented was objectionable . . . we cannot say that it should have been similarly obvious to Ege that the *substance* of the physical evidence—at least as presented by Dr. Warnick—was complete bunk"). The habeas writ was brought after the statute of limitations had expired, but the petitioner claimed that the statute had been tolled by the newly discovered evidence of a letter from the prosecutor's office "concerning the unreliability of Dr. Warnick as an expert witness in two previous murder trials." *Id.* at 370. Thus, while the Sixth Circuit agreed that the letter was newly discovered evidence with respect to the due process claims, it was not with respect to the ineffective assistance claims. *Id.*

95 No. 179564, 1999 WL 33446496 (Mich. Ct. App. Apr. 23, 1999), *rev'd*, 625 N.W.2d 783 (2001). This is one of the two cases that the Sixth Circuit cited in *Ege*, 485 F.3d at 372, where the bite-mark expert "was totally unreliable—in one case, because DNA evidence later excluded the defendant as a possible suspect; in the other, because a second expert undermined Warnick's probability determination."

96 Rawson, *supra* note 66.

97 *Wright*, 1999 WL 33446496 at *3 (showing testimony of prosecution expert, Dr. Warnick).

98 *See* Pretty & Sweet, *supra* note 54, 89-90 (discussing errors in Rawson's study).

possible positions for each tooth, found that the probability of finding two sets of six teeth each was 1.4 x 10^{13}. He assumed a world population of 4 billion, and stated that a match at five teeth would positively identify the biter to the exclusion of all others. The fundamental problem with using the product rule in this manner is that it assumes that each position of each tooth is independent, an assumption that has been shown to be false.[99] In addition, the article on which the expert based his testimony concerned the uniqueness of human dentition rather than the uniqueness of bite-marks, both of which have been criticized widely.[100] Ultimately, *Wright* was reversed and remanded to the trial court for an admissibility hearing regarding the statistical probability statement, the conviction was vacated, and remanded for a new trial.[101]

The more usual probability statements, however, are not quantified, but simply assert that the marks are "consistent"[102] with defendant's teeth; "positively match;"[103] or that the expert has a "reasonable degree of dental certainty" that the defendant's teeth made the marks.[104] These formulations for conclusions reflect current professional advice to experts, such as that in a treatise on bite-mark evidence, acknowledging that "there is no quantitative base for bite-marks analysis . . . [and] forensic dentists should refrain from such statistics."[105] Rather, in the next chapter, the text asserts that "human dentition is certainly unique; this has been established, although, as previously stated, not in a mathematically sound fashion."[106] Using words like "consistent" and "match" hardly solve the problem. These statements depend entirely on the expert's subjective assessment.[107]

99 *See id.*

100 *See, e.g.*, Rothwell, *supra* note 73, at 229 (explaining that "there is no study of large populations to establish [the theory of uniqueness] firmly" and noting that there is "no conclusive demonstration of the distinctive nature of a single bite pattern"). Notably, Dr. Warnick was sued for gross negligence by a murder suspect arrested for murder and later exonerated by DNA evidence. Otero v. Warnick, 614 N.W.2d 177 (Mich. Ct. App. 2000) (holding that there was no duty owed by the expert to the plaintiff). Dr. Warnick had testified in a preliminary hearing that Otero was the only person in the world who could have made the marks found on the victim's body. *Id.* at 178. When Otero was excluded as the source of DNA found on the victim's body, after spending five months in jail, he was released.

101 People v. Wright, 463 Mich. 993 (2001).

102 *See, e.g.*, Brooks v. State, 748 So. 2d 736 (Miss. 1999); Furtado v. State, No. 08-00-00230-CR, 2001 WL 959437 (Tex. Ct. App. Aug. 23, 2001); State v. Arredondo, 674 N.W.2d 647, 660 (Wisc. Ct. App. 2003).

103 *See, e.g.*, Morgan v. State, 639 So. 2d 6, 9 (Fla. 1994).

104 *See, e.g.*, State v. Cazes, 875 S.W.2d 253, 258 (Tenn. 1994).

105 Pretty, *supra* note 55, at 543.

106 *Id.* at 561.

107 *See* J. M. Kittelson et al., *Weighing Evidence: Quantitative Measures of the Importance of Bitemark Evidence*, 20 J. FORENSIC ODONTO-STOMATOLOGY 31, 36 (2002) ("[B]itemark evidence is inherently qualitative, and the use of quantitative measures to describe the importance of bitemark evidence would be misleading.").

Crucially, they mask the absence of data for the experts' unfounded assumptions about the uniqueness of bite-marks and the registration of these marks on the skin of the victim. Without data, such assertions are meaningless.

F. *Methodology*

Not only are the assertions of "match" subjective, but the methodology itself consists entirely of subjective comparisons. There are no official standards, no guidelines, and no criteria. The attempt of ABFO to achieve some methodological standardization was never implemented.[108] Although a number of variations exist,[109] the basic technique is comparing the marks made on the victim to a cast made of the defendant's teeth. Usually this is done by photographing the victim's marks, sometimes after excision, or, if there are impressions left in the skin, making a mold from the impressions. The defendant's model is either compared to a life-size photograph of the victim's marks, or a transparent overlay of the defendant's model is compared to the victim's marks. Dr. West, a forensic odontologist who practiced primarily in Mississippi, was wont to simply place the model onto the victim's wounds.[110]

At each step of the process, distortions may occur. Photographs must be taken quickly, since "the clarity and shape of the mark may change in a relatively short time in both living and dead victims."[111] Moreover, the position of the victim matters, because distortions will occur if photographed in a position other than the one in which the victim was bitten.[112] In order to judge the scale, some point of reference must be included in the photograph of the victim's marks.[113]

When making overlays and tracings, errors often are introduced.[114]

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108 *See* Bowers, *supra* note 15, at S106 (noting that ABFO's attempt to achieve objective guidelines "failed, not surprisingly, due to inter-examiner discord and unreliable quantitative interpretation").

109 *See, e.g.*, Pretty & Sweet, *supra* note 54, at 90 (noting "the wide variety of techniques").

110 *See, e.g.*, Howard v. State, 945 So. 2d 326 (Miss. 2006).

111 Rothwell, *supra* note 73, at 226.

112 *See, e.g.*, DeVore, *supra* note 59 (studying distortion of marks on living volunteers depending on the position of the volunteer during the photograph, and concluding that the degree of distortion was so great that only if the exact position of the body when bitten could be replicated should photographic images be used for comparison); Barbenel & Evans, *supra* note 85 (studying distortions in bite marks in both living and dead victims).

113 *See* Mark L. Bernstein, *Two Bite Mark Cases with Inadequate Scale References*, 30 J. FORENSIC SCI. 958 (1985) (noting the inaccuracy of small plastic rulers used as reference scales).

114 *See* David Sweet & C. Michael Bowers, *Accuracy of Bite Mark Overlays: A Comparison of Five Common Methods to Produce Exemplars from a Suspect's Dentition*, 43 J. FORENSIC SCI. 362 (1998) (finding that hand-traced overlays were inaccurate and generally unsuitable for use, and that radiographic overlays were more accurate).

When comparing the photographs or tracings of the victim's marks to the overlay or tracings of the suspect's teeth model, errors can be introduced also.[115] Moreover, even if more objective techniques are attempted, (by the use of radiographic overlays, for example) ultimately, the comparison of the photograph of a bite-mark to an overlay of the defendant's dentition is a subjective process.

When more precise methods have been attempted, they have been a dismal failure. When computerized complex image analysis was attempted in order to provide greater objectivity, and tested against a real legal case, a different biter from the already convicted (on the basis of expert bite-mark testimony) defendant was identified.[116] Either the defendant was wrongly convicted, or the computer was inaccurate, but the attempt at computerization was abandoned.

Error rates appear to be high, although they have never been rigorously quantified. A study published in 1974 found that false positive identifications occurred 24% of the time.[117] Proficiency testing was attempted by ABFO, which conducted four studies of its diplomates.[118] In the first study, ABFO found that error rates were "unsatisfactorily high."[119] Two subsequent studies were never published. The fourth reported an impressive sounding 85% successful match rate for the thirty-two diplomates analyzing four cases.[120] However, as Dr. Bowers points out in his critique, the poorest level achievable by this study was 71%.[121] Thus, as Dr. Bowers demonstrates, the actual median false positive rate (that is, declaring a match for a non-biter) was 63.5% and the false negative error rate (declaring no match when, in fact, the biter had made the marks) was 22%.[122] This error rate, especially the false positive rate, is disturbingly high.

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115 *See* Rothwell, *supra* note 73, at 230 ("In even the most careful process, each stage introduces errors.").

116 *See* A.S. Naru & D. Sykes, *Digital Image Cross-Correlation Technique for Bite Mark Investigations*, 37 SCI. & JUST. 251 (1997) (observing that the skin may not record bites accurately enough to enable analysis).

117 Whittaker, *supra* note 78 (bite marks on porcine skin had a 24% false positive identification rate).

118 *See* Bowers, *supra* note 14, at 248-49 (discussing the four tests).

119 *Id.* at 248.

120 Kristopher L. Arheart & Iain A. Pretty, *Results of the 4th ABFO Bitemark Workshop—1999*, 124 FORENSIC SCI. INT'L 104-11 (2001).

121 Bowers, *supra* note 14, at 251, tbl.2 (explaining that if an examiner got one match wrong by linking it to an innocent suspect, he would still get the remaining five dentitions right by not erroneously matching them).

122 *Id.*

II. WHAT ARE THE COURTS DOING?

No one seriously contends that bite-mark testimony is based on "sufficient facts or data," or that it is the "product of reliable [meaning scientifically valid] principles and methods," reliably applied to the facts of the case.[123] If examined in any but the most superficial manner, it is obvious that not one of the *Daubert* factors can be met: the theory that partial impressions of unique dentition can be made on the skin of now-dead victims and that the marks made can be traced back to the biter is wholly untested, and all indications are that it is not true. The few times it has been tested, its error rate has been extraordinarily high. There are some articles reflecting this research placed in journals that are specialized for the purposes of criminal litigation, such as the Journal of Forensic Science and Forensic Odontology, the Journal of Forensic Odonto-Somatology, and a very few in the American Journal of Dentistry, but none in mainstream scientific journals like Science, Nature, and the Lancet.

No full-time academic graduate training exists for this specialty. There is little research, and no research is funded by major national granting agencies, such as the National Institute of Health. As for the field's general acceptance in the scientific community, it depends on how you define the community.[124] If the community is limited to people making their living testifying about bite-marks, it is a foregone conclusion that they will reach a consensus that it is "scientific."[125] It also depends on what the community in question must agree on. While testifying forensic odontologists may all agree on their assumptions about the uniqueness of human dentition and their own ability to "match" marks on the victim's skin to a particular person's dentition, there is simply no consensus (even among this limited group) about proper methodology. Although ABFO has issued guidance on many aspects of bite-mark comparisons, it has never addressed the best comparison method to use.[126] So how does this stuff get past the gatekeepers?

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123 FED R. EVID. 702 (as amended Dec. 1, 2000).

124 *See* Beecher-Monas, *supra* note 5, at 8 (discussing the problem of defining the "community" so narrowly that a small cohort of testifying "experts" can agree that their testimony is valid without ever being subject to the scrutiny of the general scientific community).

125 Notably, a number of forensic odontologists have been outspoken in their criticism of the empirical basis of their profession. *See, e.g.*, Bowers, *supra* note 14; Kittelson et al., *supra* note 107; Pretty & Sweet, *supra* note 54; Rothwell, *supra* note 73.

126 *See* Pretty & Sweet, *supra* note 54, at 91 (noting that a court would not be able to determine whether a bite-mark expert was using a generally accepted methodology by reviewing the literature).

A. *Failure to Challenge the Scientific Basis of Bite-Mark Evidence*

One of the huge flaws in the idea of judicial gate-keeping is its reliance on the adversary system to challenge suspect expert testimony. Many defense attorneys simply do not challenge the scientific basis of bite-mark evidence.[127] This failure to challenge prosecution experts could be attributed to under funded and overworked public defenders' offices. It also could be attributed to the defense's not being sufficiently informed. Surprisingly, however, many attorneys do not even seek to obtain expert assistance for their clients.[128] And when the defense does hire an expert, it is another forensic odontologist, who, for obvious reasons, is unwilling to expose his field as complete bunkum. For example, at the trial of Kennedy Brewer, who was later exonerated by DNA evidence, the defense stipulated "that there is a body of scientific knowledge which allows for the identification of individuals based upon bite mark examination on soft tissue."[129] Rather than challenge the science, the defense challenged the expert's qualifications (the infamous Dr. West, who had by this time been suspended from ABFO).[130] When

[127] *See, e.g.*, Ege v. Yukins, 485 F.3d 364 (6th Cir. 2007) (affirming in part and reversing in part the district court's grant of habeas, finding that although bite-mark evidence is admissible, and therefore an objection would have been unavailing, the statistics used to declare a match should have been objected to); State v. Duncan, 802 So. 2d 533 (La. 2001) (affirming the exclusion of defendant's photographic evidence of real victims' actual bite marks where counsel introduced expert testimony that the marks in question were not caused by bites, but counsel did not challenge the scientific basis of bite-mark evidence); Walters v. State, 720 So. 2d 856 (Miss. 1998) (no pre-trial motions seeking forensic odontologist); State v. Fortin, 917 A.2d 746 (N.J. 2007) (remanding on signature crimes testimony; bite mark match testimony apparently unchallenged); Del Torro v. State, No. 04-99-00599-CR, 2001 WL 487996 (Tex. Ct. App. May 9, 2001) (holding that it was not ineffective assistance to fail to request *Daubert* hearing); State v. Arredondo, 674 N.W.2d 647 (Wisc. Ct. App. 2003) (no ineffective assistance although defense counsel failed to challenge basis of match testimony).

[128] *See, e.g.*, Jackson v. Day, 121 F.3d 705 (5th Cir. 1997) (no attempt to obtain defense expert); Howard v. State, 945 So. 2d 326 (Miss. 2006) (defense counsel declined to hire expert); *Walters*, 720 So. 2d 856 (finding no ineffective assistance for failing to obtain a defense bite-mark expert because the defense cross-examined the prosecution expert and "bite mark evidence was but one small bit of evidence identifying the defendant").

[129] Brewer v. State, 725 So. 2d 106 (Miss. 1998); 819 So. 2d 1169 (Miss. 2002) (remanding on newly discovered DNA evidence).

[130] *Brewer*, 725 So. 2d at 125-26 (discussing West's suspension and remarking that the "organizational difficulties" did not affect his qualifications). In at least one case, habeas has been granted on the basis of the defense counsel's deficient performance in failing to object. *See* Ege v. Yukins, 380 F. Supp. 2d 852 (E.D. Mich. 2006) (finding that defendant was deprived of a fundamentally fair trial where the only evidence linking the defendant to the crime was the improperly admitted testimony of a forensic odontologist that a mark on the victim's cheek was a human bite that matched the defendant's dentition, and that out of 3.5 million people residing in the Detroit metropolitan area, the defendant was the only one whose dentition could match the mark). In two cases involving the notorious Dr. Michael West (who claimed to be able to identify marks by shining a blue light on them, a technique no one else could replicate, and which caused his suspension from the American Board of Forensic Odontology, and resignation from

the defense proffered its own expert, Dr. Souviron, he testified that Dr. West (the prosecution expert) was "brilliant" and that Souviron used the "direct comparison" method himself. The defense expert merely disagreed that the marks on the body (which was in "the early to moderate stages of decomposition") were bite-marks at all.[131]

In another such case, the evidence linking the defendant to the crime consisted primarily of two pieces of evidence: the defendant's confession and the testimony of a forensic odontologist that marks found on the victim's body "matched" the defendant's bite.[132] Apparently, the defendant's trial counsel failed to object to the prosecution's forensic odontologist, and did not proffer any counter-testimony.[133] Thus, one-half of the significant evidence in the case went wholly unchallenged. After defendant's conviction, the issues on appeal concerned the confession and the defendant's fitness to stand trial (the defendant had an IQ of 56, could not count backward, tell which direction was east or where the sun came up), but not the bite-mark testimony.[134] The habeas petition similarly omitted any reference to the bite-mark testimony.

On appeal, when appellate lawyers bring ineffective assistance claims, they also tend to overlook the bite-mark evidence, and those that do bring claims on that basis are singularly unsuccessful.[135] *Leal v.*

the International Association of Identification), the challenges were not to the scientific validity of the testimony, but to the expert's qualifications. *See, e.g.*, Brooks v. State, 748 So. 2d 736, 739 (Miss. 1999) (holding that even though the defense made no objection to the bite-mark testimony at trial, "because of the controversial nature of bite-mark evidence," the court took the opportunity to announce—without analysis—"that bite-mark identification evidence is admissible in Mississippi"); *Brewer*, 725 So. 2d at 125 (noting that although the defense challenged the expert's qualifications, the defense and prosecution "stipulated that there is a body of scientific knowledge which allows for the identification of individuals based upon bite mark examination on soft tissue"). For a discussion of the checkered history of Dr. West, as well as his continued use as a prosecution expert, see Paul C. Giannelli & Kevin C. McMunigal, *Prosecutors, Ethics and Expert Witnesses*, 76 FORDHAM L. REV. 1493, 1501-06 (2007) ("The reckless use of a tainted expert should be a due process violation.").

131 *Brewer*, 725 So. 2d at 116, 126.

132 United States *ex rel.* Young v. Snider, No. 01 C 6027, 2001 WL 1298704 (N.D. Ill. Oct. 25, 2001) (declining to issue writ of habeas), *aff'd*, Young v. Walls, 311 F.3d 846 (7th Cir. 2002) (upholding voluntariness of confession).

133 *Snider*, 2001 WL 1298704 at *2.

134 *Young*, 311 F.3d 846 (upholding refusal to issue writ of habeas corpus).

135 *See, e.g.*, Jackson v. Day, 121 F.3d 705 (5th Cir. 1997) (reversing the district court's holding that counsel's failure to retain a forensic odontologist was ineffective assistance because although "this expert testimony would have aided the defense, it merely would have rebutted the testimony of the state's expert"); Walters v. State, 720 So. 2d 856 (Miss. 1998) (holding that no ineffective assistance of counsel for failing to obtain a defense bite-mark expert because the defense cross-examined the prosecution expert and "bite mark evidence was but one small bit of evidence identifying the defendant"); Del Torro v. State, No. 04-99-00599-CR, 2001 WL 487996 (Tex. Ct. App. May 9, 2001) (finding that defense counsel was not ineffective for failing to seek appointment of forensic odontologist to prepare for cross-examination and provide exculpatory testimony, failing to interview prosecution expert odontologist before trial, and failing to voir dire the prosecution expert).

Quarterman,[136] a capital murder case involving prosecution bite-mark testimony, sought post-conviction relief twice, but without success.[137] Apparently, the defense had consulted an expert (another forensic odontologist) who agreed with the conclusion of the prosecution expert that the defendant's bite matched the marks on the victim.[138]

At the evidentiary hearing held in the state habeas action, the prosecution expert testified that he was sure "within a reasonable medical certainty" that the victim's bite-marks were caused by the petitioner's teeth.[139] The defense expert (who was consulted, but did not testify at trial) did not contest the validity of the field of expertise, nor the qualifications of the prosecution's expert, remarking instead that every dentist is qualified to render an opinion on bite-mark evidence,[140] illustrating the problem of having a small cadre of "experts" who all reinforce the appearance of science without ever having to explain its basis.

In *Howard v. State*,[141] the court held that there was no ineffective assistance of counsel despite the failure of the defendant's lawyers to seek a defense odontologist; despite their failure to voir dire or cross-examine the dental expert who prepared the molds of defendant's teeth; and despite defense counsels' failure to challenge the prosecution's odontologist (the infamous Dr. West).[142] In the direct appeal, the court had relied on the statements of defense counsel at sidebar that an expert, Dr. Richard Souviron, had been consulted, but the defense had decided not to call him because "his prediction was that he would probably concur" with Dr. West.[143]

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136 No. SA-07-CA-214-RF, 2007 WL 4521519 (W.D. Tex. Dec. 17, 2007).

137 Leal v. Dretke, No. Civ. SA-99-CA-1301-RF, 2004 WL 2603736 (W.D. Tex. Oct. 20, 2004) (denying habeas); *Quarterman*, 2007 WL 45251519 (denying habeas based on International Court of Justice violation, but granting certificate of appealability).

138 *Dretke*, 2004 WL 2603736.

139 *Id.* at *13.

140 *Id.*

141 945 So. 2d 326 (Miss. 2006). The trial was complicated by the defendant's taking over his own case pro se because it had taken two and a half years to get to trial. *Id.* The original lawyers were directed to act as stand-by attorneys. Predictably enough, the defendant was convicted. *Id.*

142 More than twelve years ago Mark Hanson ran an exposé of West's testimony in the ABA Journal. *See* Mark Hanson, *Out of the Blue*, 82 A.B.A. J. 50 (Feb. 1996) (discussing the numerous cases in which West has testified on everything from bite marks to bleach stains and the complete lack of scientific evidence for any of the testimony). In several of the cases in which he testified about matching bite marks, DNA evidence from the victim has later excluded the convicted defendant. *Id.* This exposé did not, however, appear to have slowed West's testimonial exploits. He was the prosecution expert in *Brewer v. State*, 819 So. 2d 1169 (Miss. 2002), in which DNA found on the victim's body and tested after the conviction excluded the defendant as the source. *See* Shaila Dewan, *Despite DNA Result, Prosecutor Retries a '92 Rape-Murder Case*, N.Y. TIMES, Sept. 6, 2007, at A1 (discussing the capital murder trial and subsequent DNA test showing that the semen in the victim's body was not the defendant's, and noting that despite this apparent exoneration, the prosecution had decided to retry the defendant).

143 *Howard*, 945 So. 2d at 349 (emphasis omitted).

In his petition for post-conviction relief, however, the defendant proffered an affidavit from Dr. Souviron, which demonstrated that the defense counsel had misled the trial court, since Dr. Souviron stated that by the time of trial he had already disagreed in two cases with Dr. West, and in addition, because the victim's body had decomposed for five days, was exhumed and un-embalmed, it would be difficult to know if the marks were bite-marks at all.[144] Moreover, Dr. Souviron averred that, had he been retained, he could have guided the defense voir dire of the prosecution expert, because "Dr. West's statements during voir dire were either half true or misleading" regarding "his expulsion from ABFO, the American Academy of Forensic Sciences and the International Association of Identification" and regarding West's testimony in three prior cases where "the pattern injuries that were interpreted as bite marks by Dr. West were not bite marks."[145] Although the affidavits and other documents proffered by the petitioner "point out how many times Dr. West has been proven wrong and they discuss how unscientific his methods are" that was not enough for the court to provide relief.[146] The court, in denying the petition, found that petitioner "has not proven prejudice to his defense" and remarked that "[j]ust because Dr. West has been wrong a lot, does not mean, without something more, that he was wrong here."[147]

In a partial exception to the failure of most courts to find ineffective assistance for failing to object to bite-mark testimony, the Sixth Circuit granted habeas, in *Ege v. Yukins*,[148] finding a violation of due process because trial counsel did not to object to the 3.5 million to one odds given by the state's witness, Dr. Warnick.[149] In the course of its rather convoluted opinion, the Sixth Circuit took pains to explain that "[b]ite mark evidence may by its very nature be overly prejudicial and unreliable, but it may nevertheless be admitted under Michigan evidence law, and we do not question the Michigan courts' judgment with respect to admission of the bite mark evidence standing alone."[150] The court offers no explanation of how evidence that "by its very nature" may be "overly prejudicial and unreliable" can hope to meet due process standards of fundamental fairness.

The only physical evidence in this case linking the defendant to the crime was the purported bite-mark on the victim's cheek.[151] The initial autopsy report concluded the marks to be livor mortis. The victim's

144 *Id.* at 350.
145 *Id.* at 351 (emphasis omitted).
146 *Id.* at 352.
147 *Id.*
148 485 F.3d 364 (6th Cir. 2007).
149 *Id.* at 376.
150 *Id.* (footnote omitted).
151 *Id.* at 367.

body was exhumed, nine years after the murder, but it was too badly decomposed to be able to assess the marks. Dr. Warnick, relying on the original autopsy photographs, concluded that the marks were bites, and testified at trial that the marks matched the defendant's dentition to the exclusion of anyone else in the Detroit metropolitan area.[152]

Subsequent to Ege's conviction, the Sixth Circuit noted that Dr. Warnick's expert testimony was "found to be in essence a sham by a party on whose behalf the testimony was given"[153]—the Wayne County prosecutors' office.[154] Because the letter merely flagged the unreliability of bite-mark testimony, however, the Sixth Circuit found that Ege's "free-standing ineffective assistance claim—that her counsel blundered in not objecting to Dr. Warnick's bite mark evidence" was time-barred.[155]

On the other hand, the defendant's due process claim was based on the adequacy of the physical evidence presented against her. Because the court could not say that it should have been obvious to Ege "that the *substance* of the physical evidence–at least as presented by Dr. Warnick–was complete bunk" she was permitted to bring that claim.[156] Her due process claim was founded on the improper admission of the state's bite-mark testimony, which she claimed was "both substantively and probabilistically unsound."[157]

The Sixth Circuit found that there was no foundation for connecting the bite-mark to the defendant's dentition or for the probability statement.[158] However, because at trial the defense presented evidence that the marks were not bites at all, the Sixth Circuit held that the impact of the testimony was diffused so that any error was harmless. The probability statement, however, was not diffused because the defense experts did not directly rebut it. Therefore, defense counsel's failure to object to the probability statement at trial was "objectively unreasonable" and presenting defense experts did not insulate counsel's performance.[159] Thus, the Sixth Circuit upheld the admissibility of bite-mark evidence while overturning only the

152 *Id.* at 368.

153 *Id.* at 374.

154 In this letter, the Chief of Operations of the Wayne County Prosecutor's Office explained that Dr. Warnick's testimony in two cases had been totally unreliable. *Id.* at 372. In one case the defendant later had been excluded by DNA evidence, and in the other a second expert undermined his probability statement. *Id.* As a result, the county would not approve warrants "where the main evidence as to the identity of a potential defendant is the opinion of Dr. Warnick that he/she is the source of the bite marks." *Id.*

155 *Id.* at 373.

156 *Id.*

157 *Id.* at 374.

158 *Id.* at 374-75.

159 *Id.* at 379 (finding that Ege had met "both the nested cause and nested prejudice prongs" for ineffective assistance).

quantitative probability statement given in conclusion.

B. *Admitting Bite-Mark Testimony Because Other Courts Have*

When defense counsel do challenge bite-mark testimony, they are rarely successful. Courts simply decline to engage in any serious analysis of these challenges. By far the most widely used gate-keeping avoidance technique that judges employ is admitting bite-mark evidence because other courts have done so.[160] Rather than engage in any analysis of the scientific principles on which the testimony is based, the data underlying the testimony, the methodology, error rate, or general acceptance by the scientific community, these courts skirt the entire issue by finding neither a *Daubert* nor a *Frye* hearing necessary because other courts have previously admitted the testimony (also without such hearings). For example, the court in *People v. Moreno*,[161] held bite-mark evidence to have been properly admitted despite the absence of a *Frye* hearing, because courts had been admitting this type of evidence for more than fifty years.[162]

The court in *State v. Swinton*[163] mentioned *Daubert* in passing. However, it found that bite-mark evidence was neither unreliable nor controversial, citing (pre-*Daubert*) cases rather than examining the scientific basis for the testimony.[164] The court was more concerned about the computer-enhanced methodology used in the comparison (the prosecution's expert used the soft-ware programs Lucis and Adobe

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160 *See, e.g.*, Calhoun v. State, 932 So. 2d 923, 925 (Ala. Ct. App. 2005) (finding bite-mark testimony admissible because it has "received evidentiary acceptance in nineteen jurisdictions" and "[n]o jurisdiction has rejected the admission of such evidence"); State v. Swinton, 847 A.2d 921 (Conn. 2004) (citing cases finding bite-mark testimony admissible); People v. Lester, No. 2004-198274-FH, 2006 WL 3421799 (Mich. Ct. App. Nov. 28, 2006) (finding bite-mark testimony admissible in Michigan without a "*Daubert/Frye* hearing" because it is generally accepted); Stubbs v. State, 845 So. 2d 656 (Miss. 2003) (holding that bite-mark testimony is admissible in Mississippi, citing cases); State v. Blamer, No. 00CA07, 2001 WL 109130 (Ohio Ct. App. Feb. 6, 2001) (citing Rule 702 and *Daubert* without analysis, stating "it is clear" that expert's testimony was qualified and citing other cases that found bite-mark testimony admissible); Seivewright v. State, 7 P.3d 24 (Wyo. 2000) (finding bite-mark testimony admissible in a burglary prosecution without a *Daubert* hearing because courts have widely accepted it). This phenomenon does not appear to be limited to bite-mark testimony. It also appears to be a common occurrence in handwriting testimony. *See* Risinger, *supra* note 32, at 468 (noting the string-citing of courts of appeals decisions as authority for the generic admissibility of handwriting expertise).

161 No. 1023104, 2003 WL 22132196 (Cal. Ct. App. Sept. 16, 2003).

162 *Id.* at *6. Moreover, even if the trial court had abused its discretion in not holding a *Frye* hearing, the appellate court found the testimony to be harmless error in light of other evidence in the case. *Id.* at *7.

163 847 A.2d 921 (Conn. 2004).

164 *See id.* at 933 n.14 (disagreeing with appellant's contention that bite-mark evidence was unreliable and controversial).

Photoshop, but did not create the Photoshop images himself), rather than scientific grounds.[165] Because the prosecution's bite-mark expert could not answer questions about how Photoshop worked, the court concluded that it was error to admit the Photoshopped images, but ultimately harmless, because the expert had concluded that there was a match even before seeing the images.[166]

C. *The "It Is Not Novel" Approach*

Another way that courts grandfather the admissibility of bite-mark evidence is the "it's not novel" approach. This strategy permits the judge to avoid gate-keeping because these courts assert that only novel scientific evidence requires scrutiny.[167] This was the approach of the Minnesota Supreme Court in *State v. Hodgson*,[168] which found that neither *Frye* nor *Daubert* applied to bite-mark testimony because it was "satisfied that basic bite-mark analysis by a recognized expert is not a novel or emerging type of scientific evidence."[169]

Such an approach not only ignores the cursory approach to evaluation taken by the earlier cases, but it also misconstrues the nature of scientific evidence. Just because courts made prior errors in admitting bite-mark evidence does not seem to be a particularly good reason to continue doing so, nor does it appear to be a very thoughtful approach to the problem. Moreover, even if the prior analyses had been sound, that is no guarantee that new information has not undermined the validity of the technique. These judges completely miss the changing nature of scientific information. New data may well demonstrate the fallacy of old assumptions.

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165 *Id.* at 954-55. The court disposed of the constitutional Confrontation Clause problem by finding that the defendant's expert had himself used Photoshop images to demonstrate the inadequacies of the prosecution expert's conclusion and thus had a "meaningful opportunity to probe the reliability of [the prosecution's expert's] identification testimony." *Id.* at 955.

166 *Id.* at 952, 957-58. In addition, the defense expert made what appears in retrospect to have been a huge blunder. To demonstrate the fallacy of prosecution expert's assertions regarding time of the bite in relation to the time of the victim's death, he used the molds of defendant's teeth to make a mark on his own arm, which the prosecution expert used to demonstrate to the jury what he considered to be the unique features of the dentition and how similar the marks were to those on the victim's breast. *Id.* at 958.

167 *See, e.g.*, People v. Quaderer, No. 242721, 2003 WL 22801204, at *1 (Mich. Ct. App. Nov. 25, 2003), *appeal denied*, 680 N.W.2d 899 (2004) (affirming child abuse conviction despite the absence of a *Frye* hearing because such a hearing is required only if the scientific principles are new); State v. Hodgson, 512 N.W.2d 95, 98 (Minn. 1994) (testimony connecting mark on defendant's arm to victim's teeth was not a novel type of scientific evidence).

168 *Id.*

169 *Id.*

D. *The "It's Not Science" Circumventing Gambit*

Even when courts acknowledge that some level of scrutiny is required for scientific evidence, they may avoid gate-keeping by finding that bite-mark evidence is not scientific. While *Kumho Tire* should have retired that particular gambit by explaining that gate-keeping requirements apply to all expertise, not just what the courts were calling "hard" science,[170] courts continue to permit bite-mark evidence in without scrutiny because it is not science. In *Carter v. State*,[171] for example, the court cited its own 1977 precedent for the proposition that bite-mark evidence was reliable, and then held that because such evidence was "simply a matter of comparison," it did not fall within the aegis of "scientific principles."[172] Nor did the court think there was any danger that the jury had "overestimated the value of the bite mark evidence," since it "was highly probative to rebut the defendant's contention that he was not a participant in the beating or murder of the victim but was merely present."[173] The court seems to have entirely missed the point that evidence without any empirical basis–whether or not it wishes to call it scientific–cannot be probative of anything.

The notion that "physical comparisons" are "not subject to the stringent standards applied to scientific tests" was similarly voiced by the Alabama Court of Appeals, in *Calhoun v. State*.[174] The court does not address the question of why the testimony of two prosecution experts was necessary to proclaim a match, if the jury could simply observe the marks and come to its own conclusions. Rather, the court cited bite-mark testimony's "evidentiary acceptance in nineteen jurisdictions" and noted that Florida had similarly decided that "the jury is able to see the comparison for itself."[175] This reasoning ignores the question fundamental to the relevance of bite-mark testimony: how likely the perceived physical similarity would be, had someone other than the defendant made the mark (a question that cannot be answered without a population database). Nor does the court address the distortions and subjectivity inherent in the models and photographs it believes that the jury can see for itself.

Acknowledging that bite-mark testimony could not meet *Daubert* standards, the Oklahoma solution was to exclude expert "match"

170 Kumho Tire Co. v. Carmichael, 526 U.S. 137, 147-48 (1999).

171 766 N.E.2d 377 (Ind. 2002).

172 *Id.* at 380-81.

173 *Id.* at 381-82.

174 932 So. 2d 923, 952 (Ala. Crim. App. 2005).

175 *Id.* at 952-53 (quoting Bundy v. State, 455 So. 2d 330, 349 (Fla. 1984), and rejecting the application of *Frye*'s general acceptance standard to bite-mark testimony).

testimony, while permitting expert testimony just short of that.[176] For example, in a capital murder trial, expert testimony was admissible that photographs taken of the defendant's right arm showed a "'probable bite-mark', which means, 'the pattern strongly suggests or supports origin from teeth, but could conceivably be caused by something else.'"[177] Despite the defense claims that such testimony was irrelevant because there was no connection made between the marks and the victim, the court nevertheless found it circumstantially relevant; not to the identity of the murderer, but to whether the defense had concocted the story he told the police that his brother had hit him before the murder.[178] Why or how that incident was connected to the murder the court does not explain, although the court stated that the marks could be relevant to malice aforethought.

Garrison is a troubling case. It was not tried until twelve years after the murder, and the only physical evidence linking the defendant to the murder were a piece of wire (that prosecution experts could not be sure came from a spool owned by the defendant) and a photograph of the contested marks on the defendant's arm. The defense challenged the prosecution's expert testimony and requested a *Daubert* hearing. Although the defense expert had to have transplant surgery shortly before the hearing, the judge would not postpone the hearing, and so the hearing proceeded without any defense expert.[179] At trial, the defense and prosecution experts disagreed over whether the mark was a bite at all.[180] On appeal, the defense claimed ineffective assistance of trial counsel for (among other things) failing to call an expert to testify at the *Daubert* hearing regarding the admissibility of the bite-mark testimony.[181] This reasoning completely misses the point of gatekeeping requirements and evades the appellate court's responsibility to monitor the trial court's adherence to these standards.

The court of appeals held that failing to produce an expert at the *Daubert* hearing was not ineffective assistance, even if it would have been beneficial, since the defense's bite-mark expert ultimately did testify at trial.[182] Nor did the court of appeals find that failing to grant a continuance for the hearing so that the defense expert could attend was abuse of discretion on the part of the trial judge.[183]

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[176] *See* Garrison v. State, 103 P.3d 590, 603-06 (Okla. Crim. App. 2004) (citing Crider v. State *ex rel.* Dist. Ct. of Okla. County, 29 P.3d 577 (Okla. Crim. App. 2001)).

[177] *Id.* at 603.

[178] *Id.* at 596-604 (referring to the defendant's conversation with police, regarding charges that he had filed against his brother for assault nine days before the murder).

[179] *Id.* at 613-14.

[180] *Id.* at 596.

[181] *Id.* at 612.

[182] *Id.* at 614.

[183] *Id.* at 619. *But see id.* at 619-20 (finding, however, that there was ineffective assistance regarding the mitigation phase of the capital proceedings, and thus remanding for resentencing).

E. *Absence of Meaningful Review*

The circumventing gambits of the lower courts would not be such a huge problem if there were meaningful review of their decisions. There is not. For one thing, the abuse of discretion standard gives reviewing courts ample opportunity to unthinkingly affirm the admissibility decision. For another, the courts are rightly reluctant to second-guess the credibility determinations made by the lower court.

Taking their review responsibilities seriously, however, does not entail either unthinking affirmance or appellate credibility evaluations.[184] Instead, it requires examining the process that the judge used to reach the admissibility determination.[185] Failure to follow the legally prescribed approach to admissibility determinations is not discretionary.[186] If the process was reasonably designed to discover whether there was a rational basis for the expert's testimony, then it should be upheld.[187] That is not, however, what is happening with bite-mark testimony. As noted above, the courts of appeals just uphold its admissibility based on precedent, its lack of novelty, or its unscientific basis.

Federal courts are also unwilling to step into the fray. Because habeas claims must be based on a violation of federal statute or constitutional law,[188] claims about the improper admission of bite-mark testimony tend to be based either on ineffective assistance of counsel (for failing to hire an expert, develop evidence, or make objections), sufficiency of the evidence, or due process/fundamental fairness. The

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[184] *See* Kumho Tires Co. v. Carmichael, 526 U.S. 137, 158-59 (Scalia, J., concurring) (Justice Scalia, joined by Justices O'Connor and Thomas, wrote: "I join the opinion of the Court, which makes clear that the discretion it endorses—trial-court discretion in choosing the manner of testing expert reliability—is not discretion to abandon the gatekeeping function. I think it worth adding that it is not discretion to perform the function inadequately. Rather, it is discretion to choose among *reasonabl*e means of excluding expertise that is *fausse* and science that is junky. Though, as the Court makes clear today, the *Daubert* factors are not holy writ, in a particular case the failure to apply one or another of them may be unreasonable, and hence an abuse of discretion.").

[185] *See, e.g.*, Michael J. Saks, *The Legal and Scientific Evaluation of Forensic Science (Especially Fingerprint Expert Testimony)*, 33 SETON HALL L. REV. 1167, 1183 (2003) (delineating the post-*Daubert* courts' failures to grapple with the scientific validity of fingerprint expertise and noting that "[t]hree concurring Justices in *Kumho Tire* anticipated such evasions, and suggested that they were likely to constitute an abuse of discretion").

[186] *See* Risinger, *supra* note 32, at 461 n.55 (noting that if a court violates the mandates of *Kumho Tire*, the appellate court should reverse and remand for a new determination absent harmless error).

[187] *See Kumho Tire*, 526 U.S. at 152 (explaining that the standard applies to the question of how to decide reliability as well as the decision on admissibility).

[188] *See* Herrera v. Collins, 506 U.S. 390, 400 (1993) (claims of innocence based on newly discovered evidence are not grounds for federal habeas relief absent independent constitutional violation occurring in the underlying state criminal proceeding).

admissibility of evidence in state courts is generally held to be a matter of state law.[189]

Thus, in *Milone*, when the petitioner claimed that the bite-mark evidence that had been used to convict him was unreliable under both *Frye* and *Daubert*, the Seventh Circuit held that because neither opinion purports to set a constitutional floor, the question would have to be "whether the probative value of the state's evidence was so greatly outweighed by its prejudice to Milone that its admission denied him a fundamentally fair trial."[190] Even though the petitioner's claim was that the bite-mark actually was made (and the murder committed) by someone else—a serial murderer who had confessed to the crime (and then hanged himself in his cell)—the court held that the bite-mark testimony did not deny him a fundamentally fair trial.[191] He had presented his own experts in court, and had cross-examined the prosecution experts. As for sufficiency,[192] there was opportunity, a link to the murder weapon, proximity, and—the bite-mark.[193]

Although the question before the court in *Thomas v. Beard*[194] was whether admitting unreliable evidence (bite-mark testimony) violated the petitioner's right to a fair trial, the court turned to state court precedent to determine whether bite-mark evidence was reliable.[195] Rather than examine the processes the state courts had engaged in to determine reliability, the federal court just cited to precedent, noting that "Pennsylvania courts have specifically allowed the use of bite-mark evidence, and provided there is adequate foundation for the testimony, such evidence is not per se fundamentally flawed."[196] That, of course, was precisely the petitioner's claim, that the evidence was fundamentally flawed. Rather than address that claim, the court turned to whether counsel had been ineffective in failing to present defense expert testimony on the bite-mark issue.[197] Because defense counsel had raised the issue of reliability in cross-examination and questioned the qualifications of the prosecution expert and the substance of his

189 *See* Milone v. Camp, 22 F.3d 693, 702 (7th Cir. 1994) ("[A] federal court can issue a writ of habeas corpus on the basis of a state court evidentiary ruling only when that ruling violated the defendant's right to due process by denying him a fundamentally fair trial.").

190 *Id.*

191 *Id.* (opining, without analysis, that "certainly there is some probative value to comparing an accused's dentition to bite marks found on the victim").

192 A federal court reviewing a state court conviction for sufficiency must determine "whether, after viewing the evidence in the light most favorable to the prosecution, any rational trier of fact could have found the essential elements of the crime beyond reasonable a doubt. *Id.* at 703 (quoting Jackson v. Virginia, 443 U.S. 307, 319 (1979)).

193 *Milone*, 22 F.3d at 703.

194 388 F. Supp. 2d 489 (E. D. Pa. 2005).

195 *Id.* at 527.

196 *Id.* (citing Commonwealth v. Henry, 569 A.2d 929, 934 (Pa. 1990), a pre-*Daubert* decision).

197 *Id.*

testimony, the court found counsel's performance "adequate."[198] Thus, no constitutional rights had been violated.

Raising claims of false testimony does not appear to be any more successful as a strategy. For example, in *Spence v. Johnson*,[199] the Fifth Circuit declined to characterize defense challenges to the prosecution's expert testimony as claiming false testimony. Rather, the court viewed claims of unreliability, backed up by the expert's misidentification of another woman and critiques of the expert's methodology and conclusions as going to the weight of the evidence, and as having been fully litigated in the state courts.[200] Moreover, "critically," according to the court, the defense expert (another forensic odontologist) had testified at trial that he could not rule out the defendant's teeth as a source of the bite marks.[201] This case and *Thomas* perfectly illustrate the conundrum of the defense: challenges to the entire field are undercut by presenting an expert in that same field; on the other hand, without a testifying defense expert, it is difficult to demonstrate the dissension in the field. Further, the approaches of both courts neatly ignore the crux of the matter: in *Thomas*, whether the whole field is so unreliable that a trial based on such evidence is fundamentally unfair; and in *Spence*, that an expert need not be lying to be testifying falsely. Testifying to nonsense, even nonsense the expert believes, is testifying falsely.

III. RELEVANCE REDUX: WHAT COURTS SHOULD DO

The commitment to a rational system of evidence entails the exclusion of irrelevant information.[202] If experts cannot demonstrate that their field of expertise has an empirical basis, whatever opinion the expert may have reached is irrelevant. It has no tendency to make any fact in issue more or less probable.

Relevance is the threshold criterion for admissibility. Even scholars arguing for "free proof" acknowledge the importance of screening information to ensure that it has some tendency to make a disputed issue in the case more or less probable.[203] As Roberts and Zuckerman explain the concept, "relevance, like physical presence and pregnancy, conforms to the concept of the excluded middle."[204] There

[198] *Id.*

[199] 80 F.3d 989 (5th Cir. 1996).

[200] *Id.* at 1000 (distinguishing Johnson v. Mississippi, 486 U.S. 578 (1988)).

[201] *Id.*

[202] *See* William Twining, *The Rationalist Tradition of Evidence Scholarship*, *in* RETHINKING EVIDENCE: EXPLORATORY ESSAYS 35 (1990) (discussing the rationalist tradition).

[203] *See, e.g.*, Michael S. Pardo, *On Misshapen Stones and Criminal Law's Epistemology*, 86 TEX. L. REV. 347 (2007) (book review).

[204] ROBERTS & ZUCKERMAN, *supra* note 13, at 99.

is no shade of gray here. Something is relevant or not, in relation to a disputed issue—here whether the accused can be linked to the victim through marks on the victim's body. Unless there is an empirical basis for the assertion that a link can be made, any assertion about a link is meaningless. It cannot make the link more or less probable. This legal test is basic to rationality. If something is not logically probative, no rational system of evidence should consider it.

The reason for admitting only relevant evidence is the danger that irrelevancies may be mistaken as bearing on the question at hand, and this may make the ultimate decision unfounded and inaccurate (or, if accurate, only by chance). Such evidence is affirmatively misleading. If the input is wrong, no reasoning process can be expected to make correct inferences.[205] Although inaccuracy is a possible factor in any evidence, not just expert testimony, baseless expert testimony is particularly pernicious because the entire reason it is being admitted is that the jury lacks the background knowledge necessary to evaluate it.[206] So do judges, but judges at least have the benefit of training in critical thinking, guidelines for the evaluation of scientific testimony, repeat exposure, and a measure of accountability.[207]

Moreover, there are good reasons to exclude irrelevant information from the decision process. Although irrelevant information should be disregarded in making a judgment, studies show that presenting decision makers with both irrelevant and relevant information leads to less accurate decisions than if only relevant information were presented.[208] Some of the pioneering work on this effect, known as the dilution effect, demonstrated that people responded differently to stories with the same relevant information if some were also presented with irrelevant information. For example, in making diagnoses, medical students made more accurate diagnoses when they were presented with only relevant information than if they were also given extraneous information.[209] Irrelevant information that ought to be ignored has a

[205] *See* Alvin I. Goldman, *Simple Heuristics and Legal Evidence*, 2 L. PROBABILITY & RISK 215, 219 (2003) (explaining that even deductive reasoning requires true premises in order to reach true conclusions).

[206] *See* Mark P. Denbeaux & D. Michael Risinger, Kumho Tire *and Expert Reliability: How the Question You Ask Gives the Answer You Get*, 34 SETON HALL L. REV. 15 (2003) (*Daubert* implies a view that misleading expert evidence is worse—and less amenable to correction through cross-examination—than misleading lay testimony).

[207] *See* BEECHER-MONAS, *supra* note 5, at 33-35 (discussing why judicial gatekeeping has more potential for reaching accurate conclusions about expert testimony than simply admitting the evidence subject to cross-examination).

[208] *See* Robyn M. Dawes, *Behavioral Decision Making and Judgment*, *in* THE HANDBOOK OF SOCIAL PSYCHOLOGY 497, 537 (Daniel T. Gilbert et al. eds., 4th ed. 1998) (citing studies explaining that exposure to uninformative information can influence decisions).

[209] *See* Philip E. Tetlock et al., *The Dilution Effect: Judgmental Bias, Conversational Convention, or a Bit of Both?*, 26 EUR. J. SOC. PSYCHOL. 915, 916 (1996) ("[L]inking diagnostic with nondiagnostic evidence produced more regressive predictions than people would otherwise

way of creeping into, and skewing the decision.[210]

For example, when people are asked to decide whether someone has a particular characteristic (such as aggression), irrelevant information (such as the physical attractiveness of the person in question) tends to obscure what is relevant, making for inaccurate decisions.[211] This may be due to the fact that people listen for details around which they can construct stories that comport with their views about how the world works.[212] Even irrelevant information can go into constructing these stories.

This danger is particularly salient when the irrelevant information plays into commonly held stereotypes. Jurors' prior experiences filter and order their expectations.[213] The story model of jury decision-making also helps to explain the importance of basing judgments on accurate information. This model posits that juries weave stories from the testimony at trial that fit with their pre-existing views about how the world works.[214] One of these pre-existing views is the collective mythology that a suspect can be identified from marks left behind at the crime scene.[215] Thus, any story that includes the identification of the

have made.").

210 *See* Dawes, *supra* note 208, at 532 ("Dilution effects occur when evidence that does not distinguish between hypotheses in fact influences people to change their mind." (emphasis removed)).

211 Dennis J. Devine et al., *Jury Decision Making: 45 Years of Empirical Research on Deliberating Groups*, 7 PSYCHOL. PUB. POL'Y & L. 622, 679 (2001) (discussing leniency shift toward attractive defendants).

212 *See, e.g.*, J. RICHARD EISER & J. VAN DER PLIGT, ATTITUDES AND DECISIONS 100 (1988) ("[A]ccuracy declines considerably when the number of features or the number of alternatives increases. [And] reliability with which choice rules are used tends to decrease as the decision-maker's information load increases.").

213 *See* Shari S. Diamond, *How Jurors Deal with Expert Testimony and How Judges Can Help*, 16 J.L. & POL'Y 47, 51 (2007) (observing from a series of empirical studies that the "jury is not a blank slate that merely absorbs trial evidence and instructions").

214 *See* Nancy Pennington & Reid Hastie, *Evidence Evaluation in Complex Decision Making*, 51 J. PERSONALITY & SOC. PSYCHOL. 242, 243-45 (1986) (positing a model in which jurors use their preconceptions to create a story from the evidence they heard at trial, take the jury instructions and create verdict alternatives, and attempt to find the best correlation between the story and the verdict alternatives).

215 *See* Simon A. Cole, *Where the Rubber Meets the Road: Thinking About Expert Evidence as Expert Testimony*, 52 VILL. L. REV. 803, 836 (2007) (noting that, with respect to latent fingerprint evidence, the "power of the testimony derives from the talismanic power of the word 'fingerprint,' rather than from any articulation of the probative value of the evidence," and concluding that "the cultural mythos is so strong and so deep that even judicial control over testimony may be incapable of overcoming it"). Professor Cole asserts that courts and scholars have focused too much on admissibility and too little on the over-claiming that is characteristic of forensic expert testimony. *Id.* at 838-39. The kind of expert over-claiming that Professor Cole has identified in latent fingerprint testimony is also common in bite-mark testimony, judging from the published opinions. However, in forensic odontology, where there is a professional association with all the trappings of scientific endeavors, the problem is not only a lack of professional standards (the ABFO Guidelines are not mandatory), but the absence of any basis for them.

defendant as the perpetrator will be enormously influential.[216]

When it comes to expert testimony, relevance must be considered in tandem with reliability.[217] *Daubert* and amended Rule 702 both stress reliability of expert testimony as a facet of relevance, and therefore of admissibility.[218] Another way of expressing this notion of reliability is through the concept of warrant, which depends on how well the testimony is supported.[219] The task is to distinguish well supported from poorly supported evidence. This requires some judgment. With lay testimony, a judge can assess whether, if true, the testimony would have any tendency to make an issue in the case more or less true.[220] But with expert testimony, this requires another step. The reason for this is that unlike the opinions of lay witnesses, which must be "rationally based on the perception of the witness,"[221] expert witnesses testify on "scientific, technical, or other specialized knowledge."[222] In order to qualify as "knowledge" rather than rank speculation, the proponent of the evidence must demonstrate warrant. The problem is that warrant—unlike admissibility—is not an all or nothing proposition.[223]

Just as relevance must be considered in relation to some issue in the case, warrant (reliability) must be considered in relation to the claims that are being made for the evidence. For example, epidemiology studies are almost never perfectly analogous to a particular tort case being tried, having generally been done on some cohort that differs in some respects from the plaintiff, but they may still be sufficiently relevant and reliable to be admissible. The theory behind epidemiology is demonstrably sound, and as long as the tests have been

216 *See, e.g.*, Saks & Koehler, *supra* note 50, at 202 (noting that "[p]opular television programs . . . reinforce the notion of individualization in the collective public imagination by offering confident pronouncements from scientists" and questioning the ability of forensic science to deliver on such claims).

217 Justice Blackmun explained that reliability for admissibility purposes is different from what scientists call reliability (which he defined as getting "consistent results") in that for legal purposes, reliability means scientific validity (which he defined as "the principle supports what it purports to show" and "trustworthiness"). Daubert v. Merrill Dow Pharm., Inc., 509 U.S. 579, 590 n.9 (1993).

218 *Id.* at 589 (finding that courts should screen expert evidence for relevance and reliability); FED. R. EVID. 702 (noting that to be admissible, expert testimony must be based on sufficient data and reliable methods).

219 *See, e.g.*, Susan Haack, *Of Truth, in Science and Law*, 73 BROOK. L. REV. 985, 997 (2008) (explaining the epistemic term "warrant").

220 Trustworthiness is also a concern with some types of lay testimony, which is why the Federal Rules exclude hearsay. *See* FED. R. EVID. 802 (a) ("Hearsay is not admissible . . . ."). Where indicia of trustworthiness exist, the rules make exceptions. FED. R. EVID. 802(b).

221 FED. R. EVID. 701(a).

222 FED. R. EVID. 702.

223 *See* Susan Haack, *Not Cynicism but Synechism: Lessons from Classical Pragmatism*, 41 TRANSACTIONS OF THE CHARLES S. PEIRCE SOC'Y 239, 240 (2005) (arguing that while admissibility is categorical, reliability is continuous).

properly performed with the requisite controls, and correctly statistically analyzed with outcomes similar to the harm suffered by the plaintiff, the imperfect reliability of the studies should not keep the testimony from being admissible. For the epidemiology example, the problem is one of extrapolation.[224]

In the case of bite-mark testimony, however, the theory of unique dentition has never been demonstrated, nor has the empirical determination that two different items (a mark on the victim and a mold of the dentition of the suspect) contain sufficient detail to substantiate a match, there are no controls, and the statistics employed are complete balderdash. Thus, while reliability may be a continuum, bite-mark identification testimony fails to reach even the extreme low end. Bite-mark testimony cannot even meet threshold relevance requirements for admissibility.

Indeed, as the Habers have pointed out with respect to fingerprint evidence, even the preliminary foundations necessary before one can begin to evaluate the empirical basis necessary for the technique's relevance have yet to be done.[225] For one thing, before the accuracy of the methodology can be assessed, the proponents of the technique must be able to establish an official protocol, or agreed description of the method.[226] As noted above, bite-mark specialists have yet to accomplish even this preliminary step. Once the protocol has been adopted by general consensus, the profession "needs to write and then adopt a report form that examiners complete that shows that each step is followed."[227] This step is necessary to ensure the reliability (i.e., replicability) of the method, and whether the practitioner has adhered to each of its steps. Formal training in the protocol, and an assessment of how well the practioner is following are also important, so that "it can be determined whether individual trainees or working examiners have learned and use the steps of the method correctly."[228] Finally, before the validity of the methodology can be evaluated, the profession must establish proficiency tests reflecting the difficulty of normal casework, and measuring performance during each step of the technique. Without such a preliminary foundation, which bite-mark experts have yet to lay, there is really no way to evaluate their claims to expertise.

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224 *See* ZEISEL & KAYE, *supra* note 17.

225 See Lynn Haber & Ralph N. Haber, *Scientific Validation of Fingerprint Evidence Under* Daubert, 7 L. PROBABILITY & RISK 87, 88 (2008) ("[T]he ACE-V method [for fingerprint identification] has not been tested for validity, and until the necessary work is performed to quantify the method and ensure that examiners are using the method correctly and consistently, the method cannot be validated.").

226 *Id.*

227 *Id.* at 93 (explaining the importance of documenting the steps the expert took to reach a conclusion).

228 *Id.* at 94 (discussing the importance of setting specific goals and assessment of whether the goals were met by the practitioner).

While reliability may be a continuum rather than categorical, at some point in the continuum, there is simply not enough support for a proposition to be relevant to any issue in the case. In popular parlance, there is no "there" there. That is precisely the problem for forensic odontology. While it may be logically defensible to admit testimony (subject to cross-examination) that has a solid scientific foundation, but has questionable application to the case at hand, that is not the situation with bite-mark identification testimony. When a forensic scientist offers testimony that a particular bite-mark is unique without any data to support that assertion, it simply cannot be warranted.[229]

Because determining relevance and reliability require the exercise of judgment, judges frequently punt on this issue, sending the evidence to the jury for its weight.[230] It is sheer nonsense—and a dereliction of gate-keeping responsibilities—to say, as courts are wont to do, that the flaws of bite-mark testimony go to its weight rather than its admissibility. First, admitting expert testimony in the first place implies that the court has found the testimony relevant and reliable—the jury knows that relevance is a basis for exclusion. Second, it is the proponent's obligation to substantiate the basis for admissibility, and admitting unreliable expert testimony transfers responsibility for demonstrating unreliability (in a criminal trial) onto the defense.[231] Third, conflicting accounts about what counts as science tend to divert the jury from the question that primarily concerns them (in criminal cases, whether this evidence demonstrates the defendant's guilt).

When experts come to different conclusions, even though both experts base their conclusions on solid science, that goes to weight. Even scientists with integrity, whose work is based on solid research, can reach different conclusions, drawing different inferences from the available evidence. But that is not the situation with bite-mark testimony. If expert conclusions, like those of bite-mark experts, are based on the illusion of science without its substance, that "expertise" should be excluded. Without an empircal basis, expert testimony simply has no place in court. It has no tendency to make the identification of the perpetrator—the disputed issue of fact to which the evidence is related—any more or less probable, and is therefore irrelevant.

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229 *Cf.* David L. Faigman, *Judges as "Amateur Scientists,"* 86 B.U. L. REV. 1207, 1224 (2006) (characterizing forensic identification evidence as "possibly the biggest embarrassment to the legal profession at this time" because "[u]nlike scientists who often make inferential leaps from general research to particular cases, forensic experts generally do not have any general data at all[, making them] . . . . essentially technicians who apply a technology built upon general statistical models that do not exist").

230 *See* Gary Edmond, *Specialised Knowledge, the Exclusionary Discretions and Reliability: Reassessing Incriminating Expert Opinion Evidence*, 31 U. NEW S. WALES L.J. 1 (2008) (using the example of facial mapping testimony in Australia).

231 *See id.* at 28.

Although cross-examination and the presentation of contradictory expert testimony are the traditional cures for "attacking shaky but admissible evidence,"[232] expert testimony that lacks any empirical foundation is resistant to this kind of correction. The reason for this phenomenon is that without data the assumptions made by the expert sound perfectly plausible. As Justice Learned Hand (over a century ago) expressed the jury's dilemma with respect to expert testimony, "how can the jury judge between two statements each founded upon an experience confessedly foreign to their own?"[233]

For example, in mock jury studies about the effectiveness of cross-examination, it apparently made little difference whether the defense challenged the expert testimony; whether the defense pointed out in cross examination that the expert's conclusions were inconsistent with prior research and that the expert had not followed standard methodology; whether the defense not only cross-examined the prosecution expert, but also put on its own expert.[234] Although the jurors discussed the expert evidence in their deliberations, and although there was a strong correlation between the prosecution expert's testimony and the jury's verdict preferences, the results did not vary among the first three conditions. This illustrates the fallibility of expecting cross-examination to expose the flaws in bite-mark testimony.

On the other hand, when an expert acknowledges a high error rate before announcing a conclusion, it does appear to make a difference. In a fourth condition, where the prosecution expert acknowledged that there was a sixty-six percent error rate in the methodology, but nonetheless opined a conclusion supporting the prosecution, there was a significant reduction in verdicts favoring the prosecution.[235] Unfortunately, no such acknowledgment has been forthcoming from bite-mark experts, who testify with certainty and without acknowledging error rates.

Empirical studies of jury decision making also demonstrate that when decision makers are unable to evaluate the expert testimony, they resort to cues, defer to expertise, and accept the most prestigious source.[236] When there is a battle of the experts, one expert may appear

[232] Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579, 596 (1993) ("Vigorous cross-examination, presentation of contrary evidence, and careful instruction on the burden of proof are the traditional and appropriate means of attacking shaky but admissible evidence.").

[233] Learned Hand, *Historical and Practical Considerations Regarding Expert Testimony*, 15 HARV. L. REV. 40, 54 (1902).

[234] *See* Joseph Sanders, *The Merits of the Paternalistic Justifications for Restrictions on the Admissibility of Expert Evidence*, 33 SETON HALL L. REV. 881, 936 (2003) (discussing the experimental work of Shari Diamond, et al., and concluding that "rulings excluding unreliable evidence promote jury accuracy even if we assume jurors are as good as judges in assessing reliability").

[235] *Id.* at 933.

[236] *See* Diamond, *supra* note 213, at 56. Professor Diamond suggests that judges permit jurors

more credible for reasons that have little to do with the scientific validity of the testimony.[237]

If, as the story model of juror decision making suggests, jurors decide cases by selecting the competing story that best fits their notions of plausibility,[238] scientific evidence that is embedded in the narrative may make the story seem more plausible than is warranted.[239] When one expert testifies that based on the marks found on the victim's body, and the model of the defendant's bite, there is a match, that is pretty persuasive story telling. Far more persuasive, for example, than the story is that we simply cannot tell what made those marks, or—if anyone—who made them.

CONCLUSION

The use of good science is a crucial component of justice. It is an important facet of justice for the litigants in the criminal justice system, it is important to the rationality of the judges' role and it is important in jury reasoning towards an accurate verdict. It is intellectually indefensible, and even cynical to continue admitting as expert testimony evidence that has not been able to demonstrate its empirical basis. Dressing the evidence in the trappings of science does not make it scientific. Science is not magic; it is the hard, painstaking work of careful research. Unless forensic odontologists are willing to engage in that empirical endeavor, they can have no knowledge to impart to the fact-finder, and their testimony should not enter a courtroom. For at least a decade now, judges have known that they are responsible for keeping junk science out of the courtroom. Yet, circumventing their gate-keeping responsibilities, judges continue to admit bite-mark testimony into evidence.

Part of this is the fault of the defense for failing to challenge the evidence.[240] Under-resourced and overworked public defenders,

to ask questions of the experts, and notes that when such questions are permitted, many questions focused on alternative explanations for expert observations. *Id.* at 58.

237 *See* Goldman, *supra* note 205, at 221 ("[O]ne expert's greater surface credibility than his opponent may be the subjectively best cue available for choosing between them, but surface credibility might be a notably unreliable cue.").

238 *See* Nancy Pennington & Reid Hastie, *A Cognitive Theory of Juror Decision Making: The Story Model*, 13 CARDOZO L. REV. 519, 520 (1991).

239 *See* Gary Edmond, *Science, Law and Narrative: Helping the 'Facts' to Speak for Themselves*, 23 S. ILL. U. L.J. 555, 579 (1999) (noting that when "embedded in a narrative, especially if considered legitimately scientific, [evidence] may heavily influence the perception of the plausibility of particular aspects of a narrative and possibly the entire narrative").

240 *See, e.g.*, Risinger, *supra* note 8, at 135 (noting an "apparent systematic failure to seriously litigate these issues on the part of the criminal defense bar" particularly with regard to bite-mark evidence, where between 1993 and 1999, in only four or five of the forty-eight cases in the study

however, have little incentive to devote time and energy to a battle that has been lost in almost every case where it has been attempted. Without a judiciary willing to take its gate-keeping role seriously, there is little point in making fruitless objections.

Moreover, unless the appellate courts are also willing to take their review duties seriously, there is little prospect for change. The abuse of discretion standard of review for trial court evidentiary decisions, made explicitly applicable to expert testimony admissibility decisions in *Joiner*,[241] gives trial court judges a great deal of leeway in making bite-mark admissibility decisions. This standard does not give unlimited leeway, however, and certainly not the kind of leeway that courts reviewing bite-mark admissibility have been giving. Any serious review of courts' strategems to avoid serious evaluation of the methodology could not but find that the courts holding bite-mark testimony admissible had failed to engage in the process set out by the federal rules and *Daubert*, and thus had abused their discretion.

The empirical inquiry envisioned by the *Daubert* trio and the amendment to Federal Rule of Evidence 702 has simply been discarded in favor of categorical admissibility by relying on precedent. Early cases in which no reliability inquiry was performed have become precedent for admissibility decisions in perpetuity, so that courts never have to address the underlying issues. This is exacerbated because in the criminal context, the only cases that are appealed are those in which the prosecution evidence was admitted, and the defendant was convicted, which tends to skew the appellate decisions in the direction of affirming admittance.[242] While habeas courts could put a stop to this by finding the admissibility of such flagrantly bogus expertise a violation of fundamental fairness, only *Ege* has done this, and then only for the quantification opinion, rather than for the bite-mark identification.

The lower courts have the tools to make proper validity assessments. The *Daubert* trilogy and the amendment to Rule 702 have been implemented routinely and (for the most part) well in the civil context. The appellate courts could find that trial courts refusing to employ these tools of analysis—or employing them in a "wooden"[243] fashion—have abused their discretion. And habeas courts could find that state systems that admit evidence without any empirical foundation

was there "any indication that that the foundational reliability of such evidence was challenged"). In the period from January 2000 through August 2008, of the forty-six bite-mark identification cases I found, there were seven foundational reliability challenges, but none that were successful.

241 Gen. Elec. Co. v. Joiner, 522 U.S. 136, 142-43 (1997).

242 *See* Risinger, *supra* note 32, at 469 (noting the problem of skewed appellate decisions in the context of criminal handwriting cases).

243 *Id.* at 460 (noting the mechanical way in which *Daubert* is applied in handwriting cases); *see also* Saks, *supra* note 185, at 1171 (noting that in post-*Daubert* fingerprint cases, "the number of cases in which the courts conscientiously applied *Daubert* and *Kumho Tire* [was] zero").

in a criminal case have violated precepts of fundamental fairness.

It does take some intellectual effort. But lawyers and judges are trained in critical thinking. Admitting testimony into evidence that has no empirical basis violates every precept of logic, rule of evidence, and notion of fundamental fairness. To continue to admit such testimony just because it has been admitted in the past defies reason. Failing to demand that the proponents of this evidence demonstrate its validity defies justice.

EXHIBIT C
APPENDIX K

Construct validity of Bitemark assessments using the ABFO decision tree

Adam Freeman
Iain Pretty*

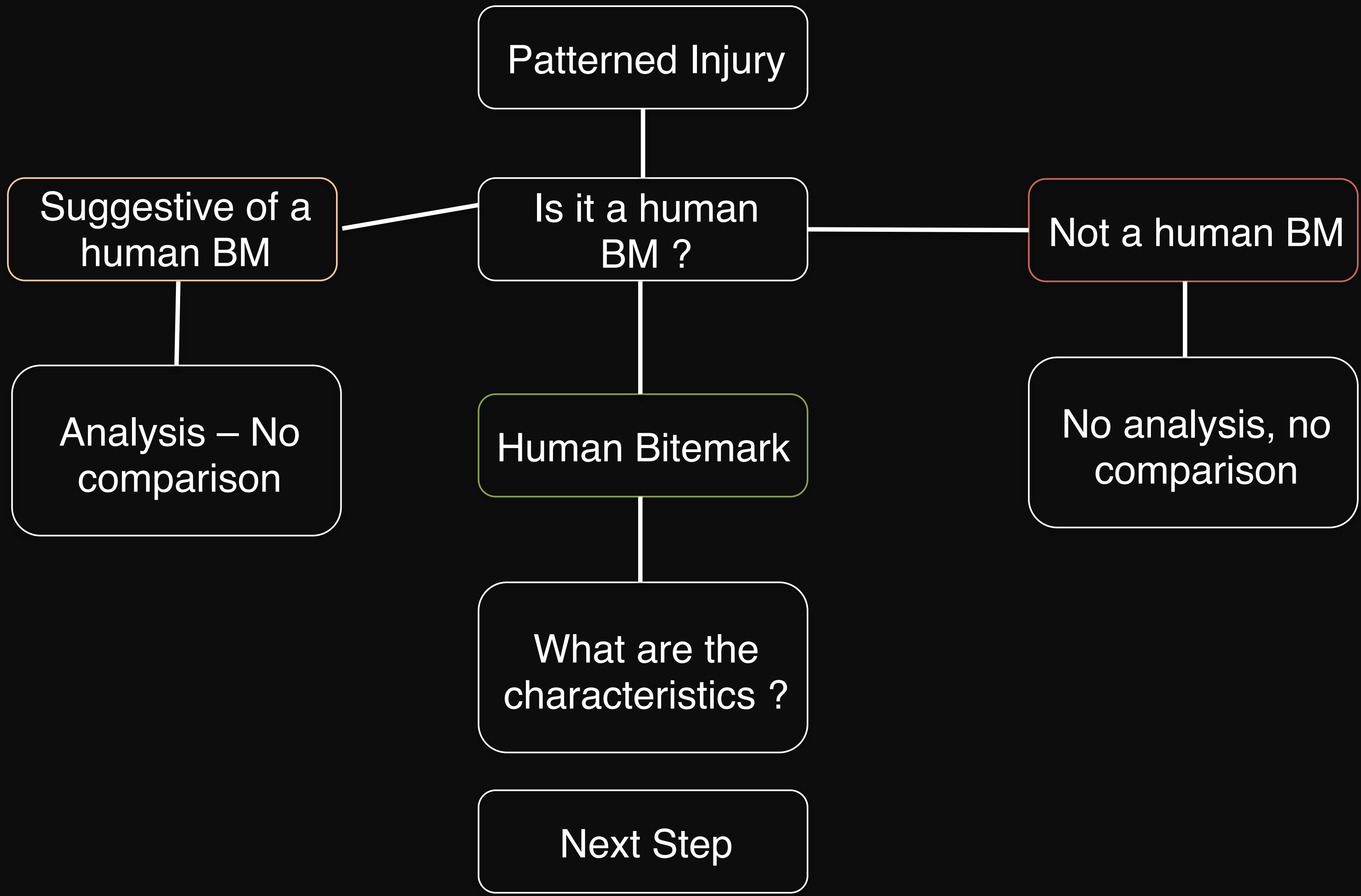
Overview of presentation

- Background
- Scientific approach
- Methods
- Results
- Impact and suggestions

Background

The decision tree is a means of formalizing the approach to bitemark analysis by taking the assessor through a series of stages and decisions that aim to ensure that the decisions made are consistent with the level of forensic evidence available.

Background – Schematic of tree



Background

This study examined Step 1 – the evaluation of the injury, is the injury a bitemark and if so, what are the bitemark's characteristics?

Today presenting data on the assessment of the injury as a bitemark only

Scientific approach

Several methods being applied to BM research:

- Mechanistic approach
- Decision making approach

In the absence of truth we are using construct validity – through reliability testing - if its not reliable its not valid.

Methods

250 cases submitted by DABFO – included an orientation shot and a close up with scale

Selected 100 cases to represent a wide spread of anatomical location, presentation, evidence quality

Presented to DABFO on an online system with anonymity of decisions

Asked if there was sufficient evidence to render any opinion, and if so, what is it?

Methods

Data collected

Demographics reported

Kappa used to measure agreement

Descriptive statistics to assess the spread of decisions and understand the reasons for disagreement

Results

38 Diplomates completed the whole study, 44 completed partially.

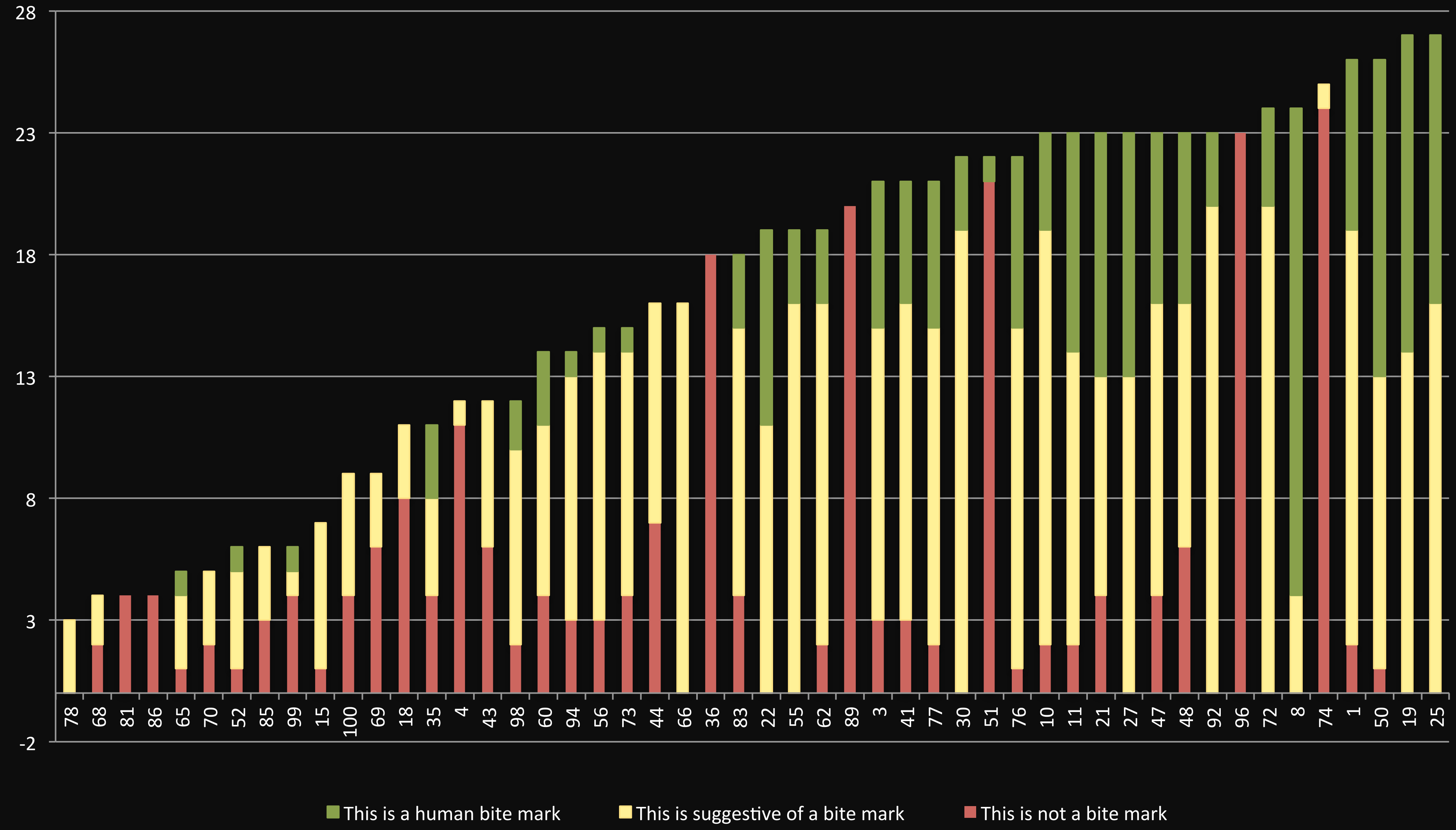
Represents a total of 3924 decisions on bitemark cases

Range of experience measured in three ways:

- How many cases in past 5 years – 18.58
- How many years have you been active – 19.87
- How many times have you testified in the past five years? – 2.05

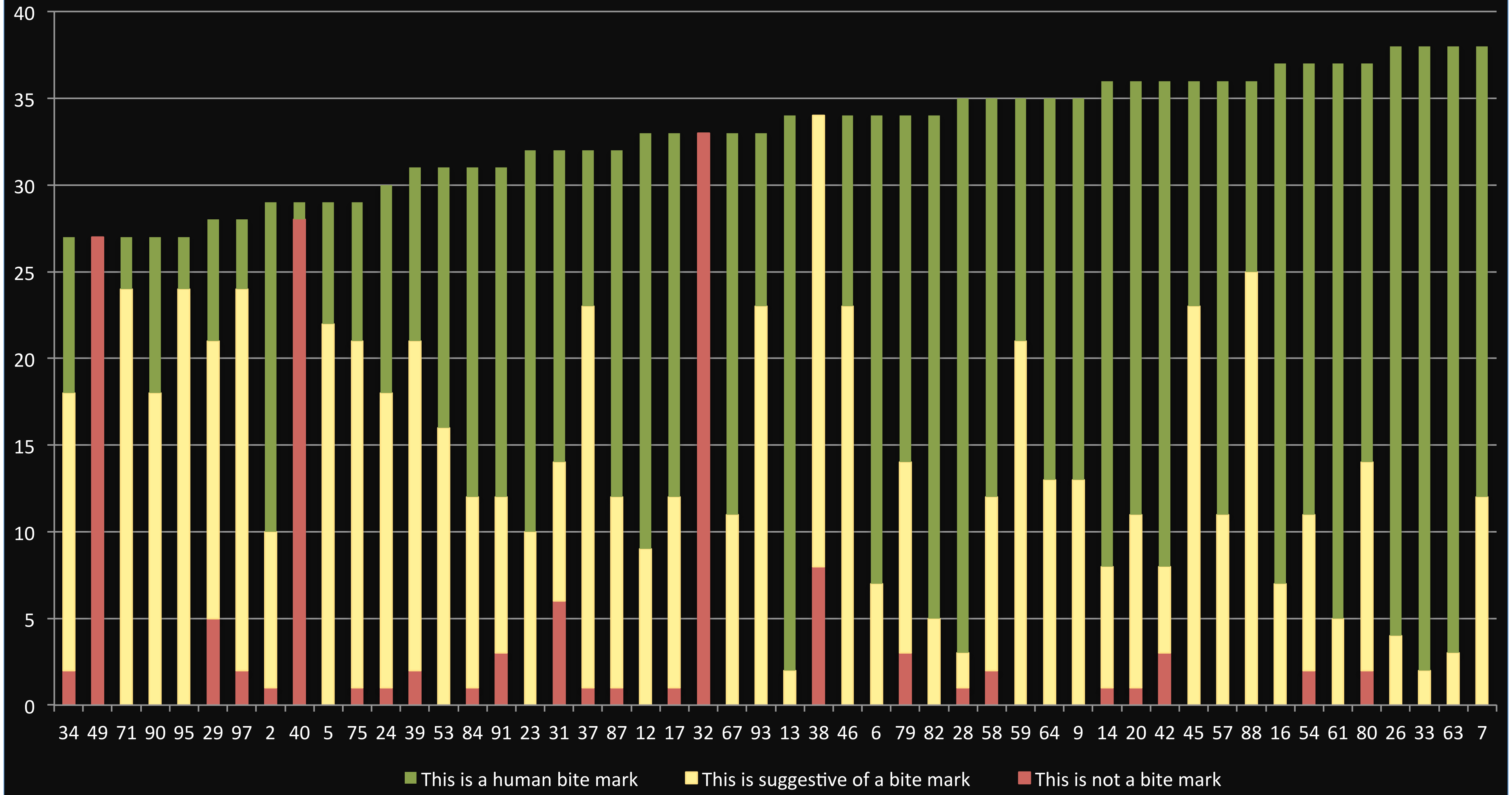
Results – decision spread

Look at the spread of decisions for individual cases.



Results – decision spread

Look at the spread of decisions for individual cases.



Impact and suggestions

All research has strengths and weaknesses

- Good number of decisions
- A lot of work – not all diplomates completed
- Some argued that not realistic approach

The study suggests level of reliability of injury assessment for bitemarks is *not currently satisfactory* from the population of assessors studied

The impact of *three choices* from the decision model has decreased reliability– removal of “suggestive” combined with greater detail on the identification of bitemarks within the decision model should be considered. The use of a simpler, dichotomous decision, should lead to increased reliability – although the decision direction of the “suggestives” is unknown.

Impact and suggestions

We need to undertake further examination of those cases where there *was higher levels of agreement* to determine how the decision tree can capture these elements to improve reliability, both for bites and non-bites.

The first step of BM analysis is determining if the presented injury is a bitemark – the current data suggest that agreement levels observed require significant improvement and means of achieving this have been proposed. A further assessment following the introduction of these changes will be required.

Thank you

We would like to thank those Diplomates who submitted their cases for inclusion in the study and for those who took the time to complete the exercise.

Thank Dr Peter Loomis, and the ABFO, for supporting this work through design, implementation and reporting of findings.

EXHIBIT D

Bitemark Evidence
TFSC Panel

November 16, 2015

David R. Senn, DDS, D-ABFO

Agenda Items

…discussion of criticisms (e.g., areas of agreement and disagreement) by the complainant and others,

…comments on Decision Tree study by Drs. Pretty and Freeman

…research performed by Mr. Peter and Dr. Mary Bush and others

…the appropriate use, role, and limitations of bitemark evidence

IP Complaint Letter

IP asks that the TFSC

...exercise its statutory mandate to investigate and report on "the integrity and reliability" of bite mark evidence as used in criminal proceedings.

What parts of the complaint letter are:

True

Partially True

Not True

two in Texas to date.[3] That this technique is responsible for so many miscarriages of justice is not surprising. As this complaint outlines, no validated and reliable science remotely supports bite mark evidence, and what science there is affirmatively disproves even the most basic assumptions which underlie it. Bite marks, moreover, "often are associated with highly sensationalized and prejudicial cases, and there can be a great deal of pressure on the examining expert to match a bite mark to a suspect." *see* Ex. A at 175 (NATIONAL ACADEMY OF SCIENCES, Committee on Identifying the Needs of the Forensic Sciences Community, STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES: A PATH FORWARD (2009) ("NAS Report")). This, along with the fact that bite mark analysis is entirely subjective, greatly increases the risk of wrongful conviction in bite mark cases.

Given the complete lack of science supporting bite mark analysis, and the grave risk of wrongful conviction use of the technique poses, bite marks represent an ideal and critical opportunity for this Commission to bring to bear its statutory mandate to "advance the integrity and reliability of forensic science" in Texas. *See* Tex. Crim. Proc. Code Ann. § art. 38.01(4)(a-1). We thus ask that this Commission undertake a thorough investigation of bite mark evidence. Our request is that this investigation include retrospective and prospective components. Retrospectively, we ask that this Commission audit those cases in which bite mark comparison testimony was offered. Prospectively, we ask this Commission declare a moratorium on the continued use of bite mark comparison evidence in criminal prosecutions until such time as the technique has been scientifically validated and proven reliable. Doing so will not only advance this body's statutory mission, but also help ensure that no more innocent Texans are incarcerated as a result of this dangerously unreliable "science."

Bite Mark Analysis Has Never Been Validated or Proven Reliable

The use of bite mark comparison evidence in criminal trials rests on a series of unproven assumptions. First, bite mark comparison evidence assumes that the biting surfaces of teeth (i.e., the dentition) are unique. Second, it assumes that human skin is capable of accurately recording the dentition's unique features. Third, it assumes that forensic dentists can reliably associate a dentition with a bite mark. Finally, bite mark comparison assumes that, given all the foregoing, forensic dentists can provide a scientifically valid estimate as to the probative value of the association. But, as this letter will demonstrate, no science supports these assumptions, and thus no science supports the conclusion that a perpetrator can be identified from a bite mark in human skin.

The Dentition Has Never Been Scientifically Demonstrated to be Unique

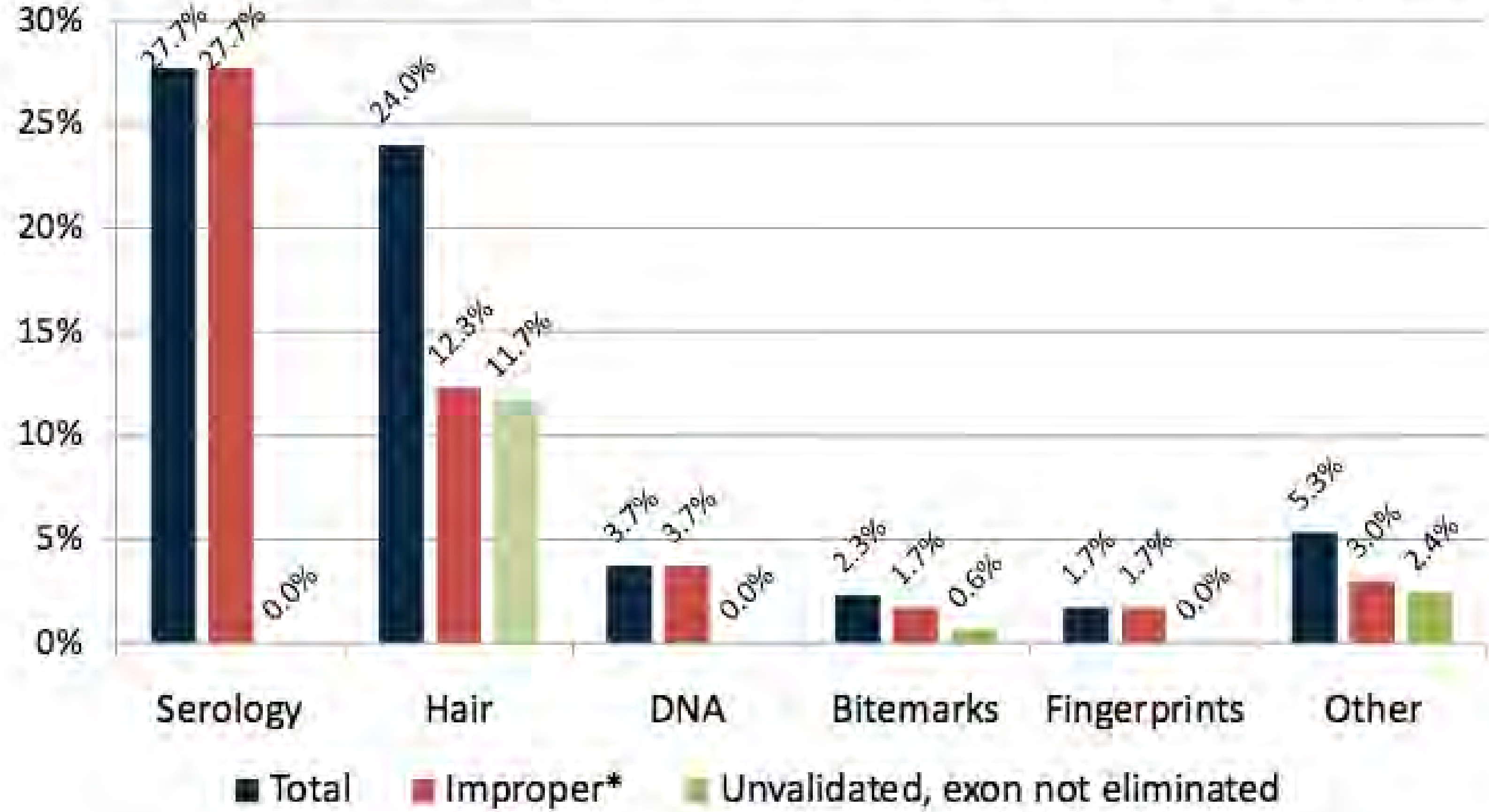
The first assumption of bite mark comparison evidence is that the human dentition (i.e., the biting surfaces of teeth) is unique. But this proposition has never been demonstrated by science to be valid or reliable. In 2009, the National Academy of Sciences ("NAS")—an organization made up of the nation's most accomplished

[3] For more on the exonerations of Calvin Washington and Joe Sidney Williams, and the probable wrongful convictions of Steven Mark Chaney and others in Texas, *see infra*.

Not True

Page 1 Paragraph 2
…of those disciplines currently in use, it is bite mark comparison evidence that poses the most acute threat to the reliability and fairness of Texas's criminal justice system

51% of 300 DNA Exonerations Involved Use of Improper/Unvalidated Forensic Science: Breakdown by Discipline



* **Improper category includes**: testimony or analysis which drew conclusions beyond the limits of science as known at that time; cases in which there was negligence in analysis, fabrications/alterations of reports and possible failures to conduct elimination testing or comparison; and withholding laboratory reports, analysis, data, or the very existence of evidence

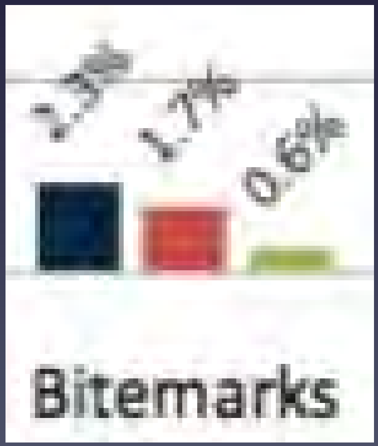
http://www.innocenceproject.org/causes-wrongful-conviction/FSBreakdownDiscipline.pdf

Posted: October 26, 2015   12:18 PM
DNA Exonerations Nationwide

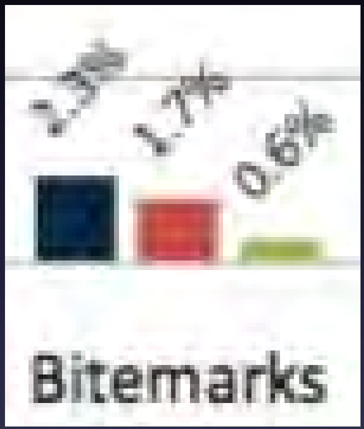
There have been 333 post-conviction DNA exonerations in the United States.

http://www.innocenceproject.org/free-innocent/improve-the-law/fact-sheets/dna-exonerations-nationwide#sthash.TpsnXOPN.dpuf

Eyewitness Misidentification Testimony was a factor in more than 70 percent of post-conviction DNA exoneration cases in the U.S., making it the leading cause of these wrongful convictions.

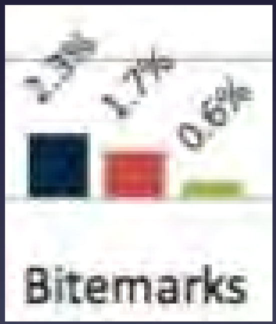


Unvalidated or Improper Forensic Science played a role in 47 percent of wrongful convictions later overturned by DNA testing.



False confessions and incriminating statements were present in approximately 28 percent of cases.

Informants contributed to wrongful convictions in 16 percent of cases.



Not True

Page 1 Paragraph 2

…no less than 24 people have been wrongfully convicted or indicted on the basis of bite mark evidence.

Some of the 21 listed cases had included two individuals. In the Washington and Williams case in Texas, only one of the defendants (Williams) was linked to a bitemark. Washington was excluded

IP listed 21 cases, 14 Exoneration and 7 Indictment

- 10 of the cases included definitive bitemark linking statements (2/10 by non-certified dentists and 5/10 from one ABFO dentist)
- Of the remaining 11 cases the BM opinions were variations of "consistent" (possible, not excluded etc)
- Several included opposing & contradictory ABFO odontologist testimony
- In 3 of the exoneration cases, panels of certified odontologists* assisted efforts by re-assessing the bitemark evidence…Pro Bono

* + Dr. Pretty (not ABFO) in one case

Of the 14 Exoneration and 7 Indictment cases:

- 5 of the total 21 cases and fully half (5/10) of the definitive opinion cases listed were from the casework of one certified Odontologist, Dr. Michael West of Mississippi
  - The ABFO had suspended Dr. West for one year following an ethics complaint
  - Dr. West resigned from the ABFO after a second ethics complaint was filed by a certified odontologist

Not True

Page 2 Paragraph 1

no validated and reliable science remotely supports bite mark evidence, and what science there is affirmatively disproves even the most basic assumptions which underlie it.

See extensive list of research submitted to the panel by ABFO President Berman which should include:

Kieser, et al,
The Uniqueness of the Human Anterior Dentition: A Geometric Morphometric Analysis" J Forensic Sci, May 2007, Vol 52, No 3

"In conclusion, it appears that the incisal surfaces of the anterior dentition are in fact unique."

Johnson, et al,
Quantification of the Individual Characteristics of the Human Dentition" Journal of Forensic Identification, 2009, Vol 59, No. 6

"It is the opinion of the authors that all pattern evidence, including human bitemarks, can have forensic value in the investigation of crime if significant detail is present."

Bernitz, van Heerden, Solheim, Owen
A Technique to Capture, Analyze, and Quantify Anterior Teeth Rotations for Application in Court Cases Involving Tooth Marks. J. For. Sci. 2006, 51 (3), 624-629.

" The measurement of each individual tooth rotation together with its individual discrimination potential will enhance the evaluation of the concordant features observed in bite marks."

Bernitz, Owen, van Heerden, Solheim. T.
An Integrated Technique for the Analysis of Skin Bite Marks.
J. For. Sci. 2008, 53 (1), 194-98.

" Each stage of the analysis adds to the confirmation (or rejection) of concordance between the dental features present on the victim and the dentition of the suspect. The results illustrate identification to a high degree of certainty."

…what science there is affirmatively disproves even the most basic assumptions which underlie it.

A asessment of some of the reported science that affirmatively disproves will follow later in the discussion

True

Bite marks, moreover, often are associated with highly sensationalized and prejudicial cases, and there can be a great deal of pressure on the examining expert to match a bite mark to a suspect.

What factors other than those listed by the Innocence Project can lead to erroneous convictions?

Predicting Erroneous Convictions: A Social Science Approach to Miscarriages of Justice

December 2012

Jon B. Gould, Julia Carrano, Richard Leo, Joseph Young

This project was conducted under Grant No. 2009-IJ-CX-4110 awarded by the National Institute of Justice, Office of Justice Programs, United States Department of Justice.

What primarily distinguishes the erroneous conviction cases from near misses…?

J. Gould, et al., "Predicting Erroneous Convictions," 99 Iowa Law Review 471 (2014)

- weaker defenses than other innocent defendants;

Ineffective assistance of counsel, or bad lawyering…defendants retain or are burdened with attorneys who lack the time, experience, or professional responsibility to zealously represent their clients. The resulting representation may include failures to investigate an alibi defense, investigate prosecution witnesses, enlist experts to challenge the prosecution's physical evidence, or even attend or stay awake for hearings.

What primarily distinguishes the erroneous conviction cases from near misses…?

J. Gould, et al., "Predicting Erroneous Convictions," 99 Iowa Law Review 471 (2014)

- prosecutors were less willing to turn over exculpatory evidence when required by law
  (Brady material)

According to the IP website, government misconduct was a factor in the Brewer, Brooks, Brown, and Krone cases.

What primarily distinguishes the erroneous conviction cases from near misses…?

J. Gould, et al., "Predicting Erroneous Convictions," 99 Iowa Law Review 471 (2014)

- cases relied disproportionately on flawed forensics and lying witnesses (non-eyewitnesses);

…what primarily distinguishes the erroneous conviction cases from near misses…?

- investigators more often engaged in tunnel vision…

Tunnel vision… tendencies "that lead actors in the criminal justice system to 'focus on a suspect', select and filter the evidence that will 'build a case' for conviction, while ignoring or suppressing evidence that points away from guilt."

Keith A. Findley & Michael S. Scott, The Multiple Dimensions of Tunnel Vision in Criminal Cases, 2006 WIS. L. REV. 291, 292

Indeed, if there is but one conclusion from our research it is that, overall, the erroneously convicted are truly cases of systemic failure.

J. Gould, et al., "Predicting Erroneous Convictions," 99 Iowa Law Review 471 (2014)

Other Challenges to Bitemark Evidence

- NAS Report
- Frye Hearings
- The Innocence Project/Defense Bar
- SUNY-Buffalo based research

National Academies:

(National Academy of Sciences)

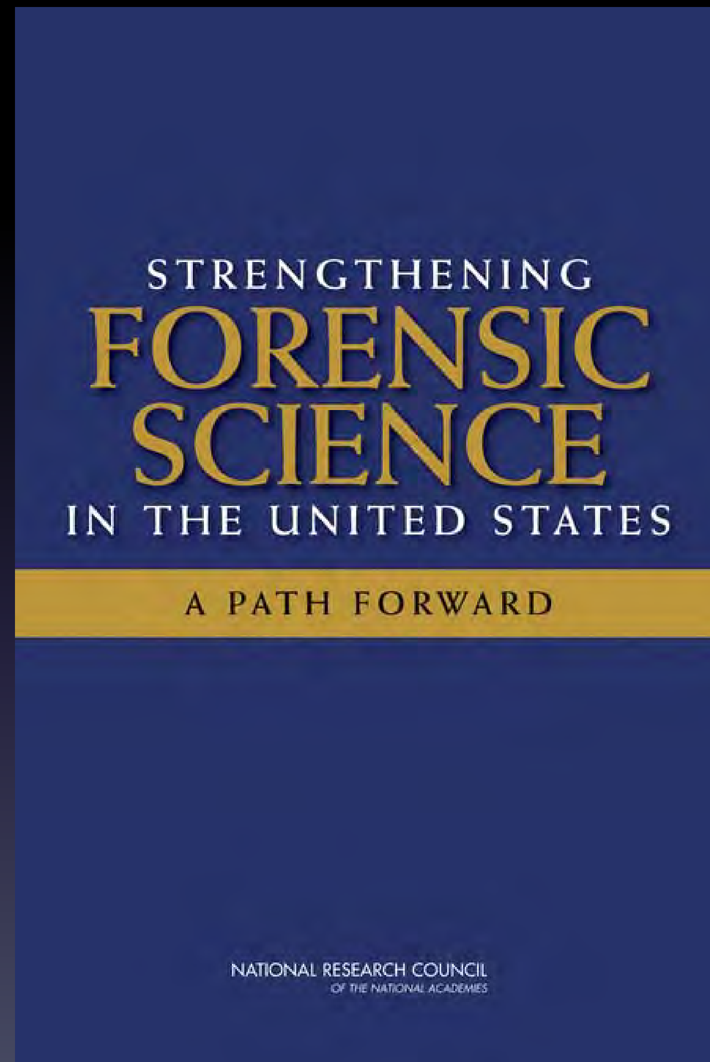
Committee on Science, Technology and Law

Policies and Global Affairs

Committee on Identifying the Needs of the Forensic Science Community

2009

"The NAS Report"



NAS Report targeted:

- Fingerprints
- Firearms and Ballistics
- Toolmarks
- Questioned Documents
- Hair Analysis
- Arson Investigation
- Forensic Odontology (but only Bitemark Evidence)

Information

Bitemark information reviewed
by the NAS committee

According to the NAS Report references…

References

120 J.A. Kieser. 2005. Weighing bitemark evidence: A postmodern perspective. *Journal of Forensic Science, Medicine, and Pathology* 1(2):75-80.
121 American Board of Forensic Odontology at www.abfo.org.
122 Ibid.
123 Rothwell, op. cit.
124 American Board of Forensic Odontology, op. cit.
125 Bowers, op. cit.
126 Bowers, op. cit.
127 American Board of Forensic Odontology, op. cit.
128 Senn, op. cit.
129 Ibid.
130 Ibid.
131 American Board of Forensic Odontology, op. cit.
132 I.A. Pretty. 2003. A web-based survey of odontologists' opinions concerning bite mark analyses. *Journal of Forensic Sciences* 48(5):1-4.
133 C.M. Bowers. 2006. Problem-based analysis of bite mark misidentifications: The role of DNA. *Forensic Science International* 159 Supplement 1:s104-s109.
134 I.A. Pretty and D. Sweet. 2001. The scientific basis for human bitemark analyses—A critical review. *Science and Justice* 41(2):85-92.

Take out the ibids and op cits from the 15 references listed…

1. Kieser 2005
2. Rothwell 1995
3. Senn 2007
4. Pretty 2003
5. Bowers 2006
6. Pretty and Sweet 2001

In the order cited

120 J.A. Kieser. 2005. Weighing bitemark evidence: A postmodern perspective. *Journal of Forensic Science, Medicine, and Pathology* 1(2):75-80.

123 B.R. Rothwell. 1995. Bite marks in forensic dentistry: a review of legal, scientific issues *J Am Dent Assoc 1995;126;223-232*

128 D. R. Senn. 2007. Presentation and examination before the National Academies: Committee on Identifying the Needs of the Forensic Science Community, Meeting 2,
Washington, D.C., April 23, 2007

132 I.A. Pretty. 2003. A web-based survey of odontologists' opinions concerning bite mark analyses. *Journal of Forensic Sciences* 48(5):1-4.

133 C.M. Bowers. 2006. Problem-based analysis of bitemark misidentifications: The role of DNA. *Forensic Science International* 159 Supplement

134 I.A. Pretty and D. Sweet. 2001. The scientific basis for human bitemark analyses—A critical review. *Science and Justice* 41(2):85-92.

132 I.A. Pretty. 2003. A web-based survey of odontologists' opinions concerning bite mark analyses. *Journal of Forensic Sciences* 48(5):1-4.

133 C.M. Bowers. 2006. Problem-based analysis of bitemark misidentifications: The role of DNA. *Forensic Science International* 159 Supplement

134 I.A. Pretty and D. Sweet. 2001. The scientific basis for human bitemark analyses—A critical review. *Science and Justice* 41(2):85-92.

132 I.A. Pretty. 2003. A web-based survey of odontologists' opinions concerning bite mark analyses. *Journal of Forensic Sciences* 48(5):1-4.

Survey of forensic dentists views on crucial components of bitemark theory and contentious areas within the discipline.

91%-believed that the human dentition was unique

78%-uniqueness could be represented on human skin

70%-believed that they could positively identify an individual from a bitemark

22%-believed that the product rule, should be applied to bitemark conclusions.

Over half…used overlays for bitemark analysis

Pretty's 2003 paper was a survey…
interesting, potentially important, but a survey

The remaining 5 sources cited by the NAS report:

1. Kieser 2005
2. Rothwell 1995
3. Senn 2007
4. Bowers 2006
5. Pretty and Sweet 2001

Chronologically

1. Rothwell 1995
2. Pretty and Sweet 2001
3. Kieser 2005
4. Bowers 2006
5. Senn 2007

Cited by committee from Rothwell:

Also, some practical difficulties, such as distortions in photographs and changes over time in the dentition of suspects, may limit the accuracy of the results.[123]

What they did not cite…

Rothwell, BR, Bite marks in forensic dentistry: a review of legal, scientific issues *J. Am Dent Assoc 1995;126;223-232*

A rational approach to bite mark evidence

…problems and limitations associated with bite marks do not necessarily relegate the whole field to question and subjectivity.

…if bite marks, particularly those involving human skin, are approached in a rational, systematic way with full understanding of the innate limitations, they can be worthwhile forensic evidence.

1. Rothwell 1995
2. Pretty and Sweet 2001
3. Kieser 2005
4. Bowers 2006
5. Senn 2007

I.A. Pretty and D. Sweet. 2001. The scientific basis for human bitemark analyses—A critical review. *Science andJustice* 41(2):85-92. Quotation taken from the abstract.

The NAS report quoted…

(Pretty and Sweet)reported thier 2001 review, "revealed a lack of valid evidence to support many of the assumptions made by forensic dentists during bite mark comparisons." 134

The Committee failed to review or did not report…

"…research suggests that bitemark evidence, at least that which is used to identify biters, is a potentially valid and reliable methodology. It is generally accepted within the scientific community…

Pretty in Bitemark Evidence, 2005

And…

Certainly forensic odontologists have been shown to embrace research and have been prepared to publish results of their performance. … With further research to answer the questions regarding spread of ability, bitemark analysis should be presented in court with a sound scientific backing.

Pretty in Bitemark Evidence, 2005

1. Rothwell 1995
2. Pretty and Sweet 2001
3. Kieser 2005
4. Bowers 2006
5. Senn 2007

Kieser cited in NAS report:
"Although the identification of human remains by their dental characteristics is well established in the forensic science disciplines, there is continuing dispute over the value and scientific validity of comparing and identifying bite marks".[120]

What they could have also cited from Kieser, but did not…
The Uniqueness of the Human Anterior Dentition: A Geometric Morphometric Analysis: J Forensic Sci, May 2007, Vol 52, No. 3

"In conclusion, it appears that the incisal surfaces of the anterior dentition are in fact unique."

Kieser, JA, et al, The Uniqueness of the Human Anterior Dentition: A Geometric Morphometric Analysis, J Forensic Sci, May 2007, Vol. 52, No. 3

Firstly, our study supports the notion of the individuality of the human anterior dentition.

Secondly, our results suggest a low, non-significant level of correlation between dental size/shape and arch shape, which means that the product rule can be applied to the assessment of these data.

Finally, our study does not suggest that the unique features of the anterior incisal surfaces documented here would necessarily be transferred to a bitten substrate

1. Rothwell 1995
2. Pretty and Sweet 2001
3. Kieser 2005
4. Bowers 2006
5. Senn 2007

C.M. Bowers. 2006. Problem-based analysis of bite mark misidentifications: The role of DNA. *Forensic Science International 159 Supplement 1:s104-s109.*

"In numerous instances, experts diverge widely in their evaluations of the same bite mark evidence"[133]

"Assertions of a "100 percent match" contradict the findings of proficiency tests that find substantial rates of erroneous results in some disciplines (i.e., voice identification, bite mark analysis)".[33,34]

Even when using the guidelines, different experts provide widely differing results and a high percentage of false positive matches of bitemarks using controlled comparison studies.[125]

Disinformation

Starting in 1984 the ABFO sponsored workshops to develop guidelines and best practices for bitemark analysis

1998-1999 Workshop was the 4th in the series

ABFO Bitemark Workshop #4

Stated Objectives

- determine the accuracy of examiners in distinguishing the correct dentition that make a bitemark

- determine whether examiner experience, bitemark certainty, or forensic value had an effect on accuracy

In presentations, publications, and sworn testimony Dr. Bowers has:

- Characterized BMW4 as a "proficiency test"
- Claimed that BMW4 established an "error rate" for bitemark analysis
- Stated that 63.5% of the participants committed false positive errors
- Stated that inculpatory opinions by forensic dentists are more likely to be wrong than right.

None of these statements has been substantiated

Bowers' claims have appeared in numerous publications…

both authored by him and by others who have excerpted or quoted him in scientific and legal journals

.

Reported in the original publication of the results of BMW#4

Arheart, K.L. and I.A. Pretty, *Results of the 4th ABFO Bitemark Workshop-1999.* Forensic Sci Int, 2001.

"The ROC area calculated by the non-parametric trapezoidal method is 0.86, a fairly high accuracy, indicating that the examiners are able to correctly identify the dentition belonging to a particular bitemark."

Arheart and Pretty

"The results of the present survey indicate that bitemark examination is an accurate forensic technique, at least with cases such as used in this study."

Dr. Bowers' disinformation (IMHO)

- has appeared repeatedly in some scientific and many legal publications
- appears on his own website and blog
- Is repeated or cited on other websites

and

- has been falsely attributed by Bowers to other investigators who were, in fact, quoting him!

In

Bowers, C.M., *Problem-based analysis of bitemark misidentifications: the role of DNA. Forensic Sci Int, 2006.* ***159 Suppl 1: p. S104-9.***

He Cites

[7] M.J. Saks, J.J. Koehler, The coming paradigm shift in forensic identificationscience, Science, 309 (2005)

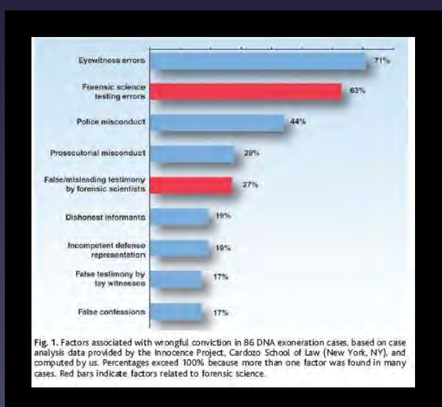


Fig. 1. Factors associated with wrongful conviction in 86 DNA exoneration cases, based on case analysis data provided by the Innocence Project, Cardozo School of Law (New York, NY), and computed by us. Percentages exceed 100% because more than one factor was found in many cases. Red bars indicate factors related to forensic science.

Fig. 1. Saks and Koehler [7] reported that of the 86 DNA exoneration cases they studied, 63% had erroneous forensic science testimony that contributed to the original conviction. They stated published results of bitemark proficiency workshops had false-positive opinions ranging as high as 64% (courtesy to Saks and Koehler [7]).

In Saks & Kohler's paradigm shift paper…

Data from proficiency tests and other examinations suggest that forensic errors are not minor imperfections…False-positive error rates for bite marks run as high as 64% (1)

…from…

(1) D. L. Faigman, D. Kaye, M. J. Saks, J. Sanders, Modern Scientific Evidence: The Law and Science of Expert Testimony, (Thompson-West, St. Paul, MN, ed 2, 2002)

And…

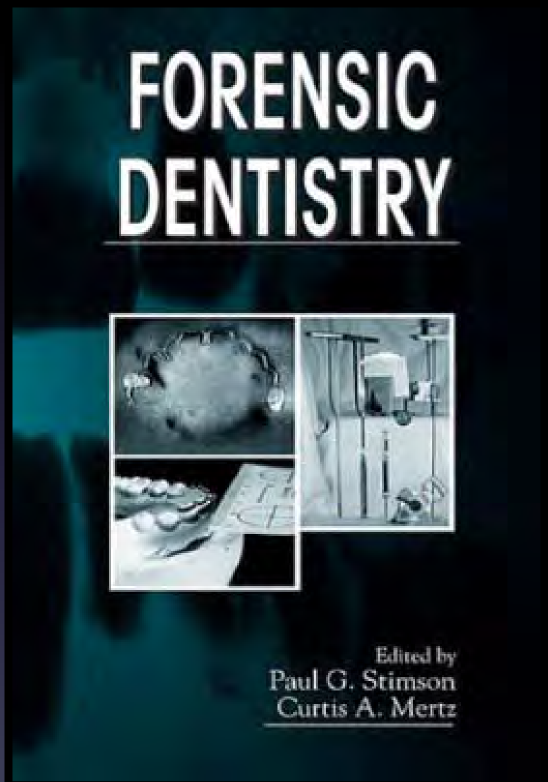
If you go to Modern Scientific Evidence (2002)… you find that the author of the chapter containing the questionable information on bitemarks is…

Bowers, CM, *Identification from Bitemarks*, Chapter 24, David L. Faigman, David H. Kaye, Michael J. Saks & Joseph Sanders, Editors; Modern Scientific Evidence: The Law and Science of Expert Testimony, West Group Publishing Co. 1998, 2002, 2004. Hardcover.

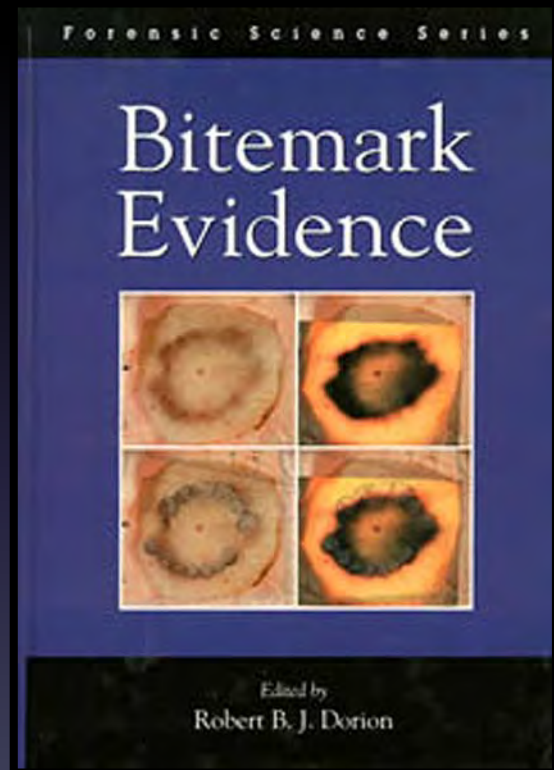
(This citation copied from Dr. Bowers CV)

Other information sources on Bitemark Evidence that were available and either not reviewed or not cited in the NAS Report include…

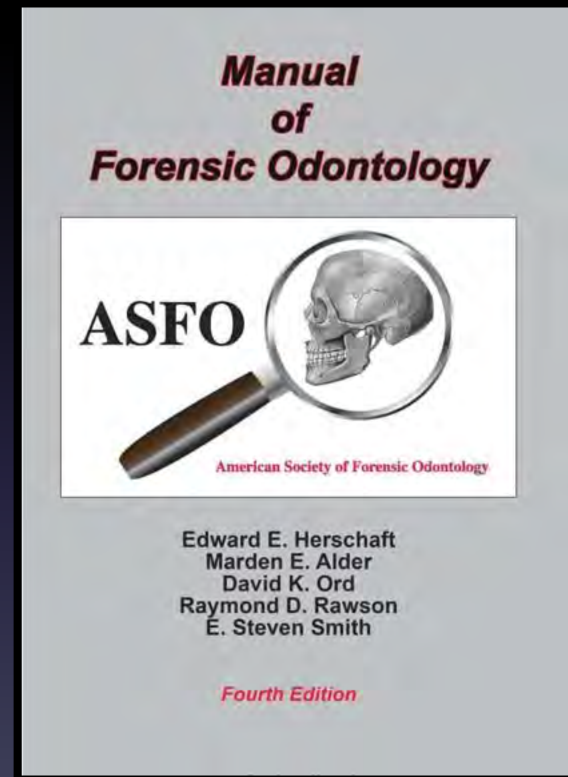
Available…but either not reviewed or not cited by the NAS committee



1997

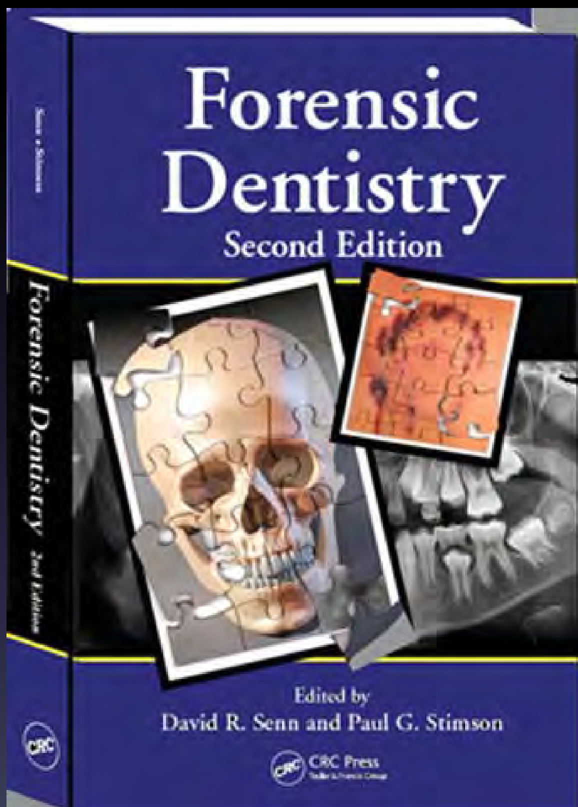


2005

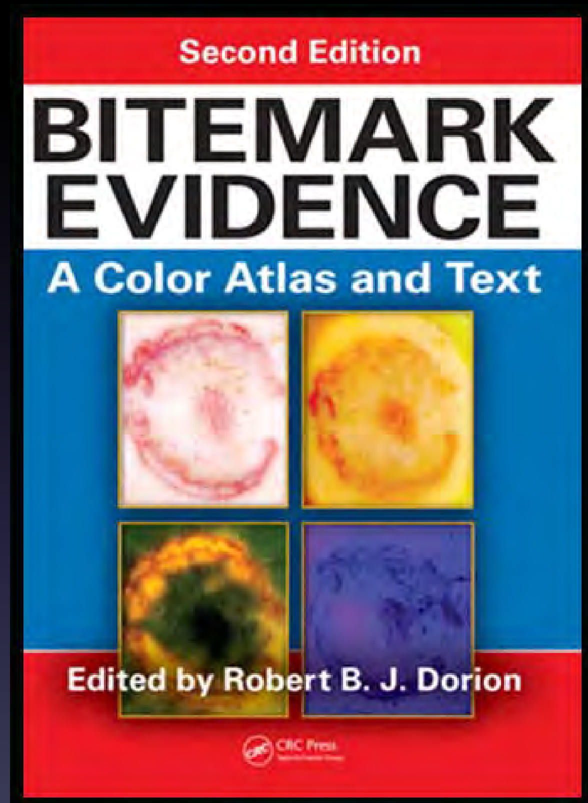


2007

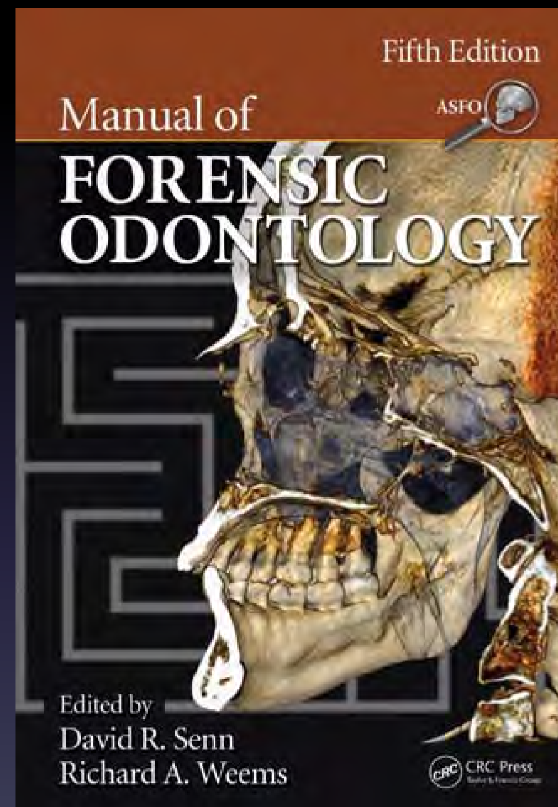
Published after the NAS Report



2011



2012



2013

1. Rothwell 1995
2. Pretty and Sweet 2001
3. Kieser 2005
4. Bowers 2006
5. Senn 2007

Attributed to Senn by NAS report

(1) The uniqueness of the human dentition has not been scientifically established.[128]

(2) The ability of the dentition, if unique, to transfer a unique pattern to human skin and the ability of the skin to maintain that uniqueness has not been scientifically established.[129]

Attributed to Senn by NAS report

1. The ability to analyze and interpret the scope or extent of distortion of bite mark patterns on human skin has not been demonstrated.

1. The effect of distortion on different comparison techniques is not fully understood and therefore has not been quantified.

1. A standard for the type, quality, and number of individual characteristics required to indicate that a bite mark has reached a threshold of evidentiary value has not been established.

Attributed to Senn by NAS report

Some of the key areas of dispute include the accuracy of human skin as a reliable registration material for bite marks, the uniqueness of human dentition, the techniques used for analysis, and the role of examiner bias.[130]

I made these statements in the spirit of full disclosure of the strengths and weaknesses of BM analysis…

But, what they did not report from my presentation before the National Academies committee….

What is the state of the art?

- Forensic Odontologists understand the anatomy and function of teeth and the dynamic mechanics of biting.
- A competent forensic odontologist can produce biter profiles from bite patterns that exhibit sufficient information to have evidentiary value.

State of the art

- Competent forensic odontologists will conform to the American Board of Forensic Odontology Bitemark Methodology Guidelines for:

    - Bitemark Evidence Collection
    - Bitemark Analysis
    - Bitemark Evidence Comparison
    - Bitemark Forensic Report Writing

And conform to ABFO standards for Ethics

State of the Art

The State of the Art is defined and demonstrated by forensic odontologists who:

- Are capable of using all known evidence collection, analysis, and comparison modalities
- Select those modalities that are appropriate for the case in question

State of the Art

- Employ blinding techniques to inhibit bias (observer effects) in
  - Evidence collection
  - Evidence analysis
  - Evidence comparison
- Make use of Dental lineups in cases with only one suspected biter
- Seek 2nd opinions from independent, blinded, competent forensic odontologists

State of the Art

- Engage in continuing study and research to improve themselves specifically and forensic odontology generally
- Recognize and abide by the Code of Ethics and Conduct

State of the Art

- Understand the scientific method
- Use the scientific method in tests and procedures to the greatest extent possible

Conclusions

(reported to the Committee but not published in the NAS report)

- Bitemark evidence is too important and valuable to the investigation and adjudication of certain crimes to be discounted or overlooked.

- The use of bite mark analysis to exclude suspects is powerful and important.

Conclusions

- In closed or limited population cases it may be possible to associate a biter and the bitemark(s) with reasonable dental, medical, or scientific certainty *for that limited population*.
- Forensic Odontology certifying bodies should properly test and periodically re-test their certified members for proficiency in bitemark analysis

Conclusions
Evidentiary Value

Forensic Odontology certifying bodies must develop clear guidelines defining the type, quality, and number of class and individual characteristics or other features that indicate that a patterned injury judged to be a bitemark has reached a threshold of evidentiary value.

Conclusions
Ethics

Forensic Odontology certifying bodies must identify and deal decisively with board certified individuals who violate established standards and ethics. This includes those who:

- Disregard standards and guidelines
- Exhibit a prosecution bias
- Exhibit a defense bias
- Give false or misleading sworn testimony

Misinformation

(Again IMHO)

The National Academies Committee published misinformation because they either failed to review or disregarded key information and literature in evaluating the practice of forensic odontology as it relates to bitemark analysis.

Misinformation

In addition to disregarding important publications and texts, they appear to have chosen only information or excerpts from that information consistent with apparent ***negative preconceptions.***

They also concurrently disregarded available information often <u>from the same authors</u> and others that was reasoned, logical, and supportive of the discipline.

Misinformation from Disinformation

The NAS Committee espoused Bowers' disinformation chiefly published in legal journals and the myriad publications that followed and quoted that same disinformation.

Construct Validity Bitemark Assessments Using the ABFO Bitemark Decision Tree

Adam Freeman, DDS and Iain Pretty, BDS, PhD

Odontology Section - 2015

G14 Construct Validity of Bitemark Assessments Using the ABFO Bitemark Decision Tree

Adam J. Freeman, DDS, 22 Imperial Avenue, Westport, CT 06880; and Iain A. Pretty, DDS, PhD, Dental Health Unit, Williams House, Lloyd Street, N, Manchester Science Park, Manchester M15 6SE, UNITED KINGDOM*

The goals of this presentation are to help attendees understand both the nature of agreement with respect to decision making and the importance of construct validity in the assessment of bitemarks.

This presentation will impact the forensic science community by informing attendees that bitemarks are currently under considerable scrutiny from judicial and scientific communities and by providing the result of an assessment of 100 injuries to determine the degree of agreement.

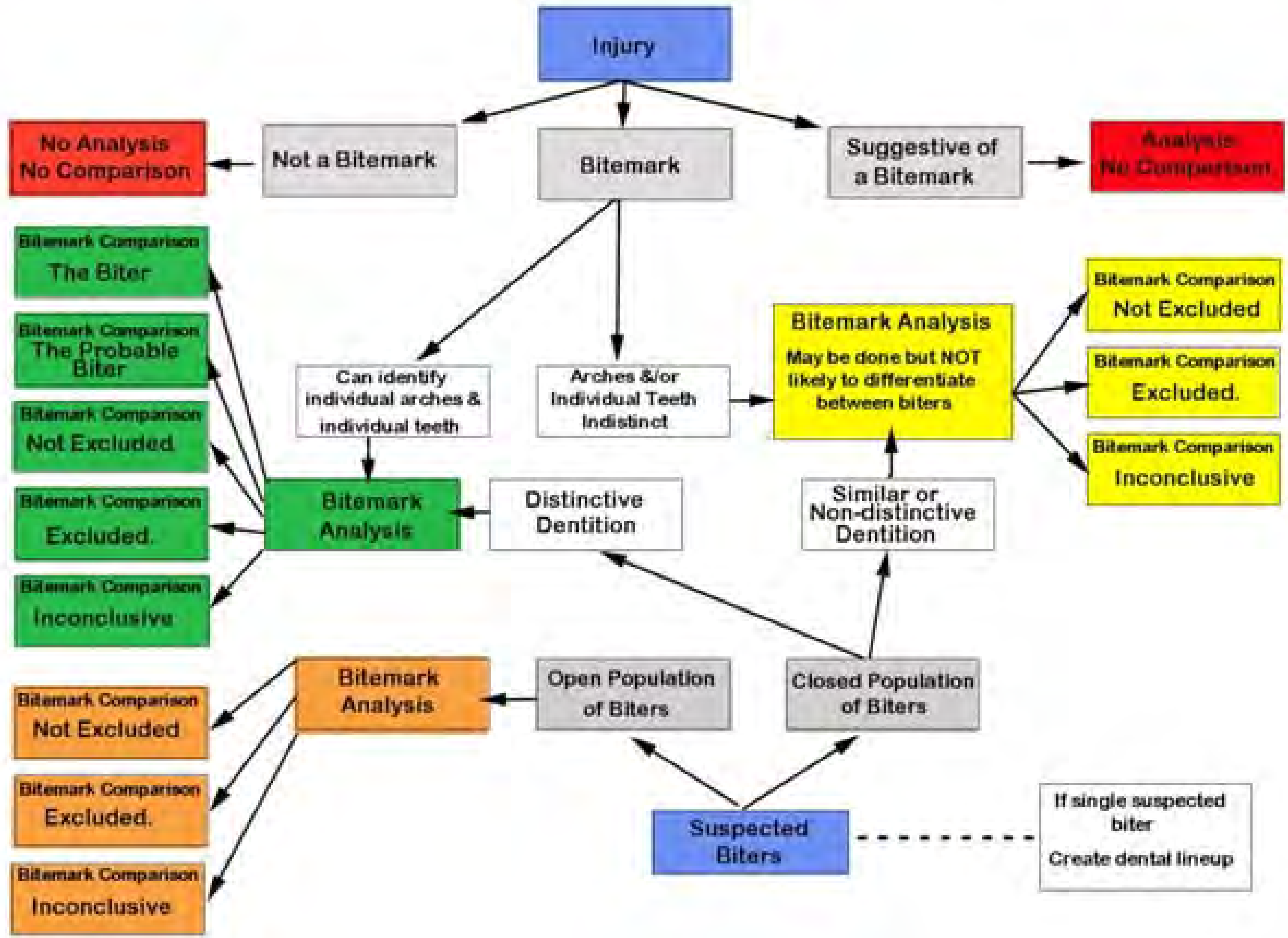
Since the criticisms within the 2009 National Academy of Sciences Report, Strengthening Forensic Science in the United States: A Path Forward, bitemarks have been an area of odontological practice that continue to be under considerable scrutiny.

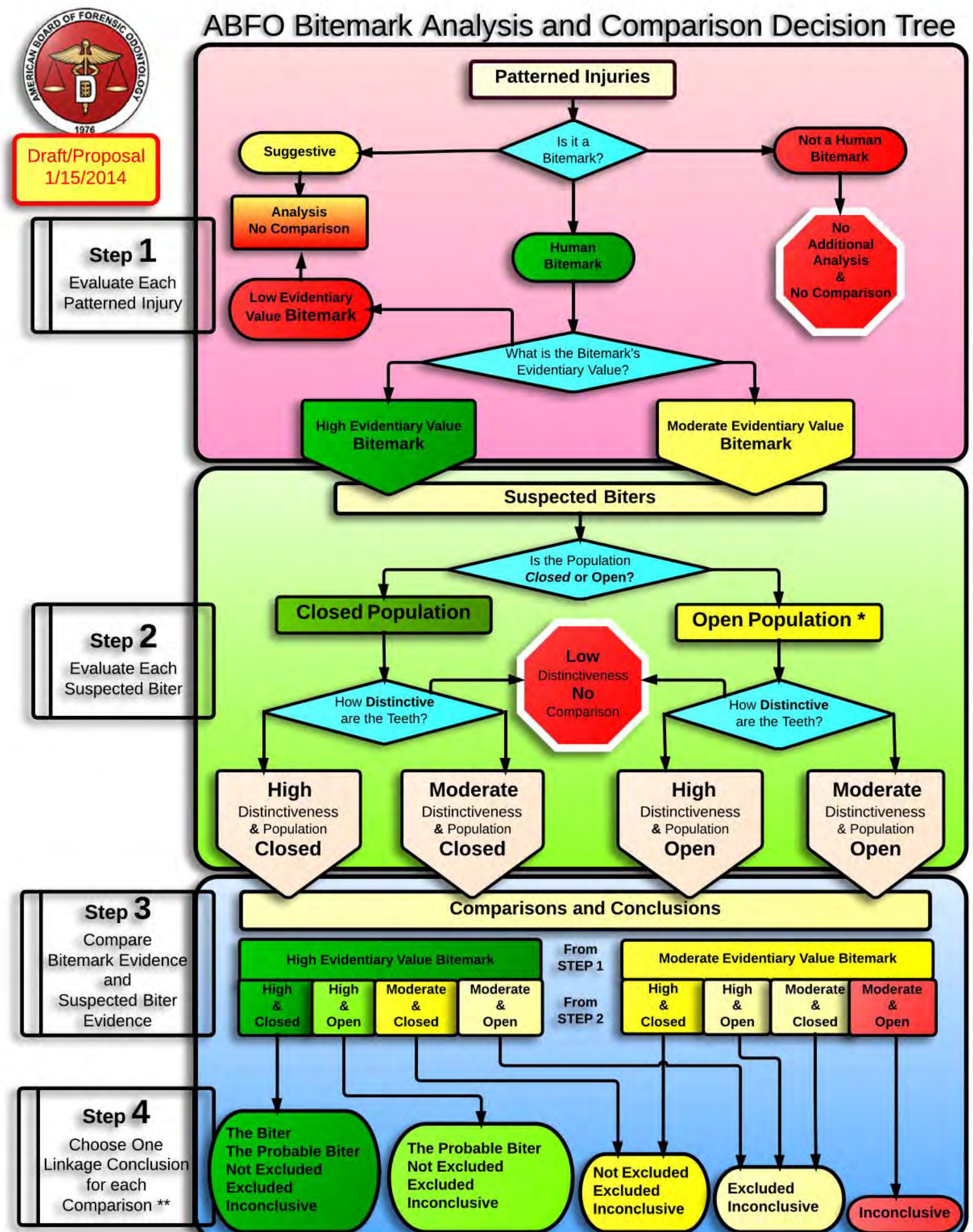
The American Board of Forensic Odontology (ABFO) has developed a decision tree to help odontologists navigate the assessment, analysis, and conclusion levels that should be applied to bitemarks. The first portion of the decision tree is to assess a patterned injury to determine if it is a bitemark, suggestive of a bitemark, or if biting can be excluded as a cause. If the injury is determined to be a bitemark, then the next step is to determine if individual arches and tooth marks are identifiable within the injury. Following this, the decision tree goes on to assess the analysis and comparison of the injury.

This research study was concerned with the first two stages of the pathway — if these are not reliable or valid then the rest of the decision tree is rendered invalid. In order to assess the level of agreement using the decision tree, the following was undertaken: 100 injuries, comprised of suspect bitemarks and other patterned injuries, were presented, using a web-based system, to ABFO diplomates. Each image set included at least one scaled and one orientation image. No contextual information was provided. Respondents were asked to rate each image as either a bitemark, suggestive of a bitemark, or not a human bitemark. For those responses where the injury was determined to be a bitemark, an additional question was asked concerning the identification of individual arches and tooth marks.

In total, 39 diplomates completed all 100 questions out of 103 diplomates contacted. As there is no established reference standard for these data, a modal approach was adopted with percentage agreement established between the respondents. Data will be presented on the each of the decision elements, including the dichotomous decision to render an opinion, the three options for stating if the injury was a bitemark, and the level of forensic significance associated with the injury.

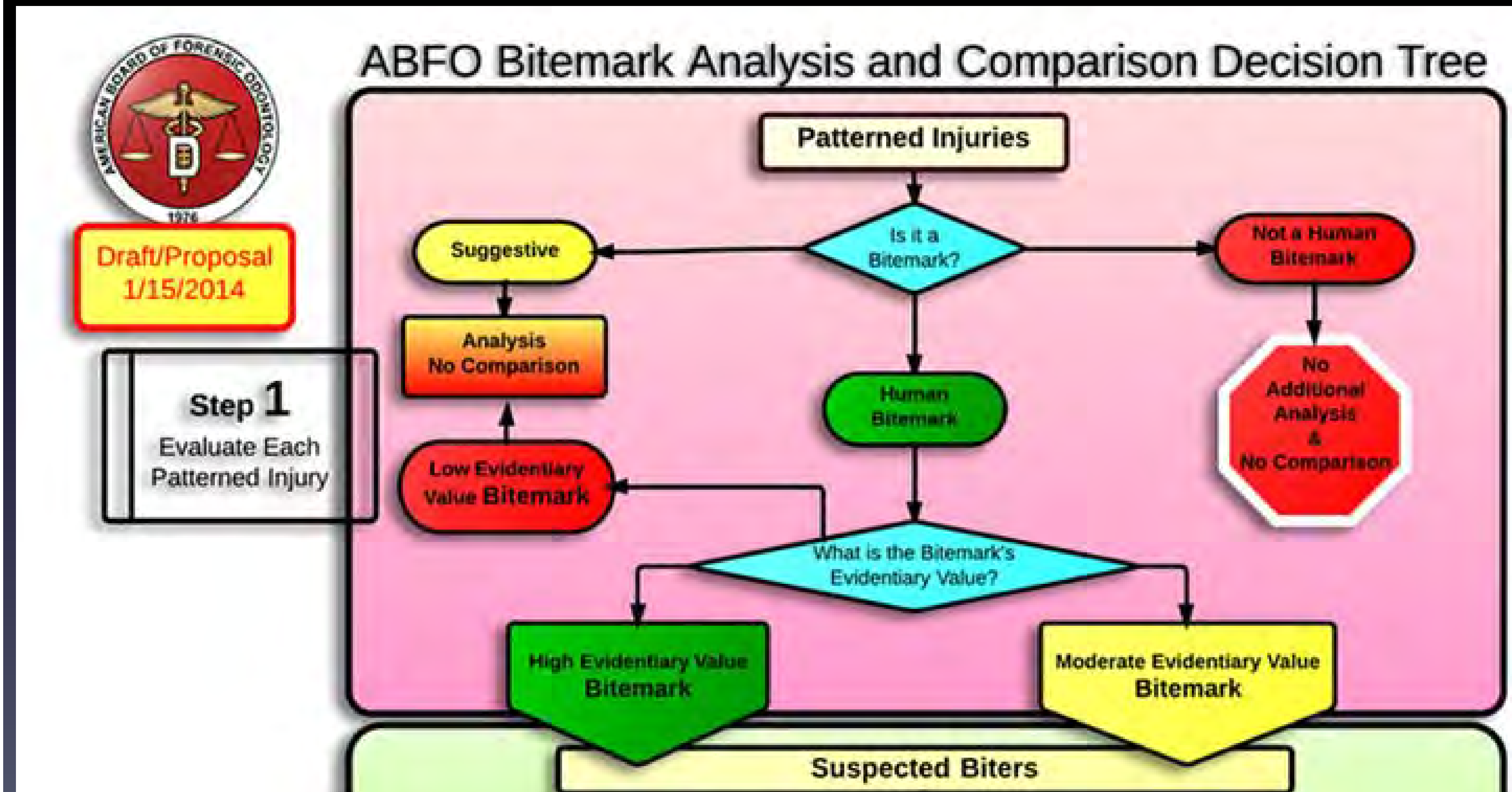
Bitemark, Agreement, Reliability


Injury
No Analysis
No Comparison
Not a Bitemark
Bitemark
Suggestive of a Bitemark
Analysis
No Comparison
Bitemark Comparison
The Biter
Bitemark Comparison
The Probable Biter
Bitemark Comparison
Not Excluded
Bitemark Comparison
Excluded.
Bitemark Comparison
Inconclusive
Can identify individual arches & individual teeth
Arches &/or Individual Teeth Indistinct
Bitemark Analysis
May be done but NOT likely to differentiate between biters
Bitemark Comparison
Not Excluded
Bitemark Comparison
Excluded.
Bitemark Comparison
Inconclusive
Bitemark Analysis
Distinctive Dentition
Similar or Non-distinctive Dentition
Bitemark Analysis
Open Population of Biters
Closed Population of Biters
Bitemark Comparison
Not Excluded
Bitemark Comparison
Excluded.
Bitemark Comparison
Inconclusive
Suspected Biters
If single suspected biter
Create dental lineup



* For Open Population Cases with a Single Suspected Biter investigators should create a dental lineup (Population remains open)
** Linkage Conclusions should be stated to a reasonable degree of certainty (scientific, medical, dental, or medical/dental)

Construct Validity Bitemark Assessments Using the ABFO Bitemark Decision Tree



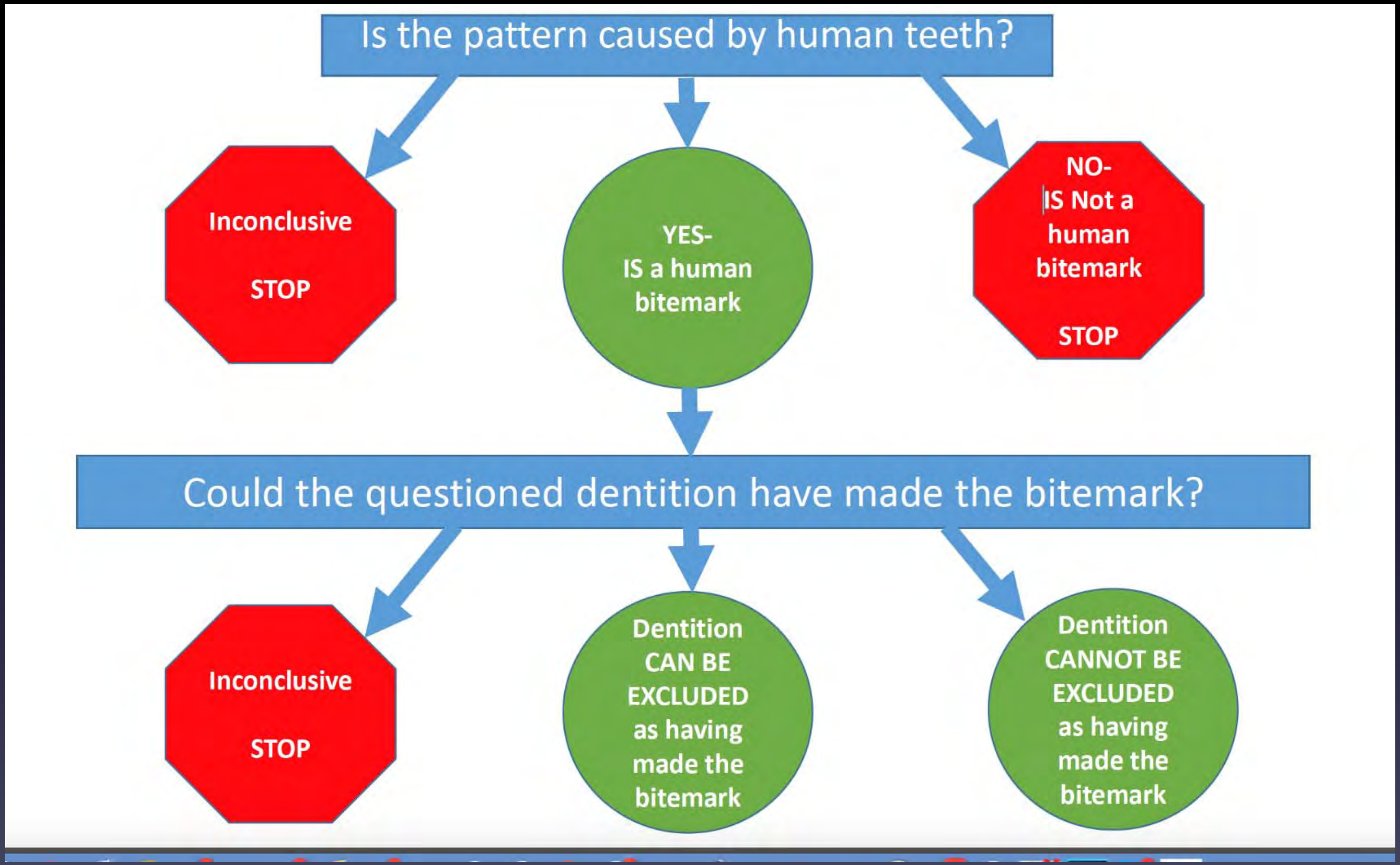
Construct Validity Bitemark Assessments Using the ABFO Bitemark Decision Tree

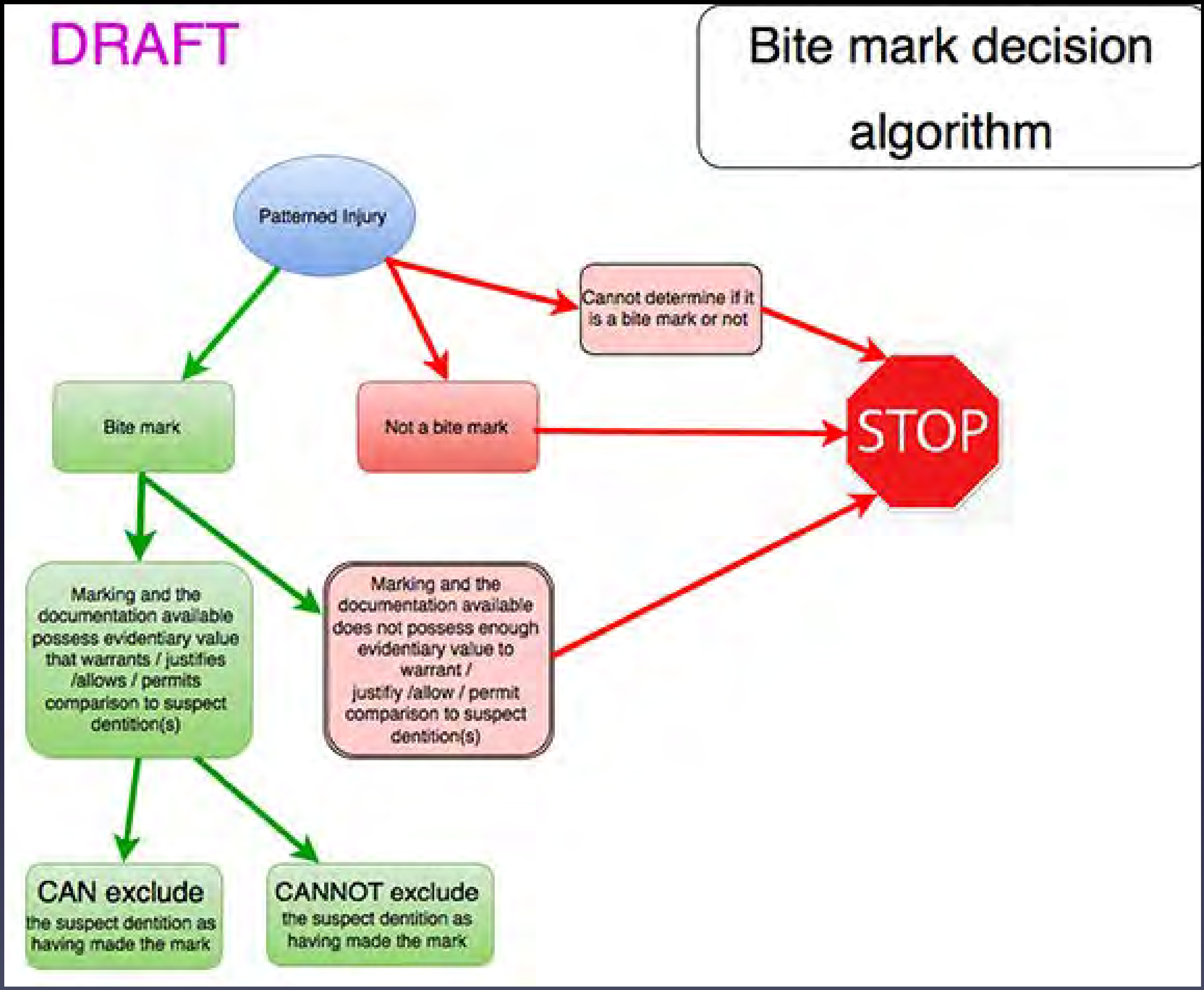
"Decision Tree study by Drs. Pretty and Freeman"

The study was designed to prove or disprove the validity of the proposed changes to the existing algorithm or decision tree

The study was not designed to be ***and was not*** a proficiency test

New Algorithm proposal





NIST/OSAC Odontology Subcommittee Bitemark Task Group

…research performed by Mr. Peter and Dr. Mary Bush and others

The Cadaveric Studies

Bush, M.A., R.G. Miller, P.J. Bush, R.B.J. Dorion, *Biomechanical factors in human dermal bitemarks in a cadaver model.* J Forensic Sci, 2009. **54**(1): p. 167-76.

Miller, R.G., P.J. Bush, R.B.J. Dorion, M.A. Bush, *Uniqueness of the dentition as impressed in human skin: a cadaver model.* J Forensic Sci, 2009. **54**(4): p. 909-14.

Bush, M.A., K. Thorsrud, R.G. Miller, R.B.J. Dorion, P.J. Bush, *The response of skin to applied stress: investigation of bitemark distortion in a cadaver model.* J Forensic Sci, 2009. **55**(1): p. 71-6.

Bush, M.A., H.I. Cooper, R.B. Dorion, *Inquiry into the scientific basis for bitemark profiling and arbitrary distortion compensation.* J Forensic Sci, 2010. **55**(4): p. 976-83.

Issues

1) The use of cadaver skin as an analogue for living human skin

2) The device used to create the simulated patterns and the improper set-up of the device

3) The methodology used to apply simulated biting forces to create the patterned injuries;

In this April 17, 2013 photo, Peter Bush and Mary Bush, research scientists at the University at Buffalo, demonstrate a modified Vise-Grip tool attached to a dental mold that is used for test bites in skin at the University in Buffalo, N.Y. (AP Photo/David Duprey)

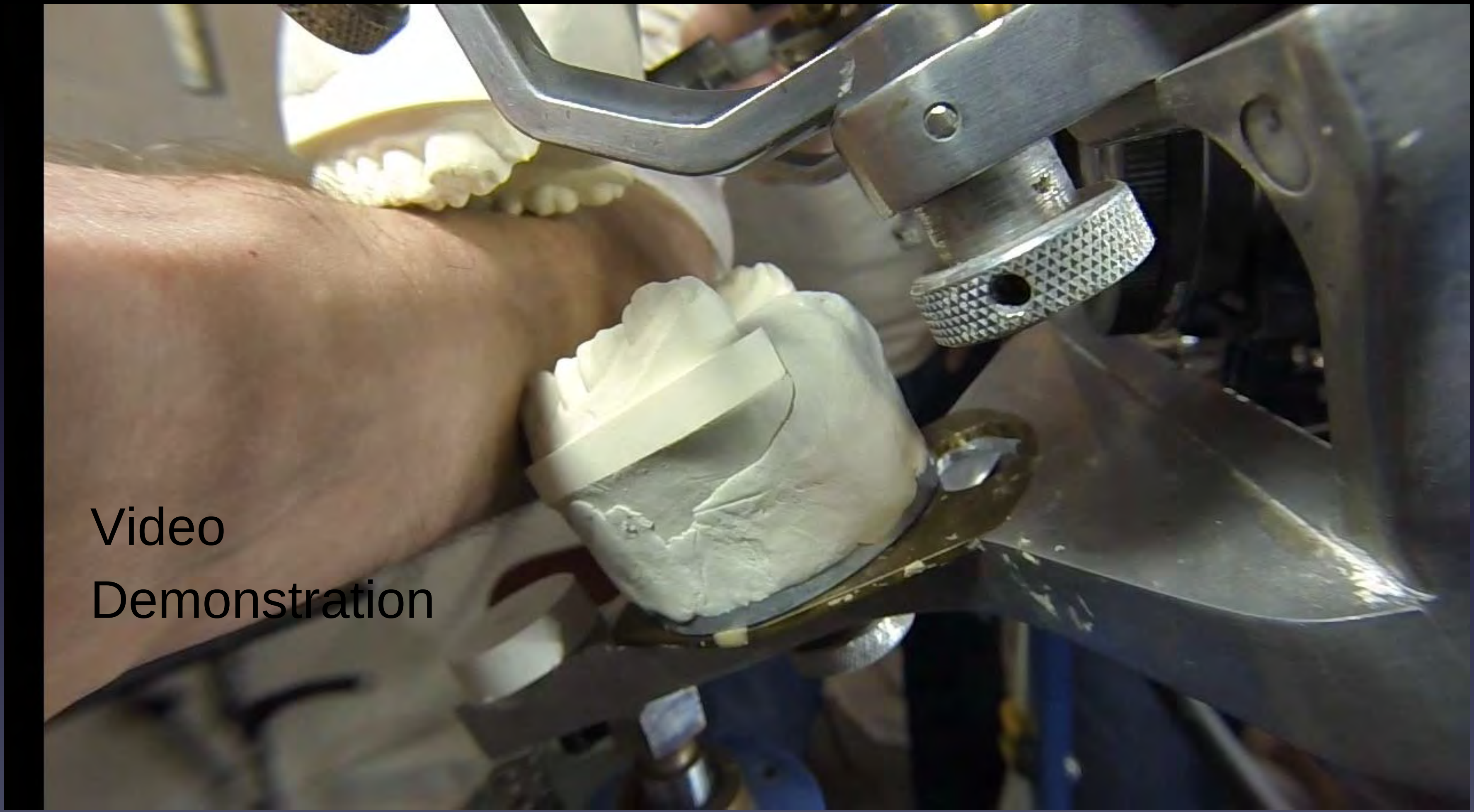
Reported that they chose a cadaver model because it was not possible to get IRB approval to use living humans

Reported that they chose a cadaver model because it was not possible to get IRB approval to use living humans

Video Demonstration

Research using live human subjects is ongoing at two universities

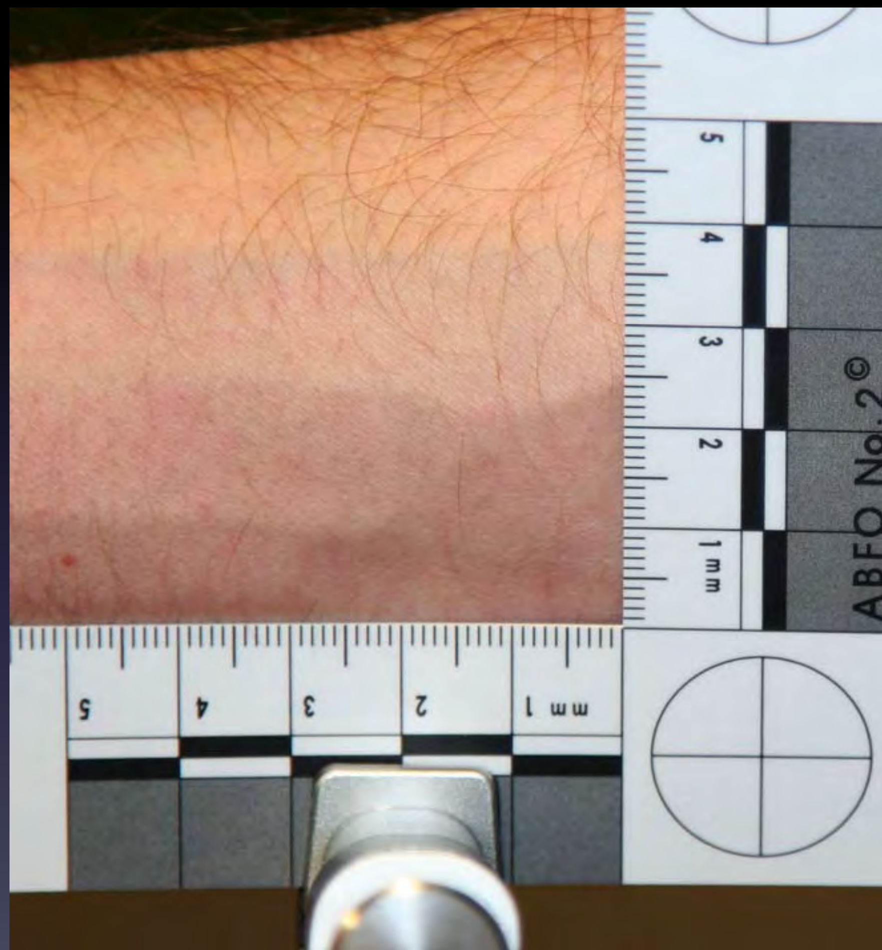
School of Dentistry
University of Texas-San Antonio

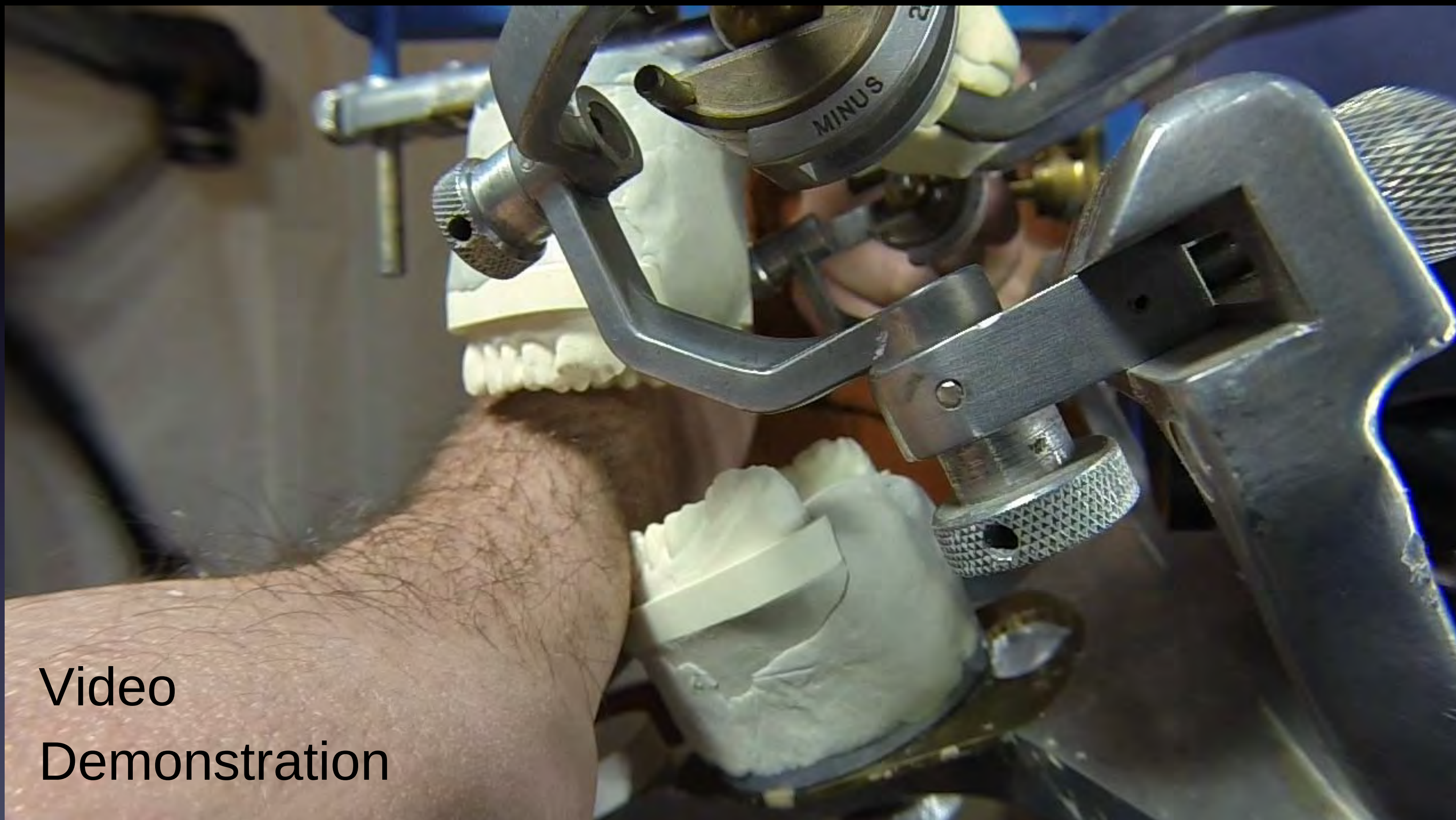



Video Demonstration

10 Minutes After Bite

24hrs After bite





Video
Demonstration


Video Demonstration

10 Minutes After Bite

24hrs After Bite

4) The timing for image capture of those transitory patterns.

5) The failure to recognize the nature and significance of the transitory patterns and distortion created, reported, and analyzed.

6) The failure to recognize the relationship between the patterns created, reported, and analyzed in these experiments to patterns analyzed in actual bitemark cases.

…research performed by Mr. Peter and Dr. Mary Bush and others

The Cadaveric Studies

- The Bush et al. cadaver studies are internally valid and extend to creating artificial bitemarks with mechanical devices on cadavers that have been subjected to refrigerated storage.

- The studies are not externally valid and do not extend to cases involving actual bitemarks on living humans or deceased individuals who were bitten when they were living

…research performed by Mr. Peter and Dr. Mary Bush and others

The Cadaveric Studies

- The Bush et al. cadaver studies' conclusions have no applicability to actual bitemark cases
- The studies make neither Dr. Bush nor Mr. Bush experts in forensic odontology or in bitemark analysis

Frye Hearings

• AL v Ramirez-Vitae	2010	Mr. Bush
• NY v Clarence Dean	2012	Dr. Bush
• OH v Douglas Prade	2012	Dr. Bush

Ohio v. Prade affidavit

As set forth in the attached affidavit from Dr. Mary Bush and Peter Bush, both of whom are experts in bite mark analysis, "research has shown that anterior human dentition is not unique, and that dental shape is not reliably transferred to human skin."

(6/26/12
Affidavit of Dr. Mary Bush & Peter Bush at P11 (Ex. N)).

Dr. M. Bush testimony in Ohio v Prade October 2012

152

Q Okay. You do not have expertise in the area of a bitemark that was inflicted in a violent altercation; is that correct?
A That is correct.

Q And you have, again, never examined a human bitemark in all your years as a dental instructor and as a scientist?
A That is correct.

Innocence Project-Texas

Innocence Project counsel criticized for profiting on exonerees

Jeff Blackburn, Texas

Phillips' lawsuit alleges that Blackburn used his position with the Innocence Project of Texas to hand-pick cases that would represent the greatest potential compensation funds. The lawsuit says he then referred the men exonerated in those cases to Glasheen. In return, Glasheen and Blackburn would divide what the lawsuit estimates to be about $8 million for fees they claim from 13 clients exonerated in recent years.

Innocence Project-Illinois

Wrongly Imprisoned for 15 Years
Thanks to an Innocence Project

A group of Innocence Project crusaders, dedicated to freeing the wrongly imprisoned, is now accused of framing a man for murder.

Simon said he was lied to and coerced into giving his confession by people working with the Innocence Project, which was trying to exonerate a different man—Anthony Porter—who had been convicted earlier of killing the young couple.

Innocence Project

- Founded in 1992 by Barry Scheck and Peter Neufeld
- Cardozo School of Law, Yeshiva University

Winning Strategy

Aggressively Challenge Law Enforcement and Forensic Science

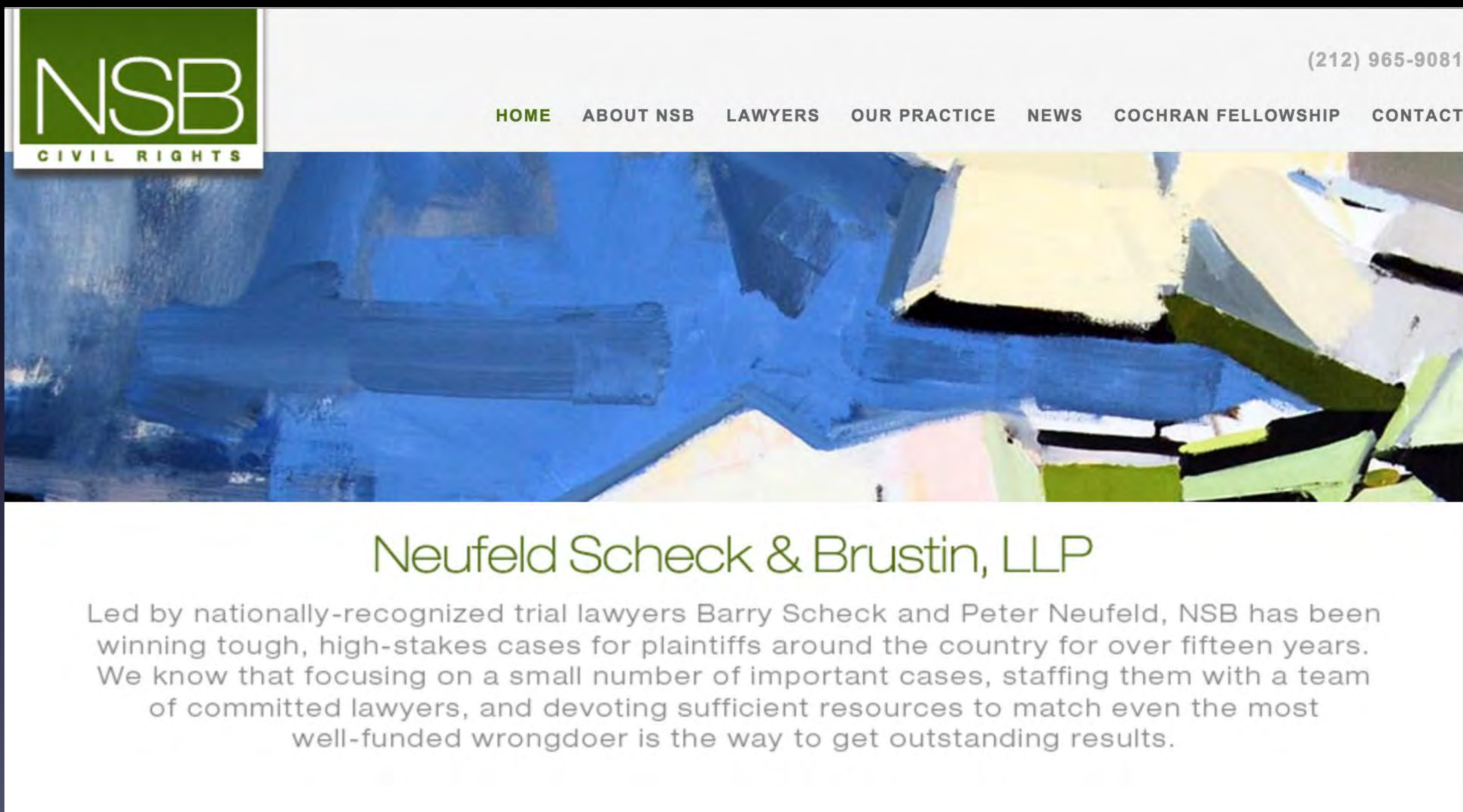
Innocence?

Looking pleased?

Cochran Neufeld & Scheck

- Simpson trial ended in 1995
- CNS formed a civil litigation firm in 1998
- After Cochran died in 2005 firm became…

Neufeld Scheck & Brustin



IP Clients become NSB Clients

NSB client Jeff Deskovic sets record for largest wrongful conviction jury verdict in U.S. history

*POSTED BY **NSBCIVIL** ON OCT 23, 2014 IN **NEWS**, **RESULTS** | **0 COMMENTS***

A federal jury has awarded Jeffrey Deskovic, who spent 16-and-a-half years wrongfully imprisoned for the rape and murder of a high school classmate before DNA testing proved him innocent, $40 million plus $1.65 million in stipulated lost wages for a total of $41,650,000—the largest wrongful conviction jury verdict in U.S. history. The jury found former Putnam County Senior Investigator Daniel Stephens liable for intentional misconduct, including conspiring to coerce a confession and fabricating evidence. The second-highest wrongful conviction jury verdict was awarded to NSB clients John Restivo and Dennis Halstead in April 2014....

Deskovic $40,000,000

NSB Wins Biggest Wrongful Conviction Jury Verdict in U.S. History

*POSTED BY **NSBCIVIL** ON APR 17, 2014 IN **NEWS**, **RESULTS** | **0 COMMENTS***

A federal jury has returned a $36 million verdict for John Restivo and Dennis Halstead, who spent eighteen years in prison for a 1984 rape and murder before DNA testing proved their innocence. The jury concluded that Nassau County Detective Joseph Volpe, now deceased, had planted hairs and hid evidence suggesting Mr. Restivo's and Mr. Halstead's innocence to secure a conviction. The verdict is the biggest jury award ever achieved in a wrongful conviction case. Click here to read...

Restivo & Halstead $36,000,000

Innocence Project is non-profit

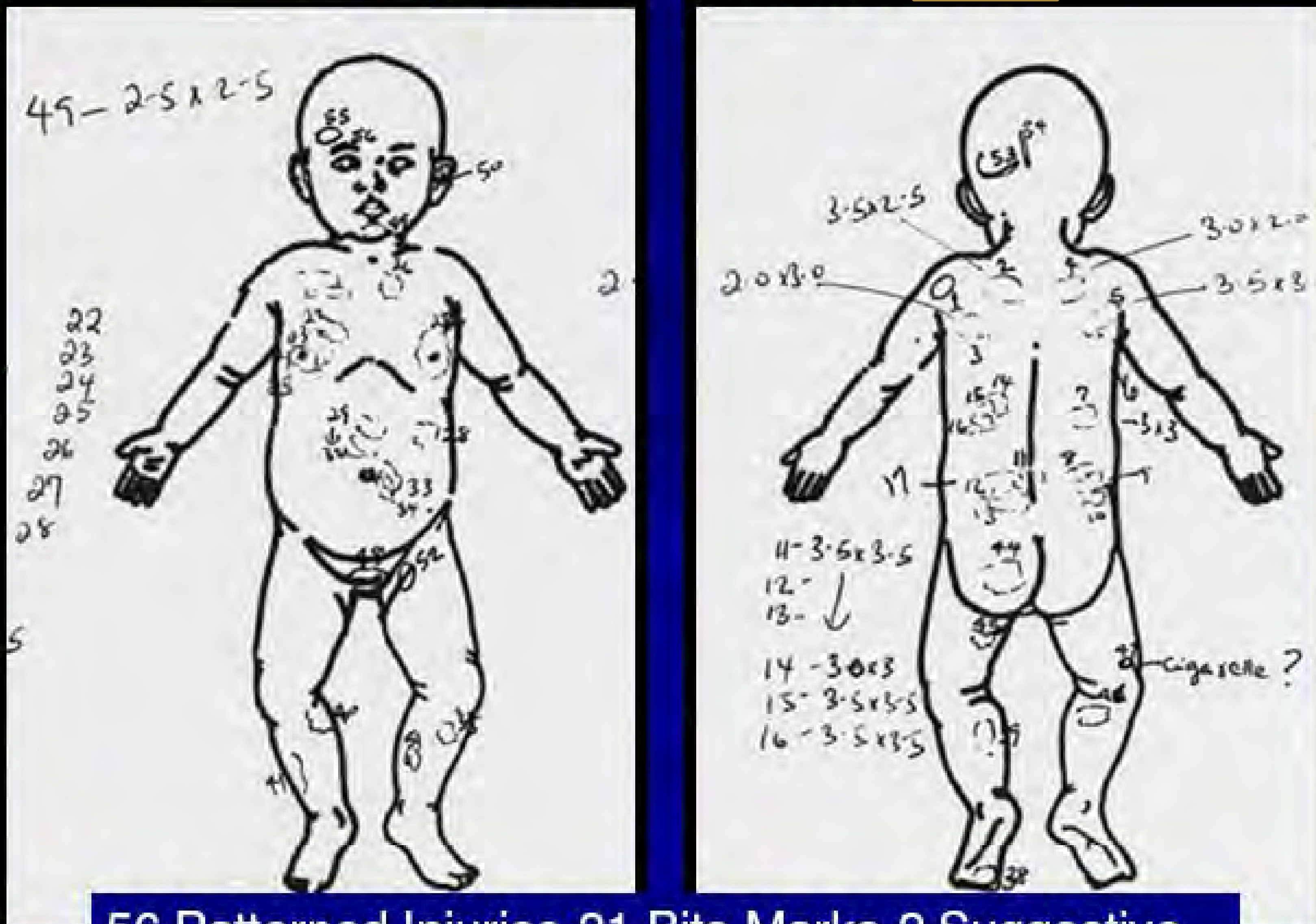
Neufeld Scheck & Brustin are not

Is Innocence
a Project or a Business?

Bitemark Cases

The Patterned Injuries of Ce, Am, & An

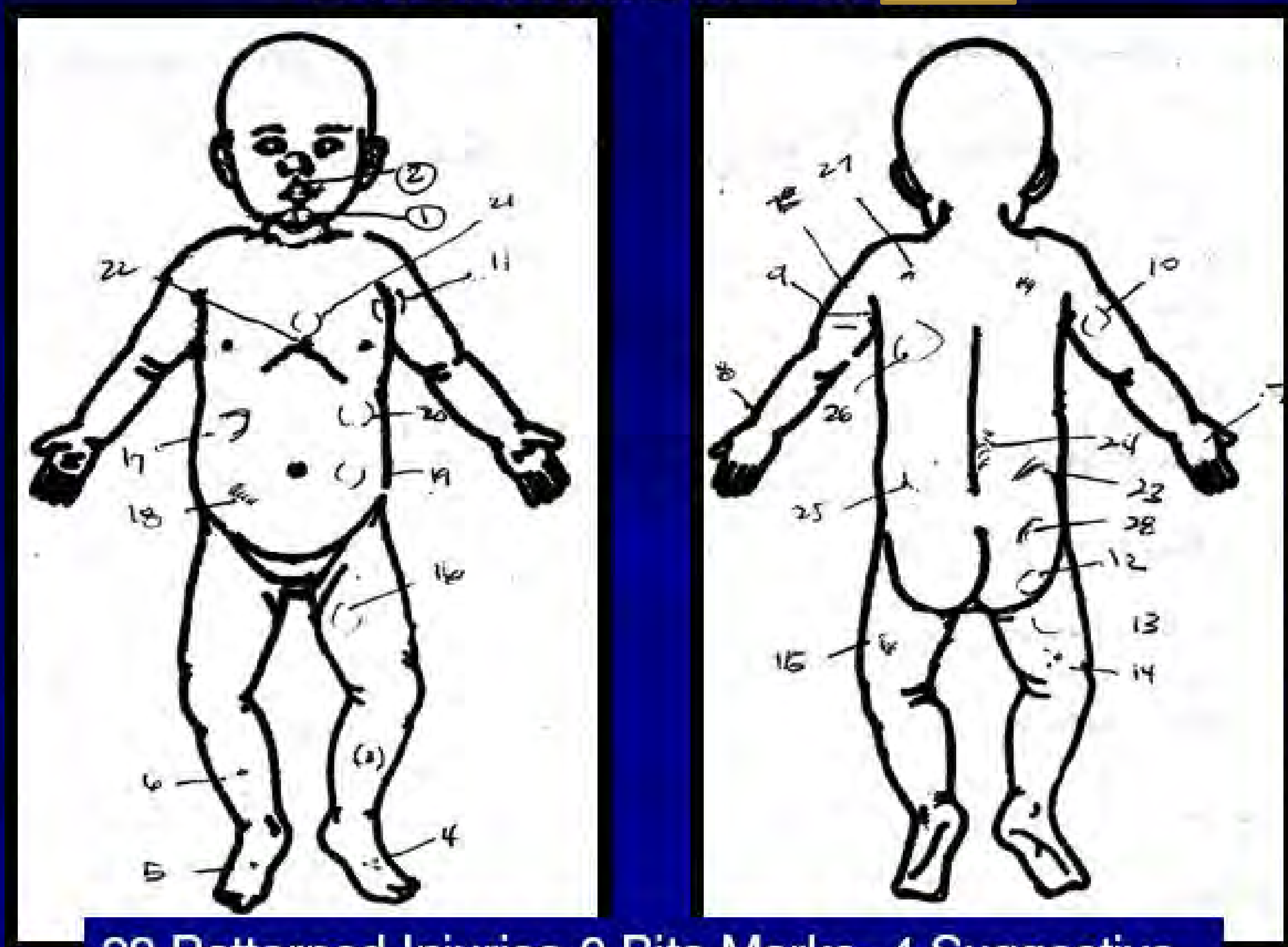
Orientation-Am[redacted]



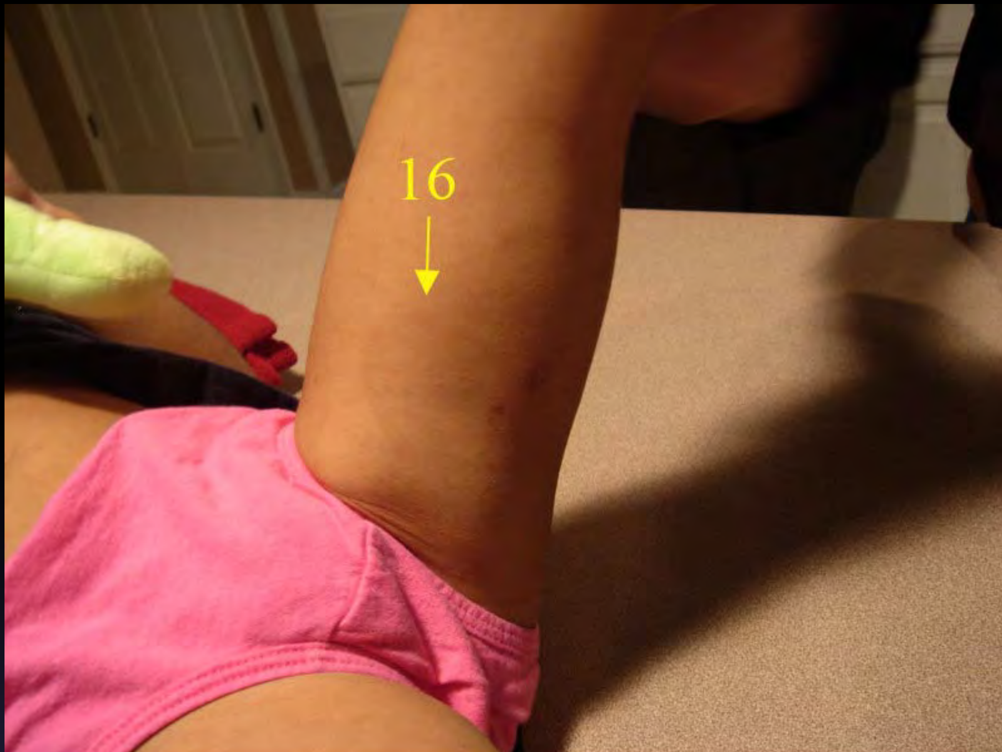
56 Patterned Injuries-31 Bite Marks-2 Suggestive


48
ABFO No. 2

Orientation-An



28 Patterned Injuries-9 Bite Marks -4 Suggestive


16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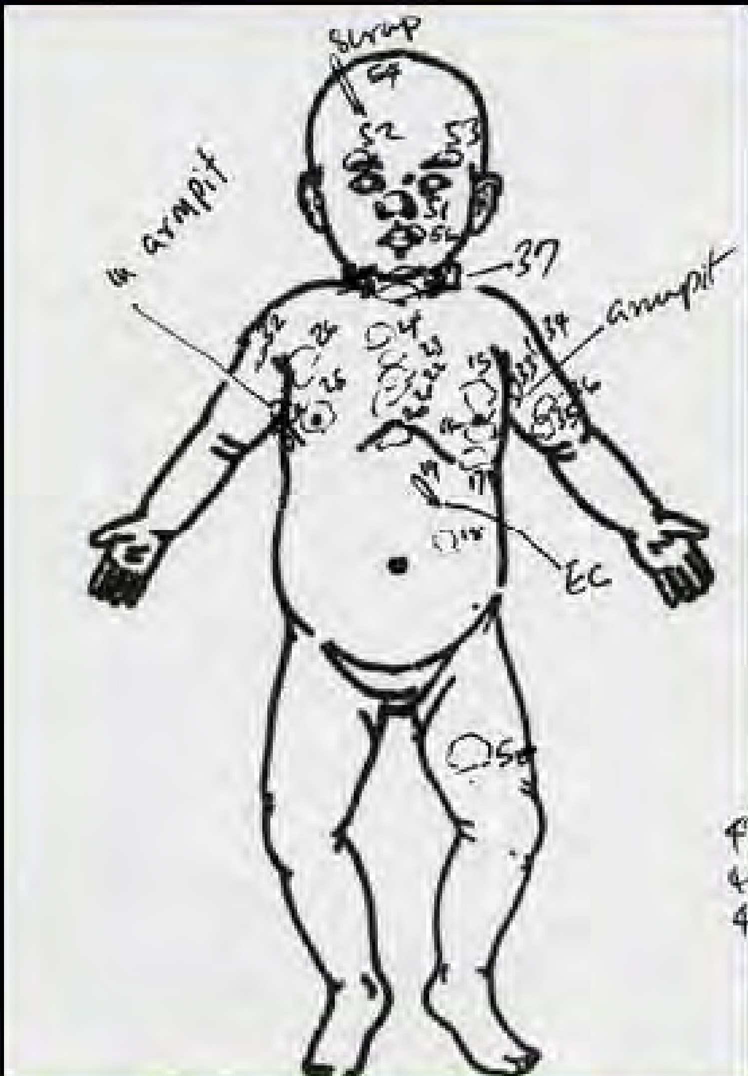
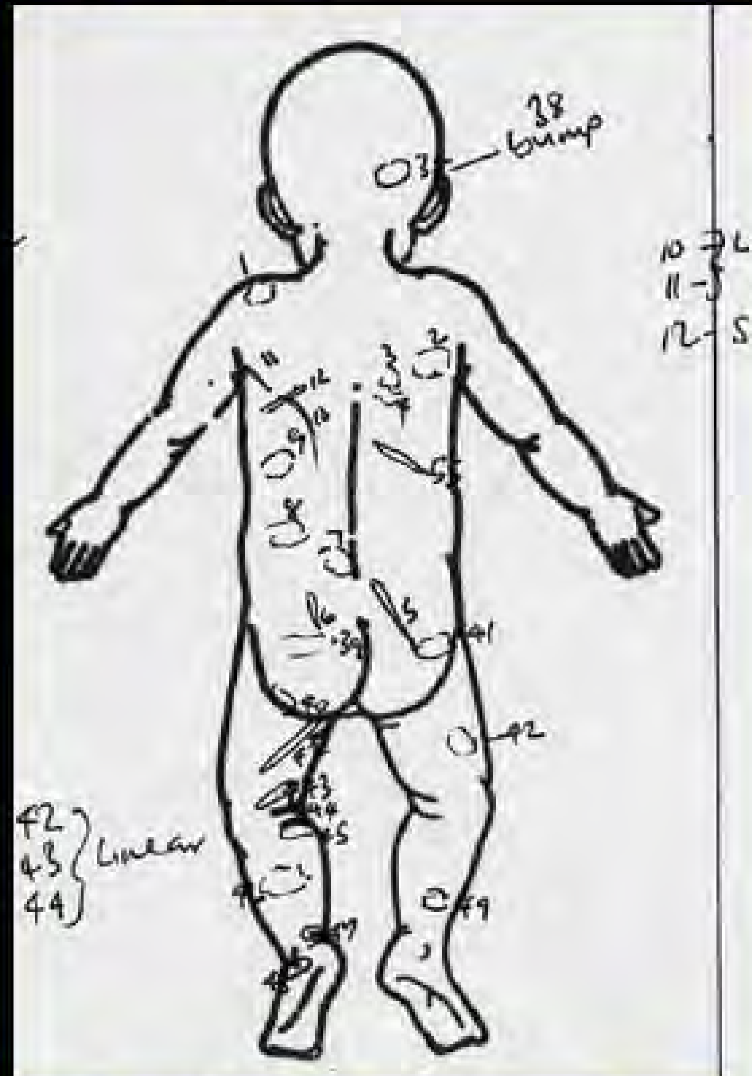
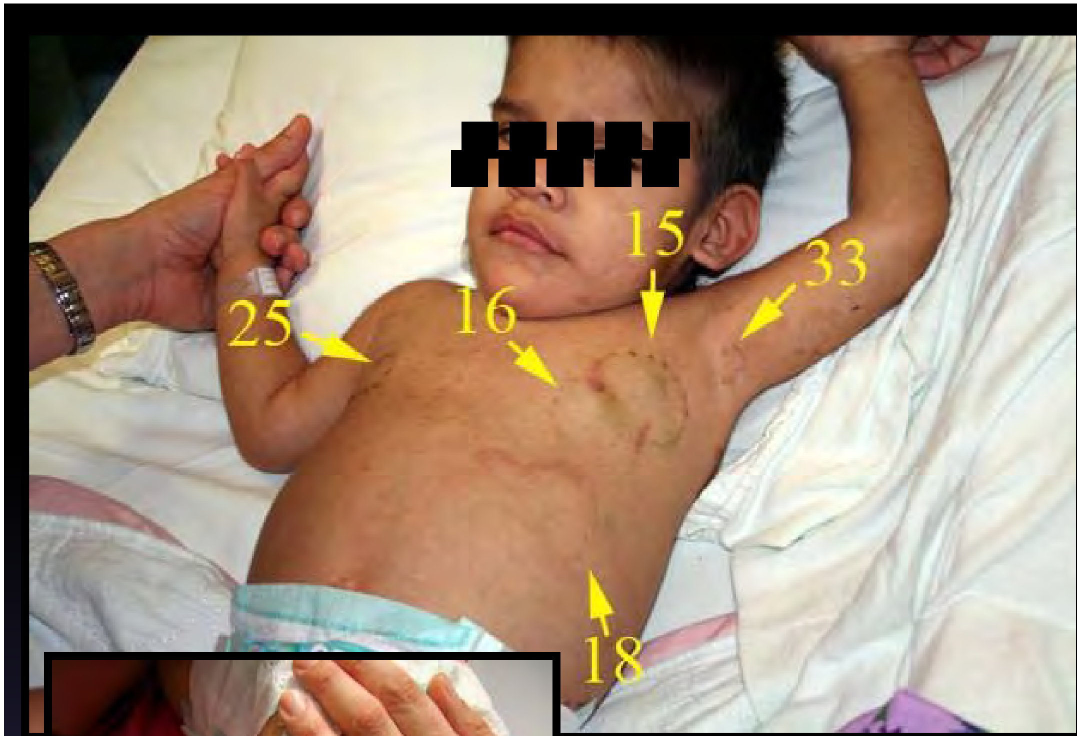
Ce[redacted]-Orientation





57 Patterned Injuries-21 Bite Marks-5 Suggestive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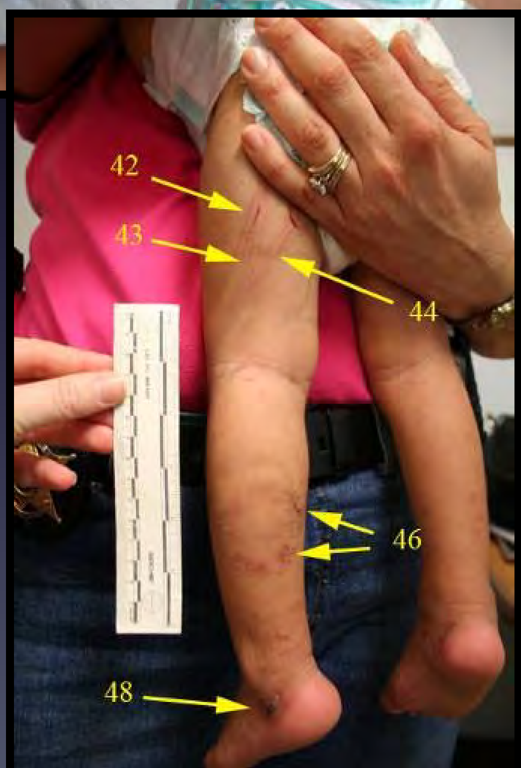
Elec.
Cord?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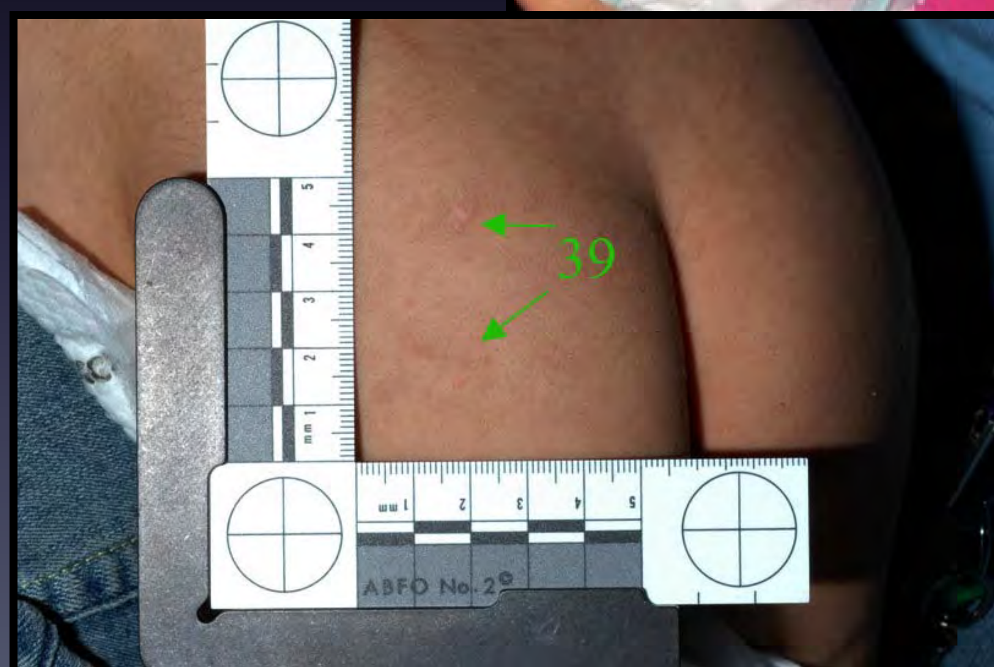
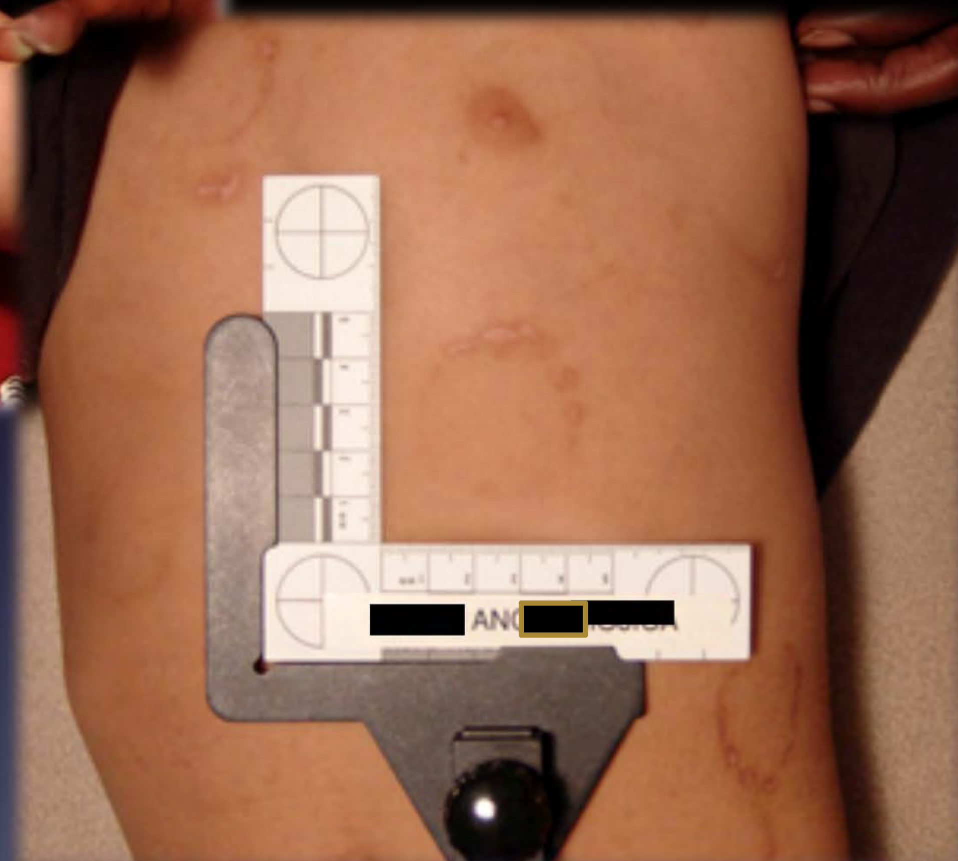

39
ABFO No. 2

Summary of Patterned Injuries

- Am[redacted]- 56 Bite Marks 31 Suggestive 2
- An[redacted]- 28 Bite Marks 9 Suggestive 4
- Ce[redacted]- 57 Bite Marks 21 Suggestive 5

- Total 141 61 11

- Bites and Suggestive of BM 72
- Other 69



Nature of Non-bite Injuries

- Linear Marks
- Contusions
- Abrasions
- Lacerations
- Mouth Injuries
- Avulsed tooth
- Burns
- Scars

Number of Non-bite Injuries

Linear Marks	18
Contusions	21
Abrasions	10
Lacerations	20
Mouth Injuries	2
Avulsed tooth	1
Burns	4
Scars	18


Ce [redacted] #28

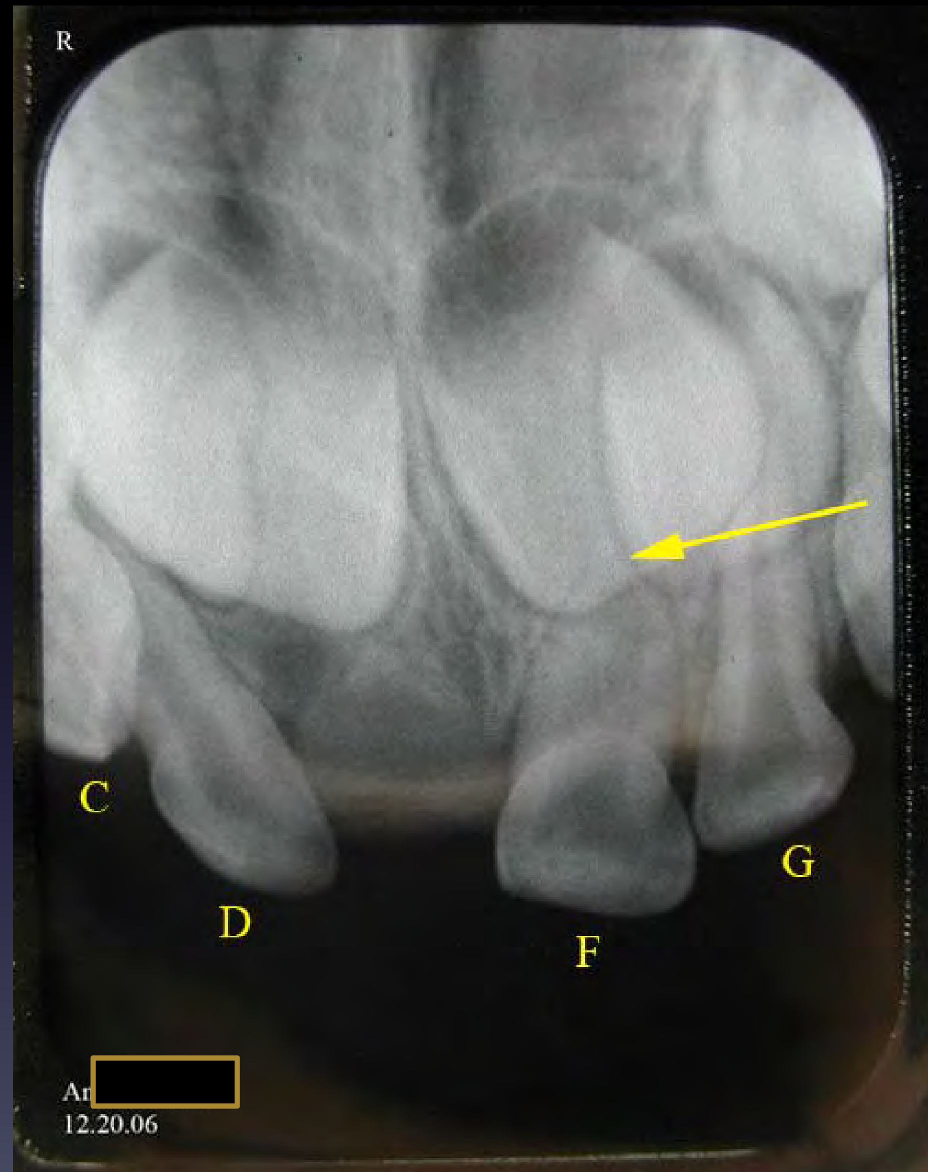

Am[redacted] #54


Am[redacted] #55


Am[redacted] #47
ABFO No. 2©


Ang[redacted] #2
2
3


3


R
C
D
F
G
Ar[redacted]
12.20.06

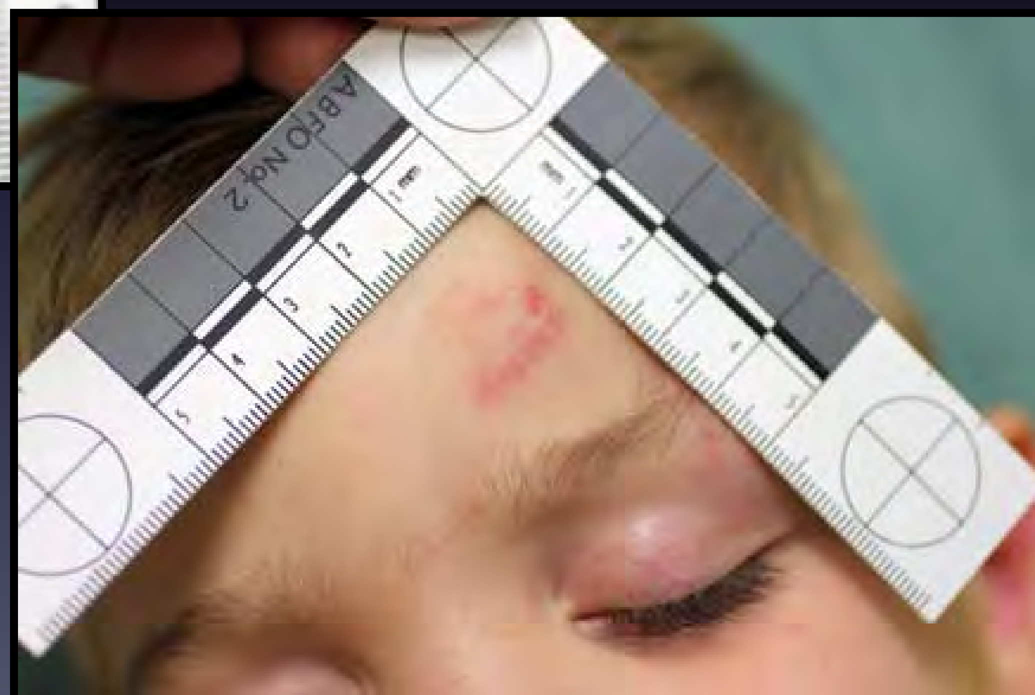

Therabite
Range of Motion Scale
CPT 95851 (millimeters)
Lateral Scale


Therabite

"Convicted child abuser gets 14 life sentences"

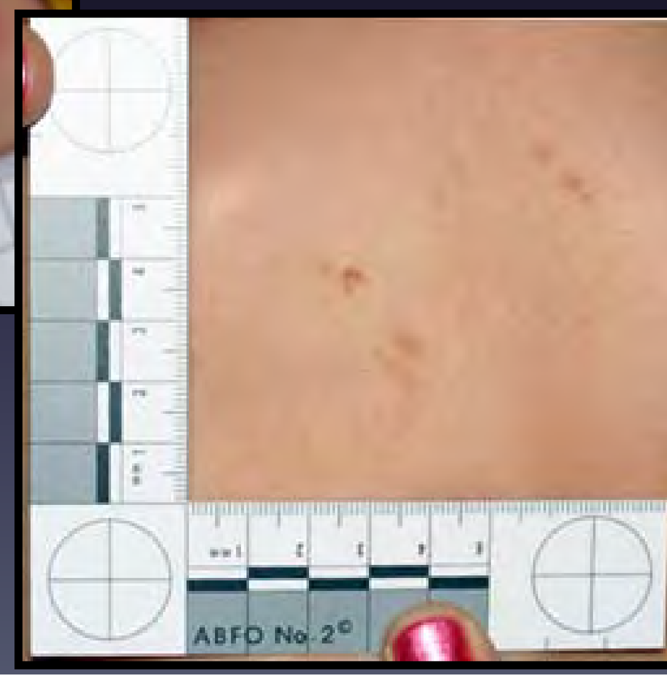
Christmas 2011

Injuries to 2.5 year old male




ABFO No. 2

Day 1 Day 2 Day 5

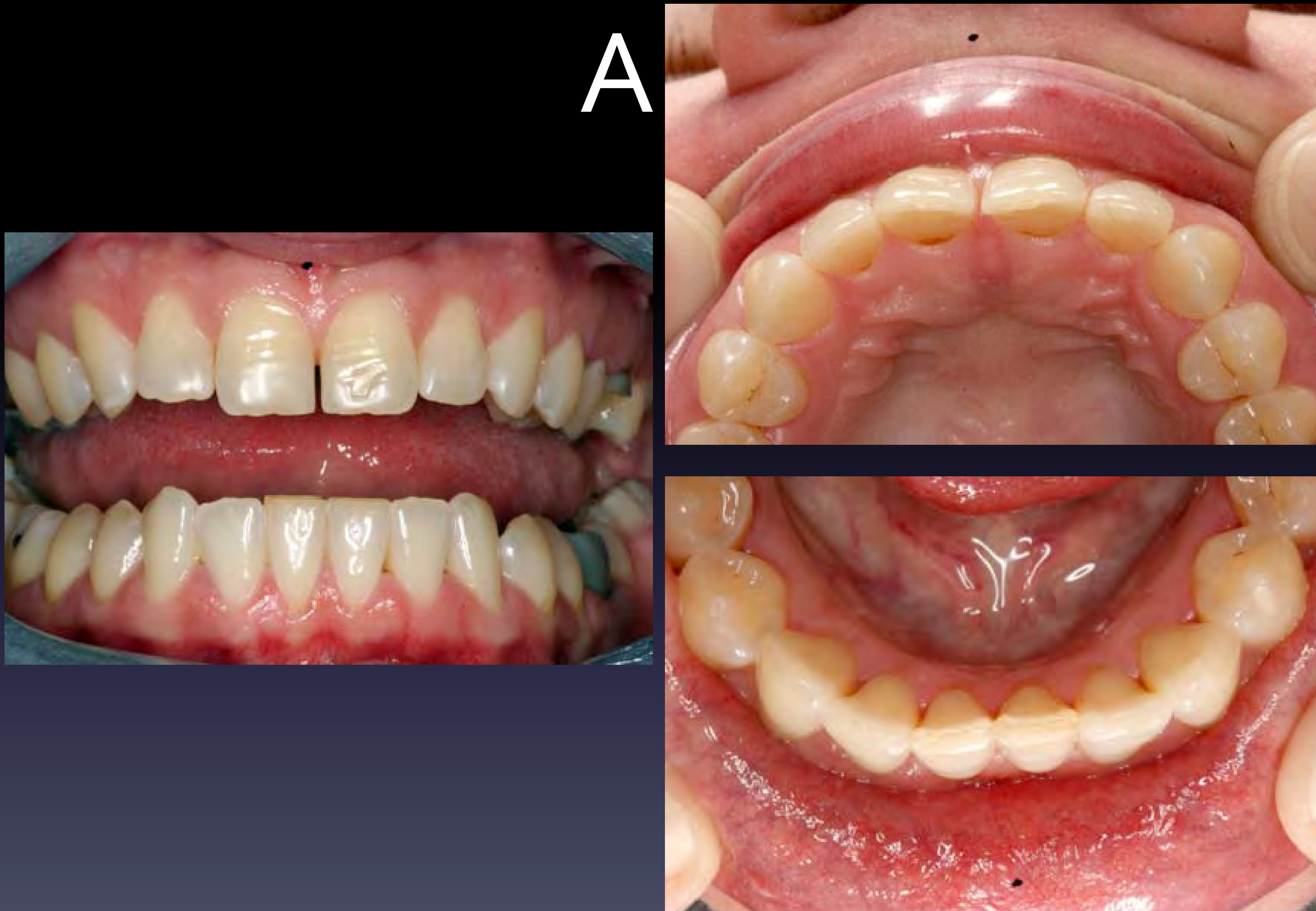


Potential Biters

Investigator Blinded
Known only as:

- A
- B
- C
- D

A

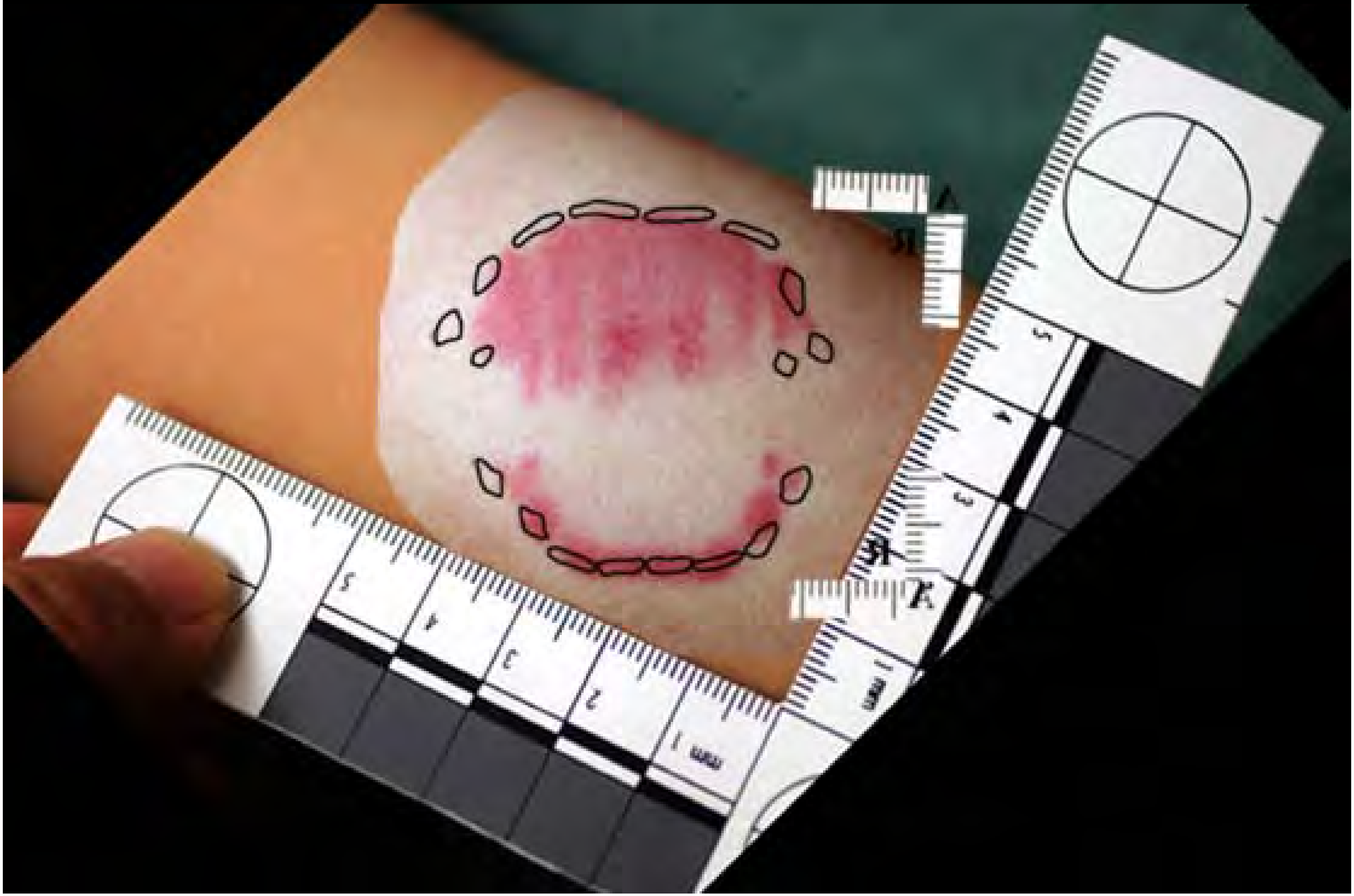


B

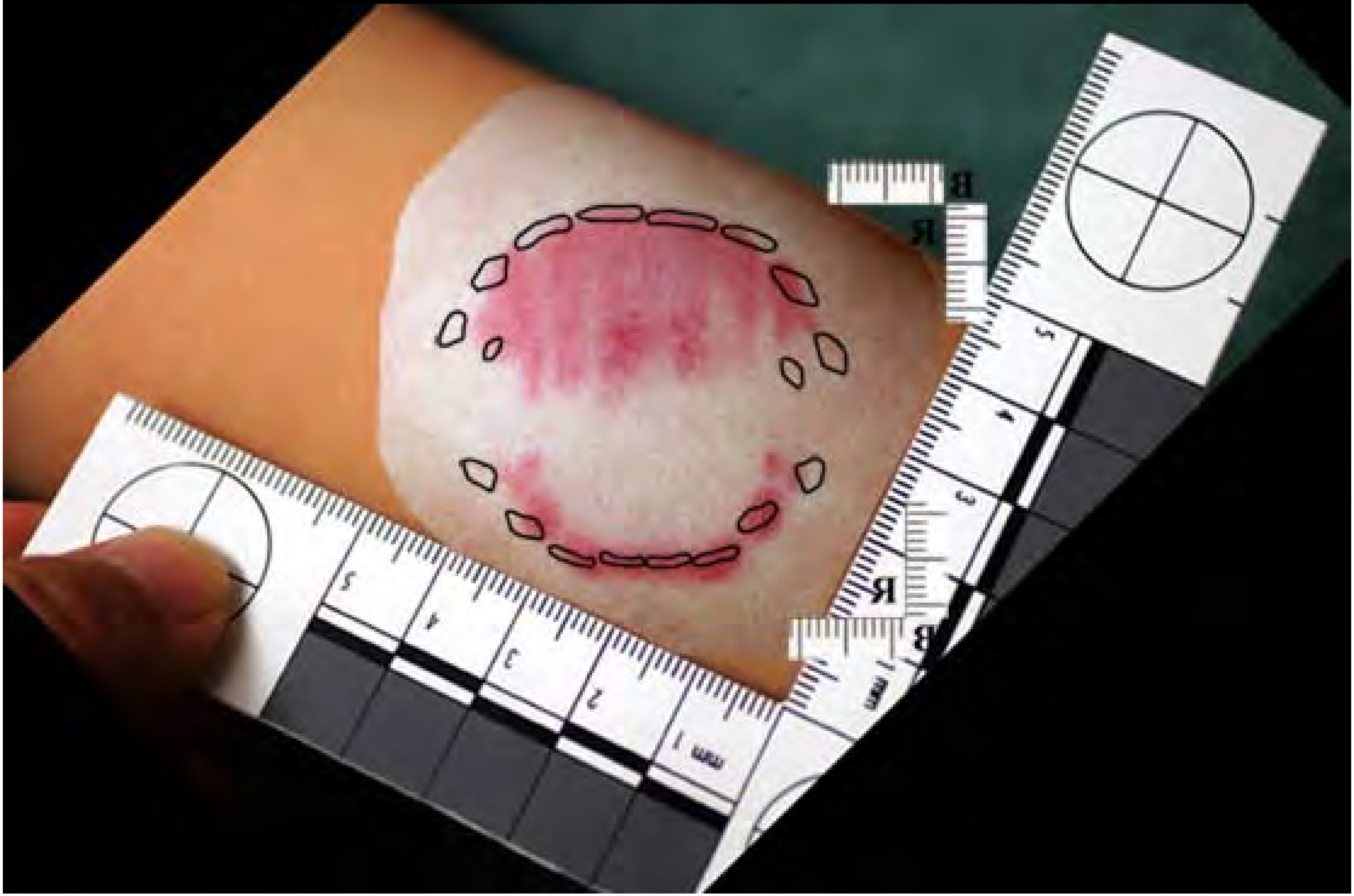
C

D

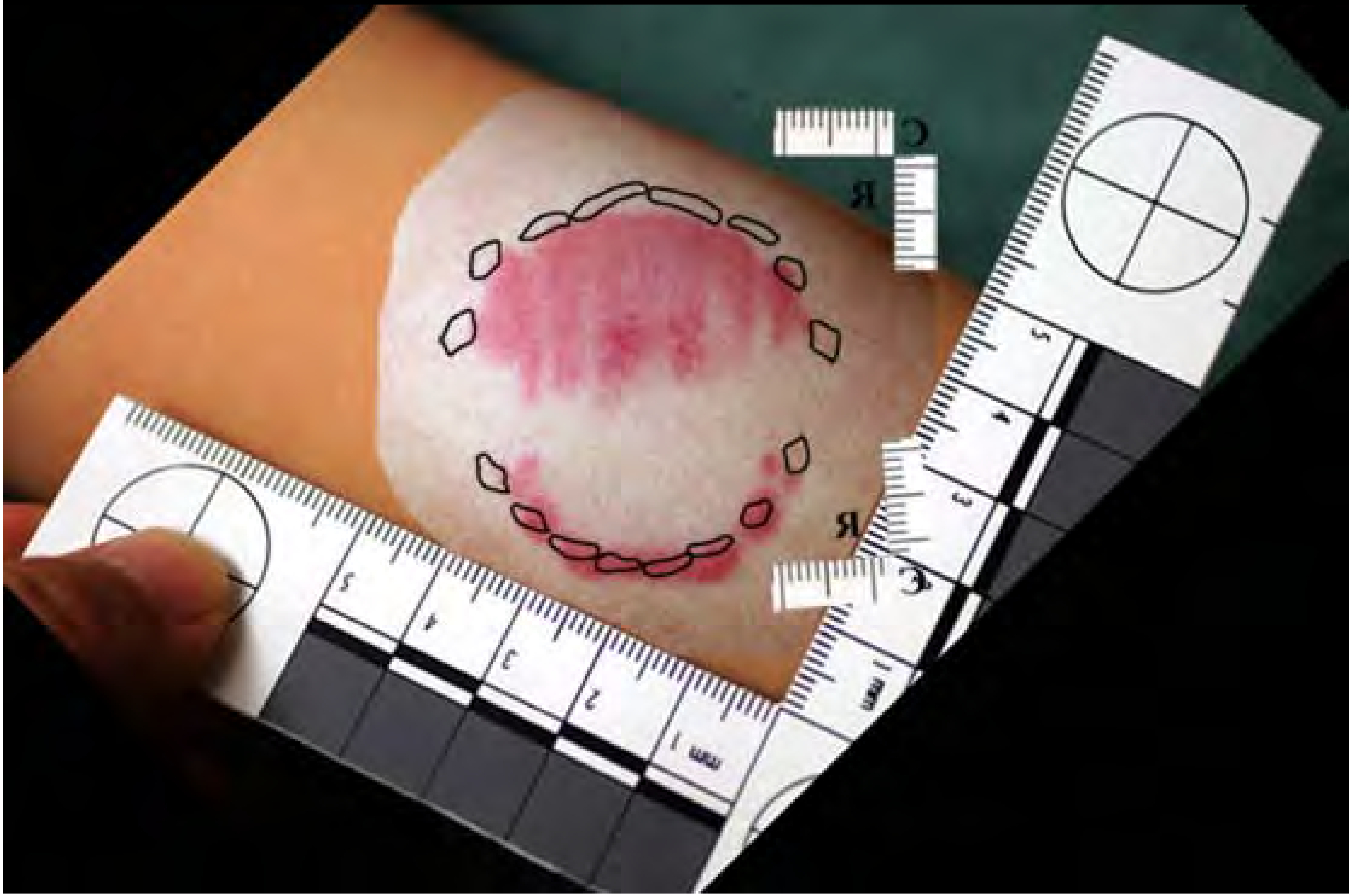
Comparisons



Comparisons



Comparisons



Comparisons

Overlay Comparison Adobe Photoshop

Potential Biters

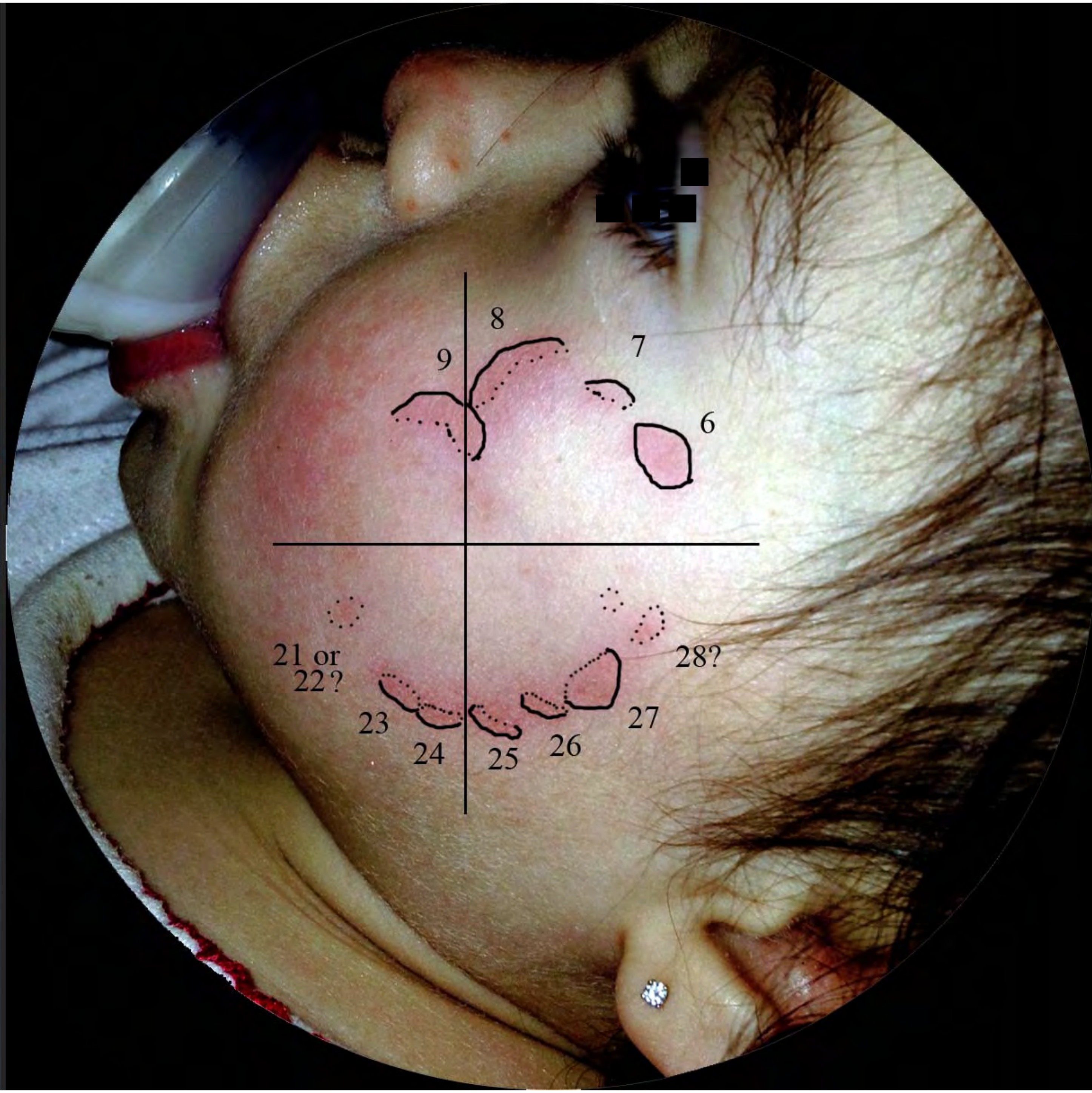
Investigator un-blinded only after comparisons and conclusions

- Mother
- Babysitter
- Babysitter's live-in boyfriend
- Babysitter's 5 year old son

Boyfriend released from custody after bitemark evidence pointed to 5 yo son of babysitter…bitemark analysis helped to establish innocence of accused.

Bitemark Profiling

- Another live in boyfriend case


8
9
7
6
21 or
22 ?
28?
23
24
25
26
27

This was another case in which a detained accused was shown to be innocent based on bitemark analysis

Healed and Healing Bite Marks

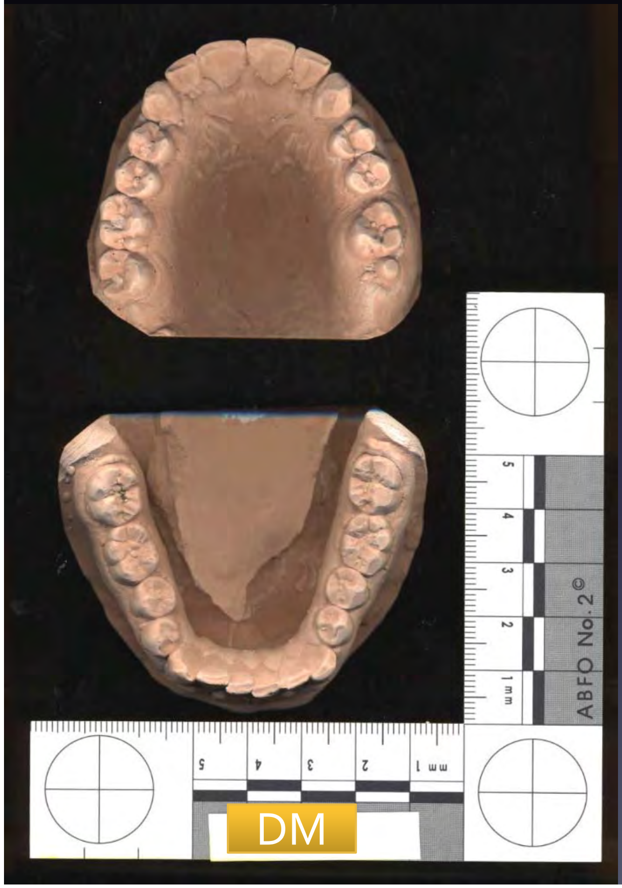
Additional Texas Cases

(The next two are not my cases)

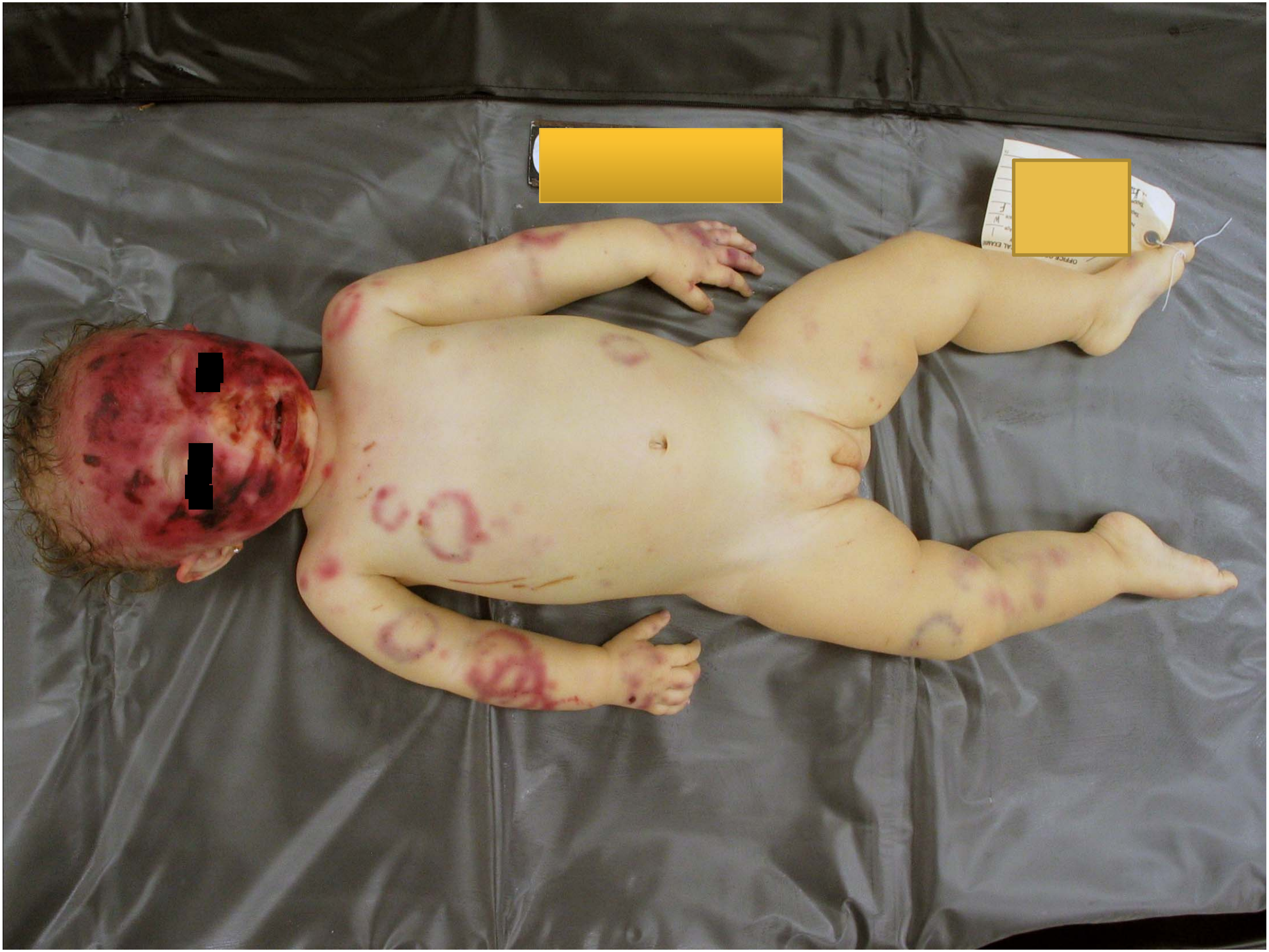
Texas v BM

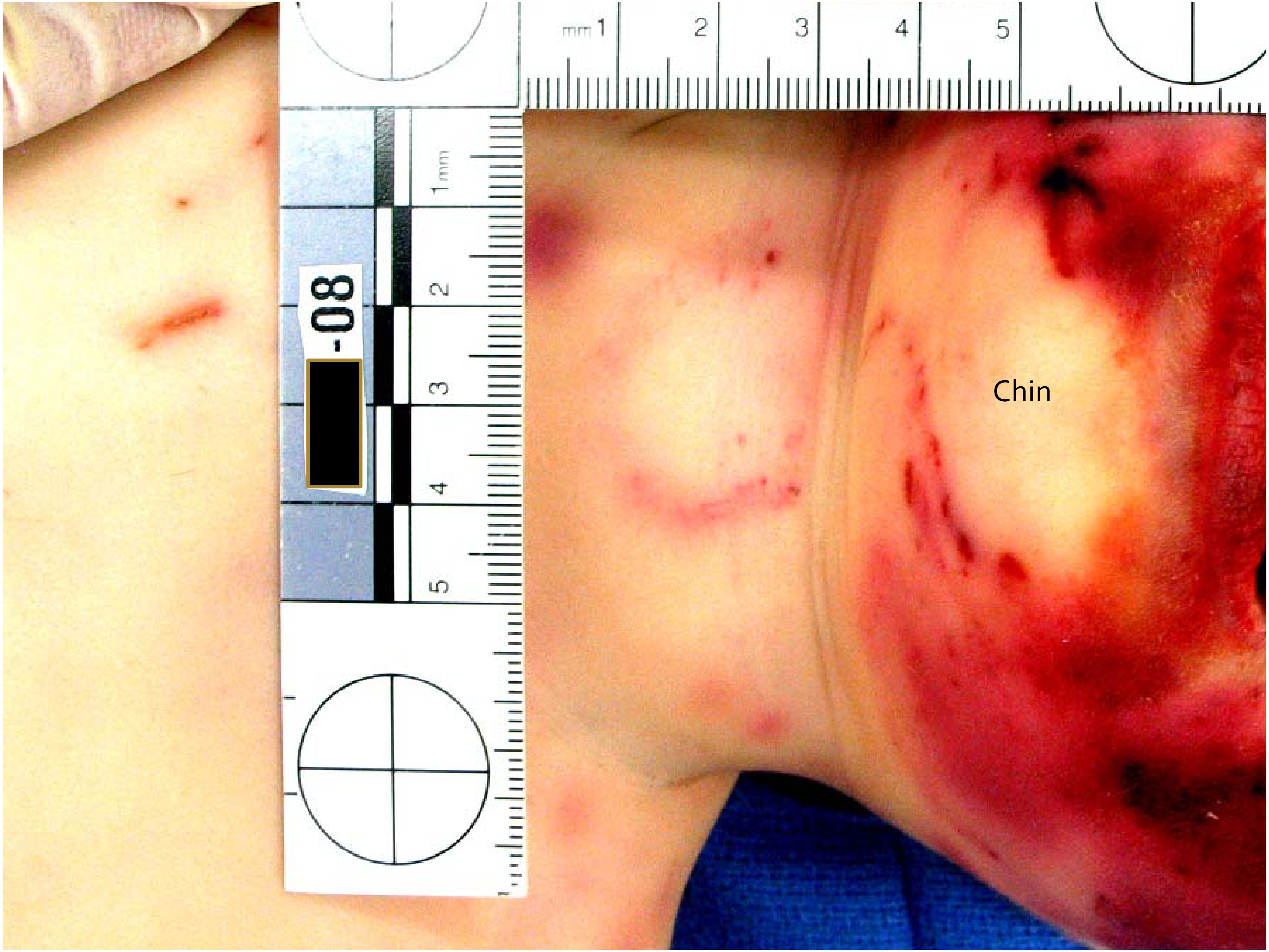
Robert G. Williams, D.D.S., D-ABFO
Chief Forensic Odontologist
Office of the Medical Examiner
Dallas County, Texas

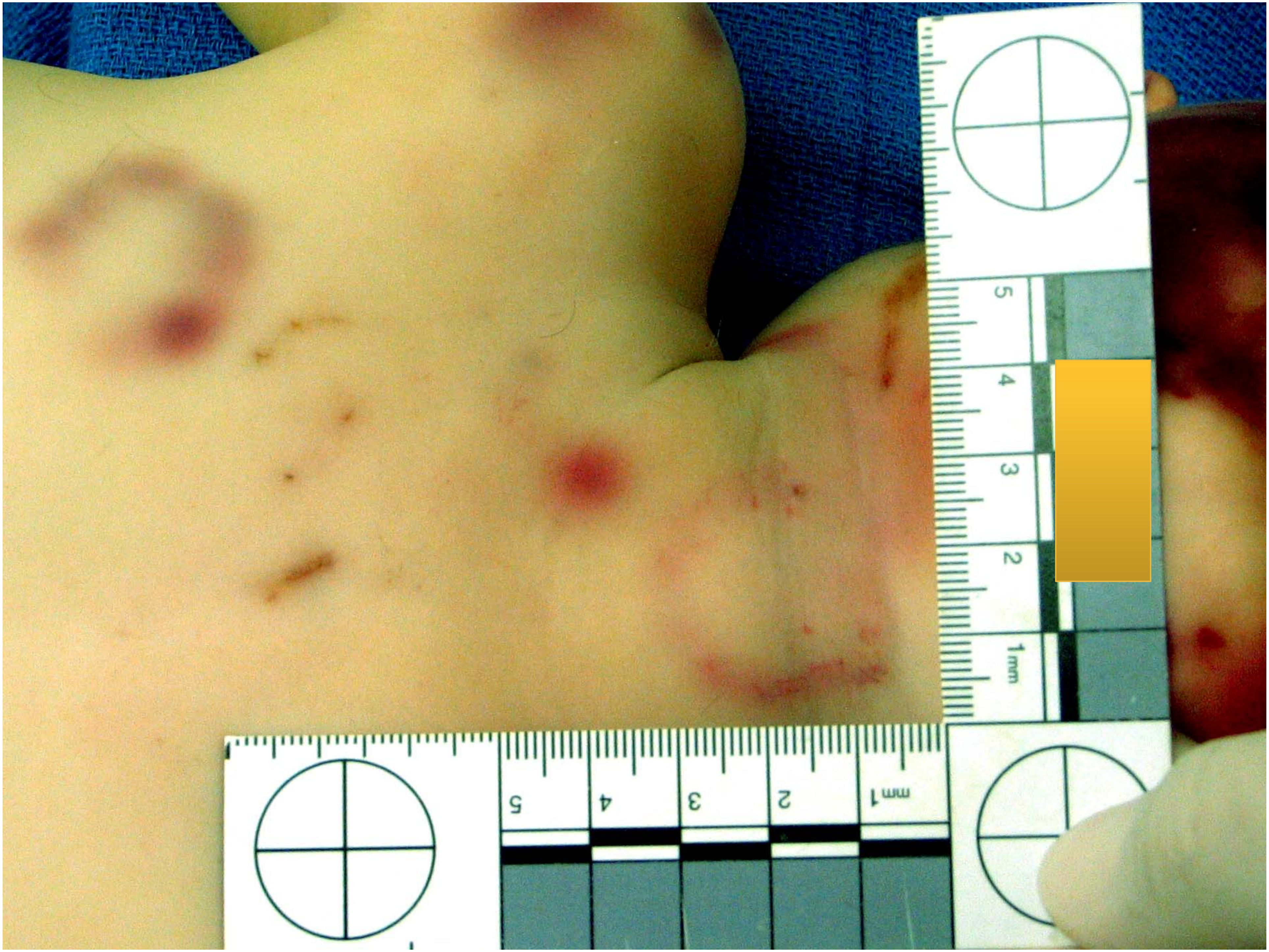
SUSPECTS = BM, DM, JC

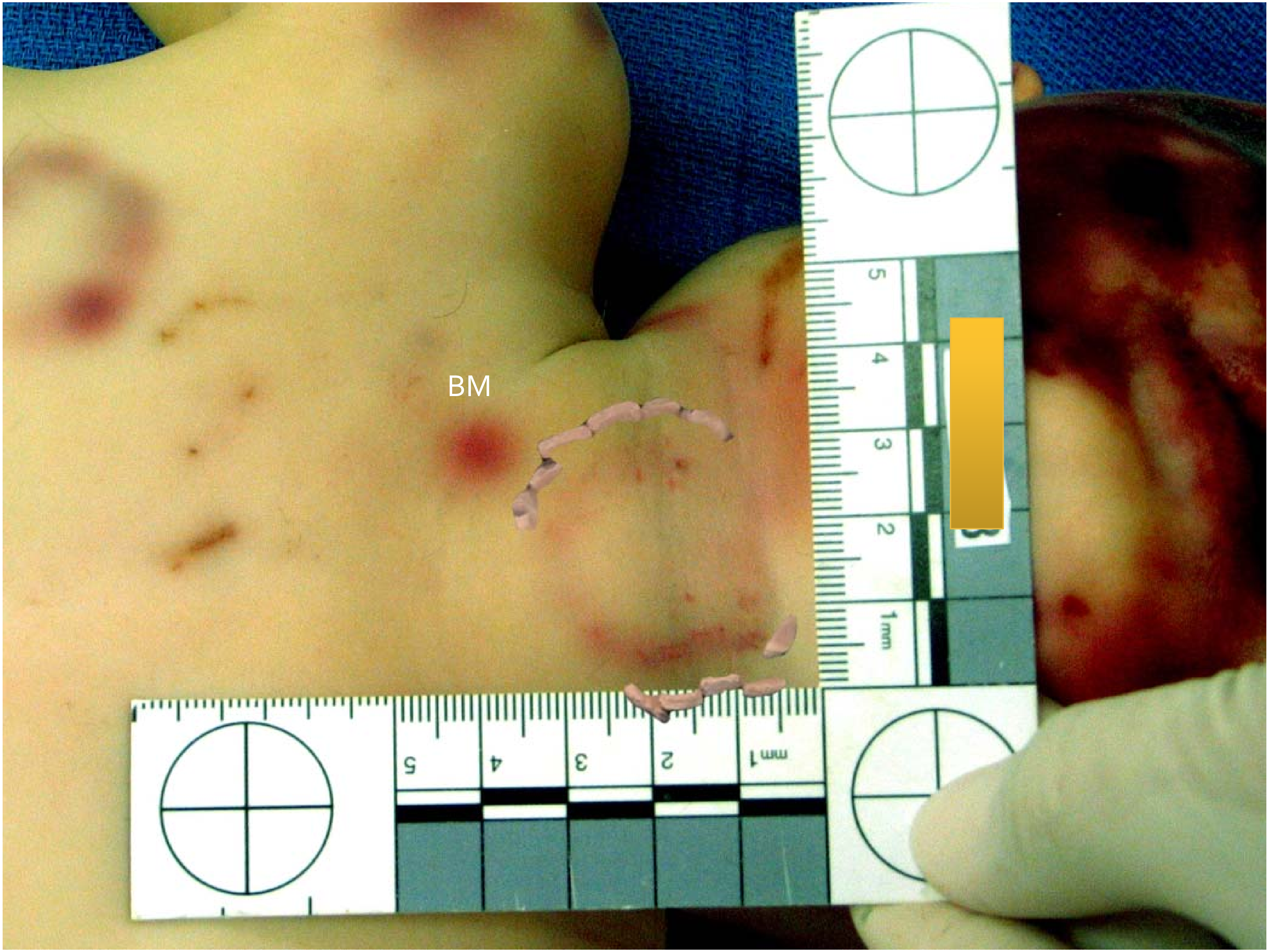


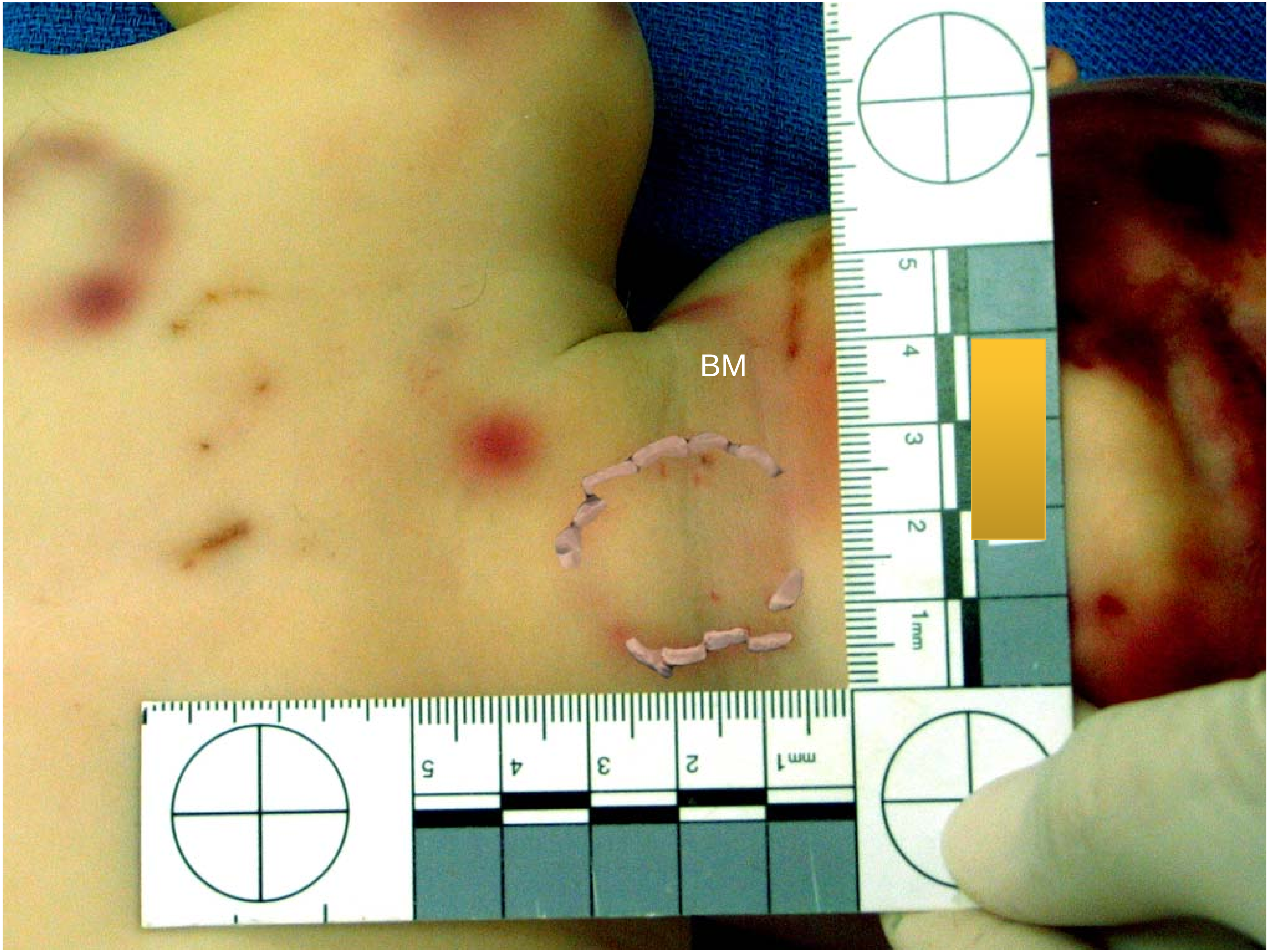
Patterned Injuries

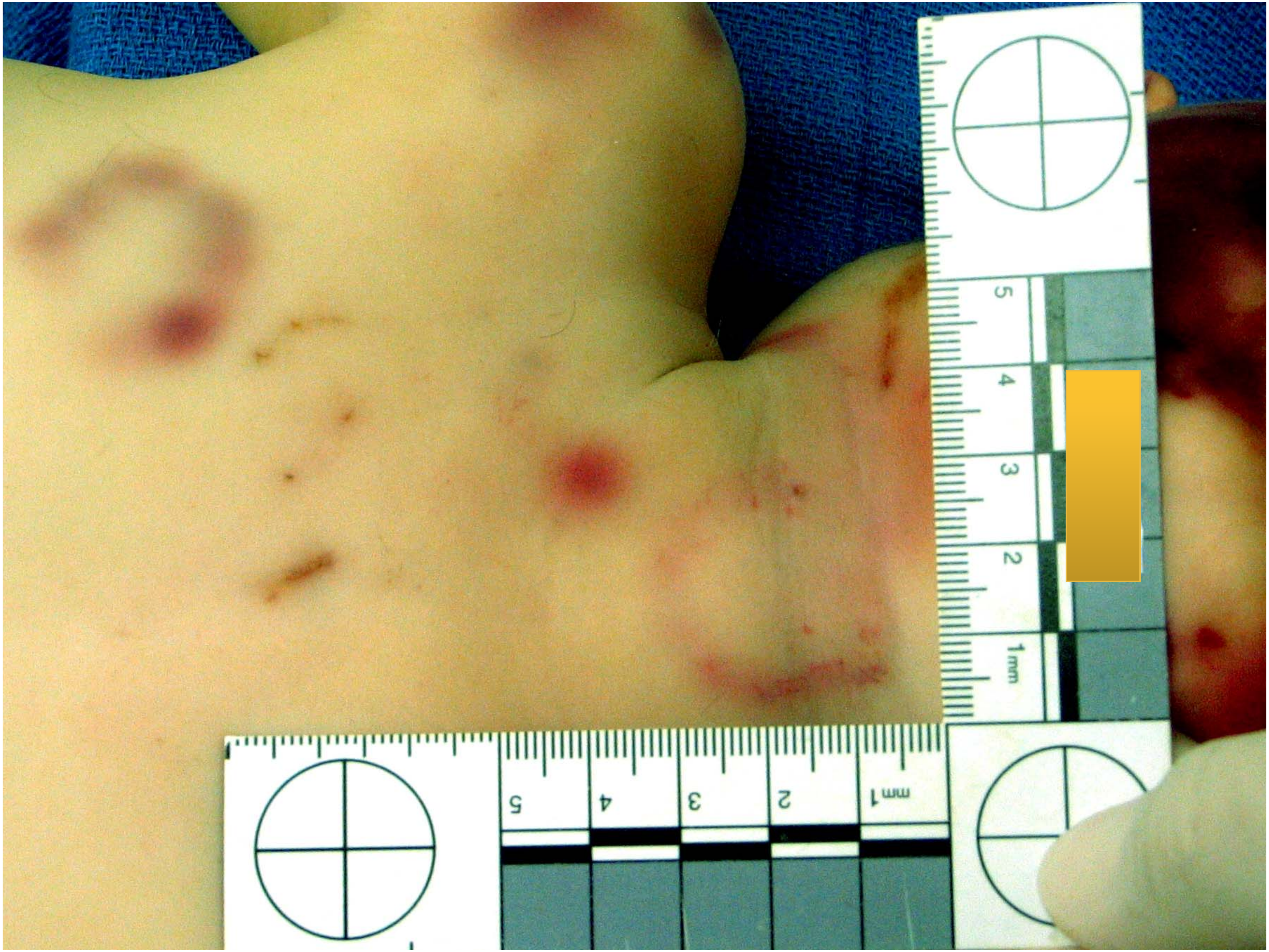


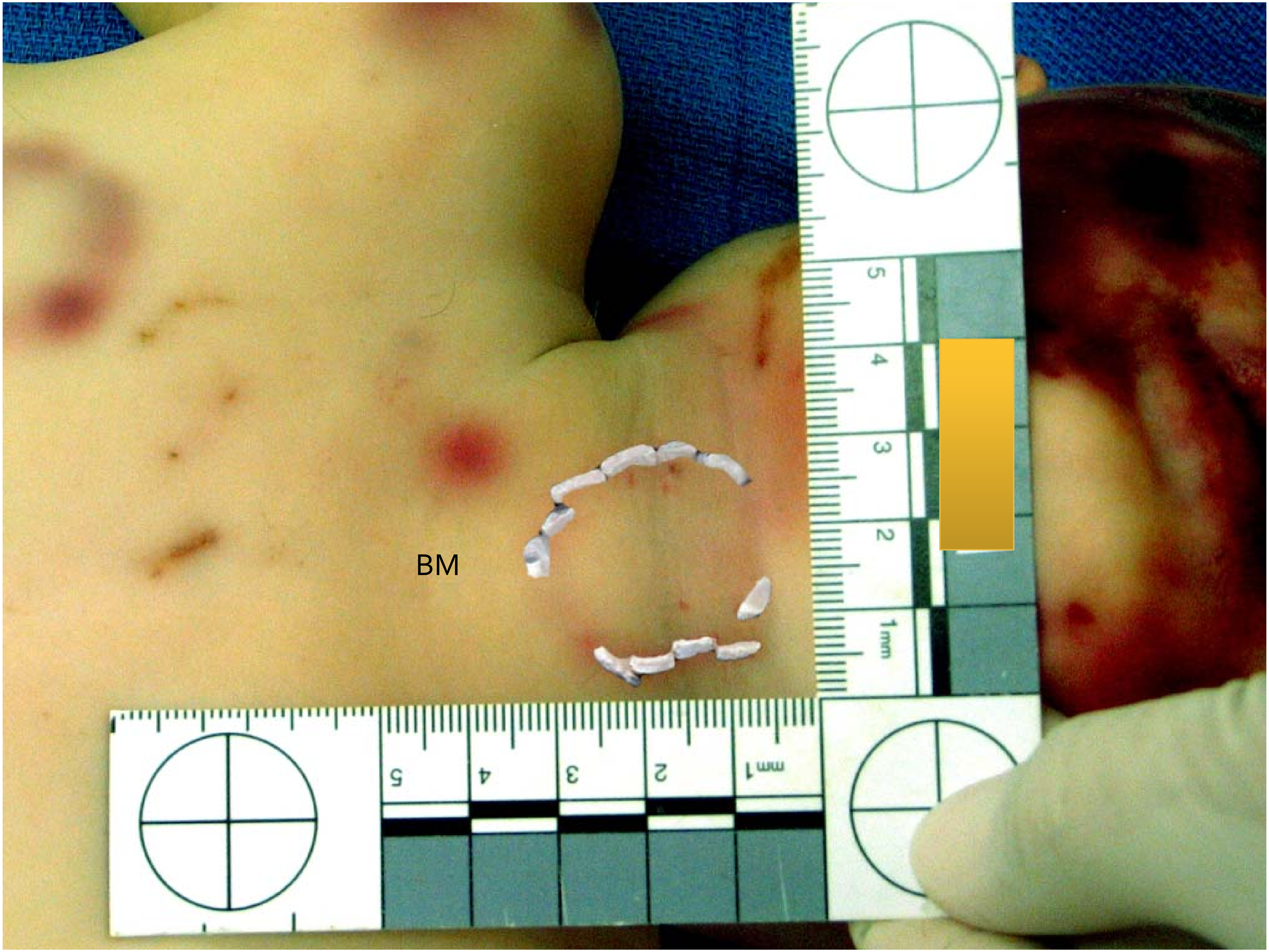

Chin




BM


BM




BM
mm 1 2 3 4 5
mm 1 2 3 4 5

DM excluded
JC excluded

BM not excluded

State v. DC

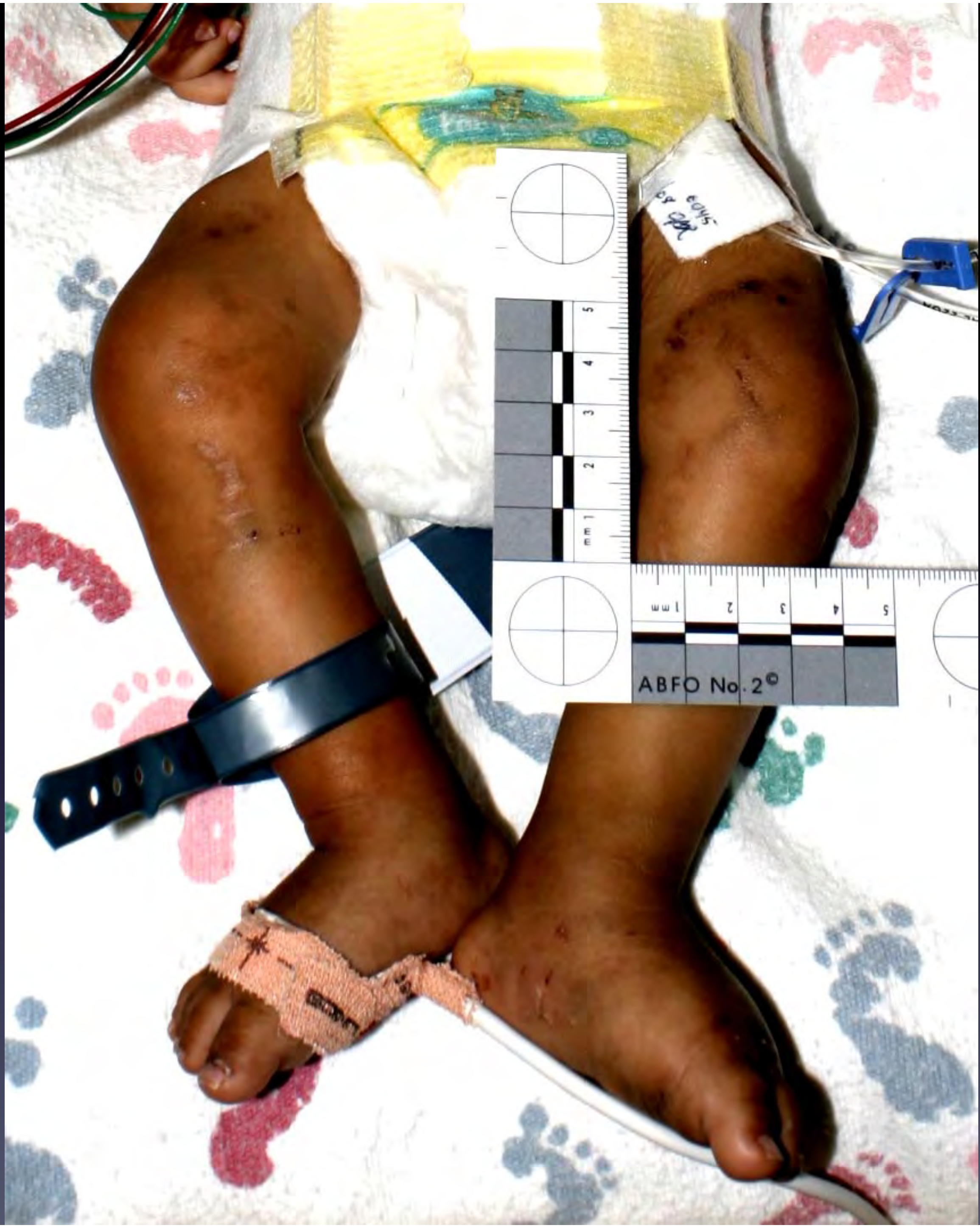
Analysis of Pattern Injuries found on the Body of DC Jr.

Robert G. Williams, D.D.S., D-ABFO

Office of the Medical Examiner

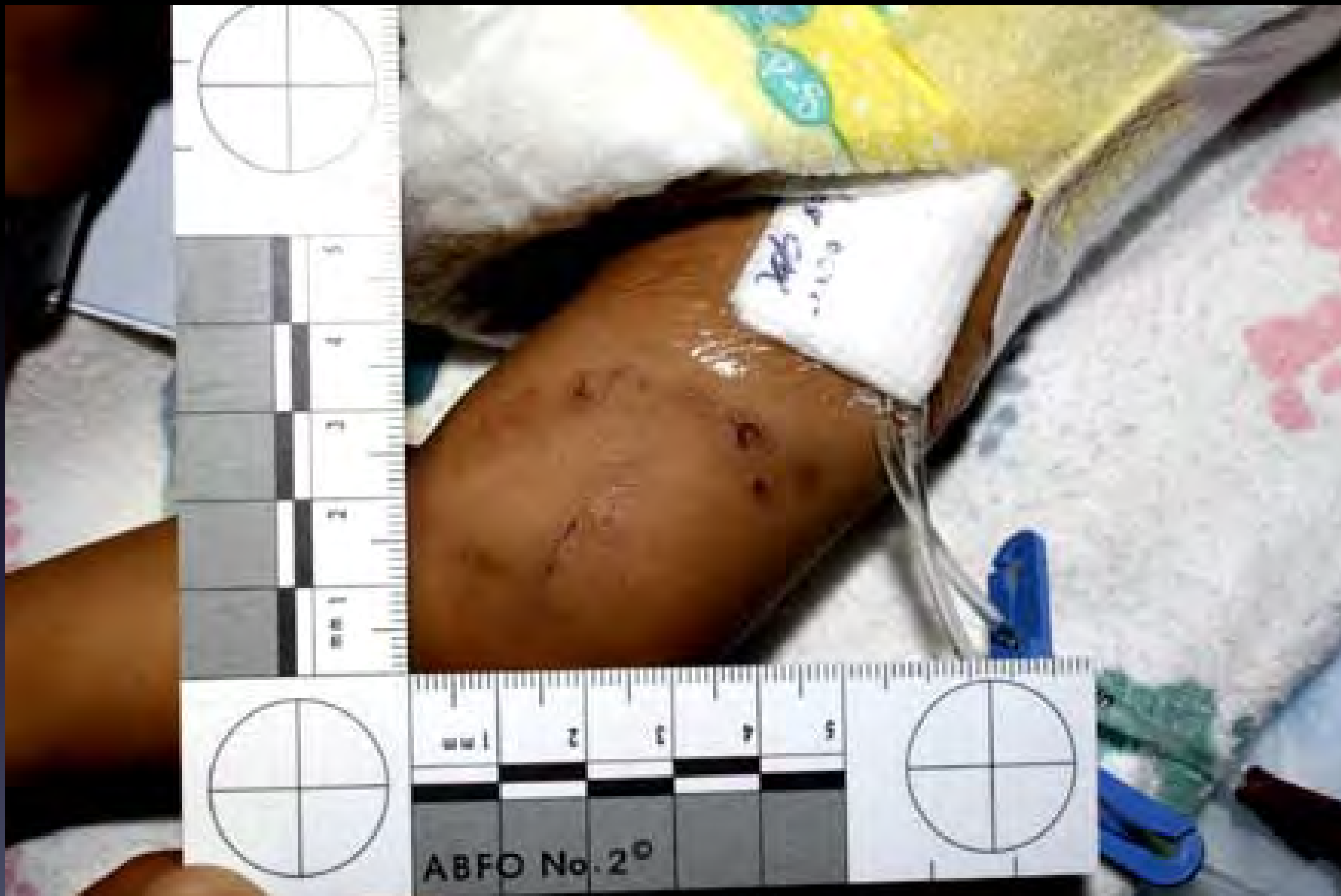
Dallas, Texas


ABFO No 2©


ABFO No. 2©


ABFO No. 2©
mm 1 2 3 4 5
1 mm 2 3 4 5
DISTAL


ABFO No. 2©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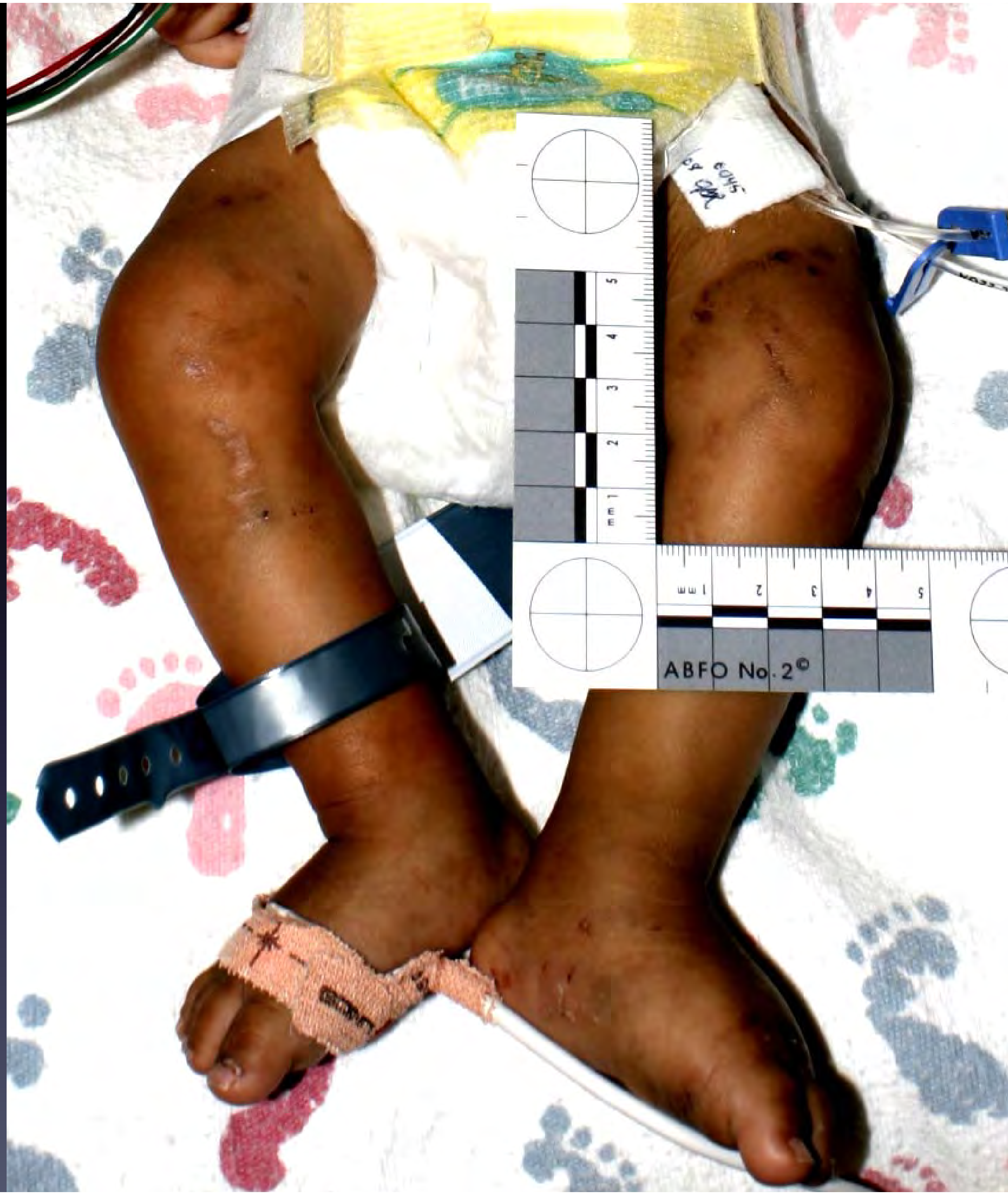
Ru[redacted] C

Da[redacted] C

Jo[redacted] C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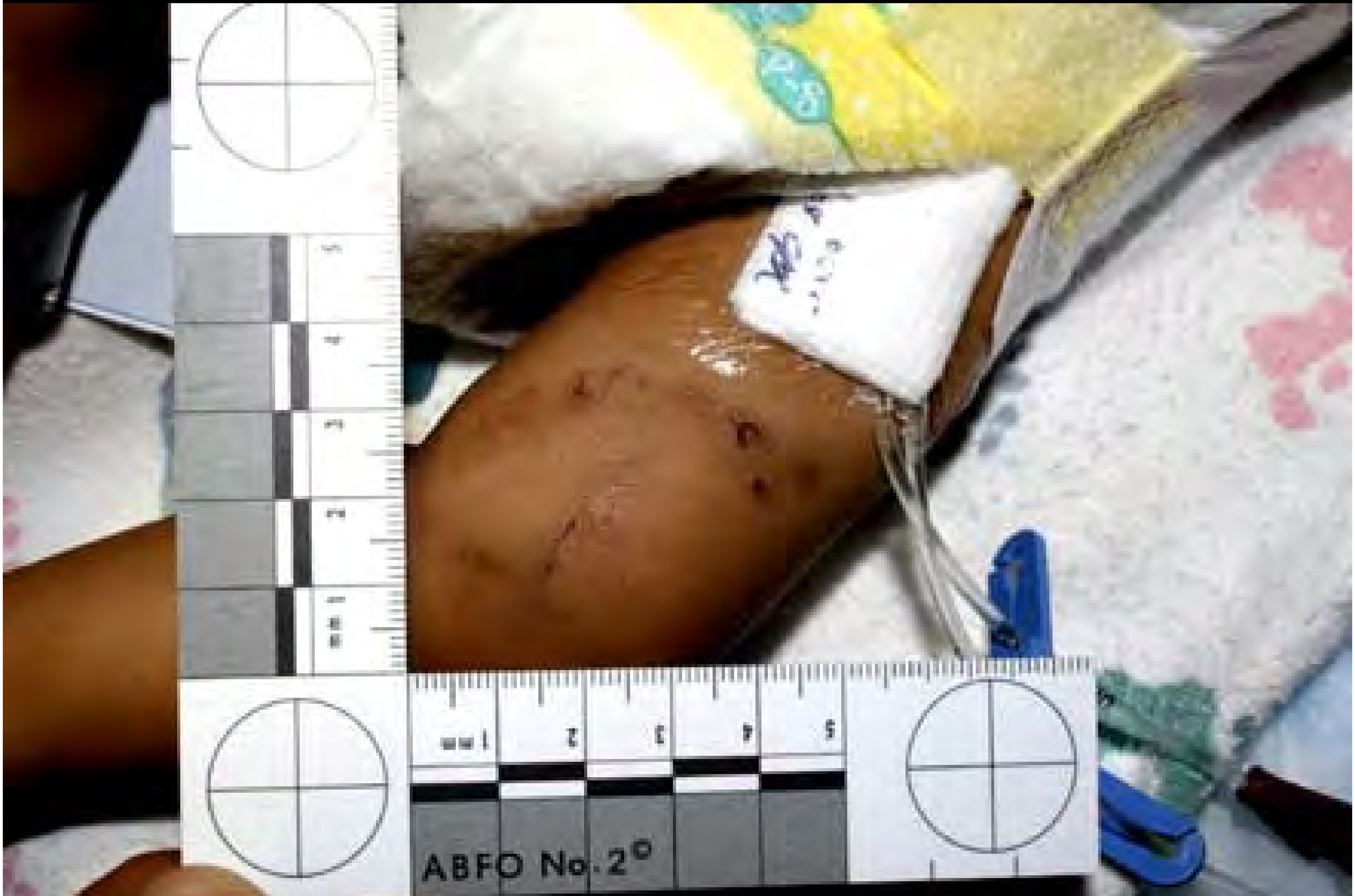
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R
J
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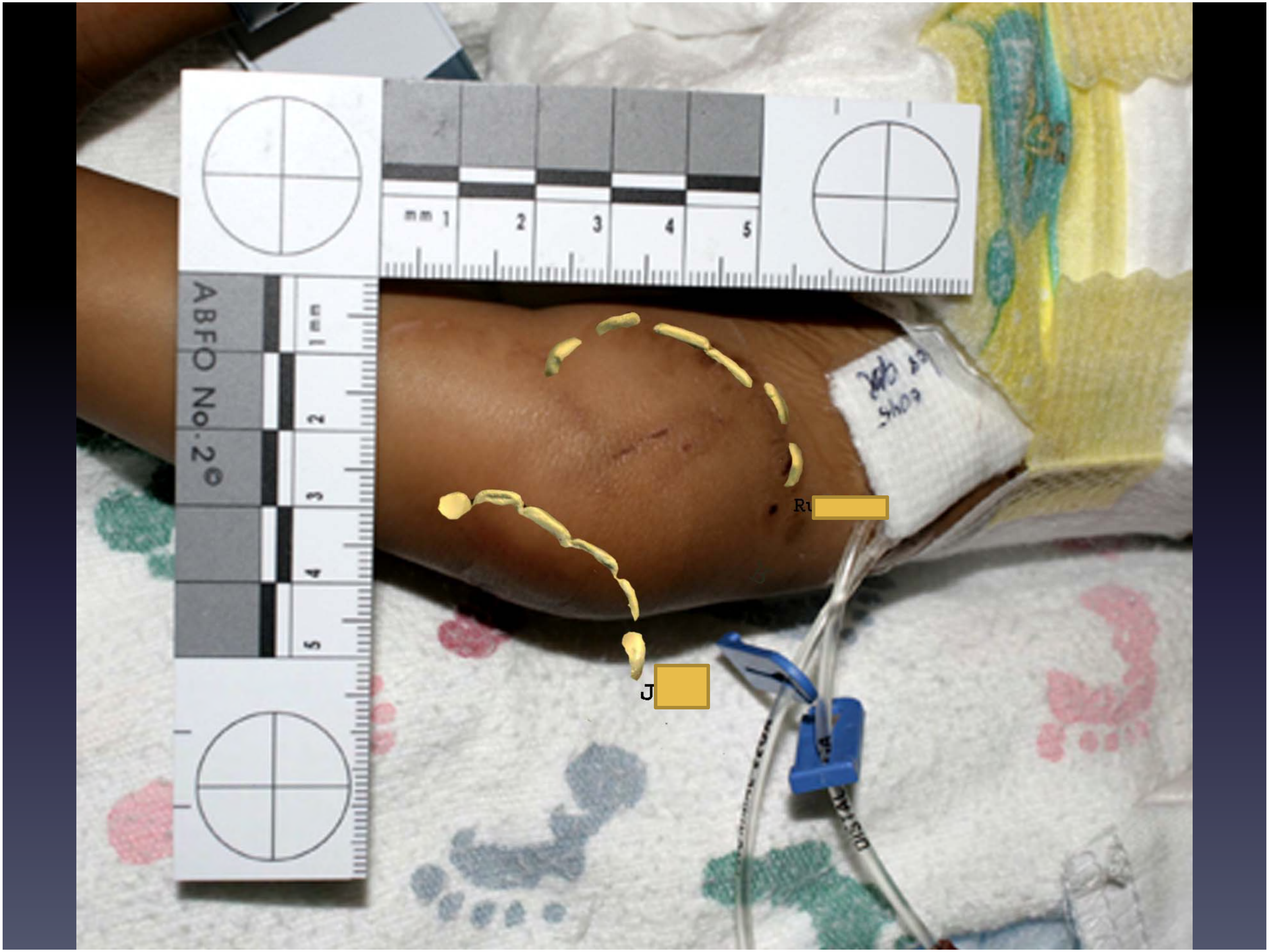
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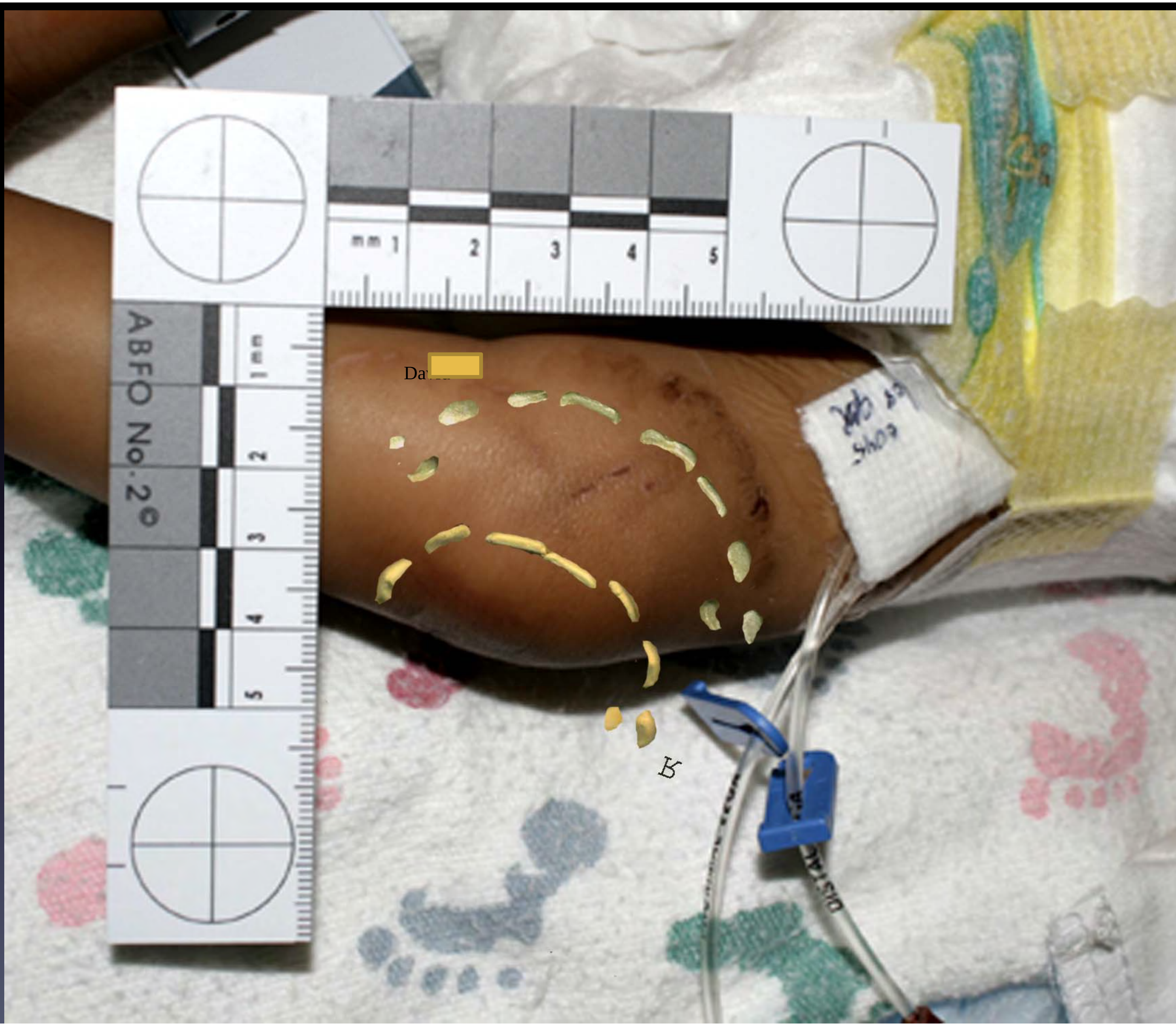
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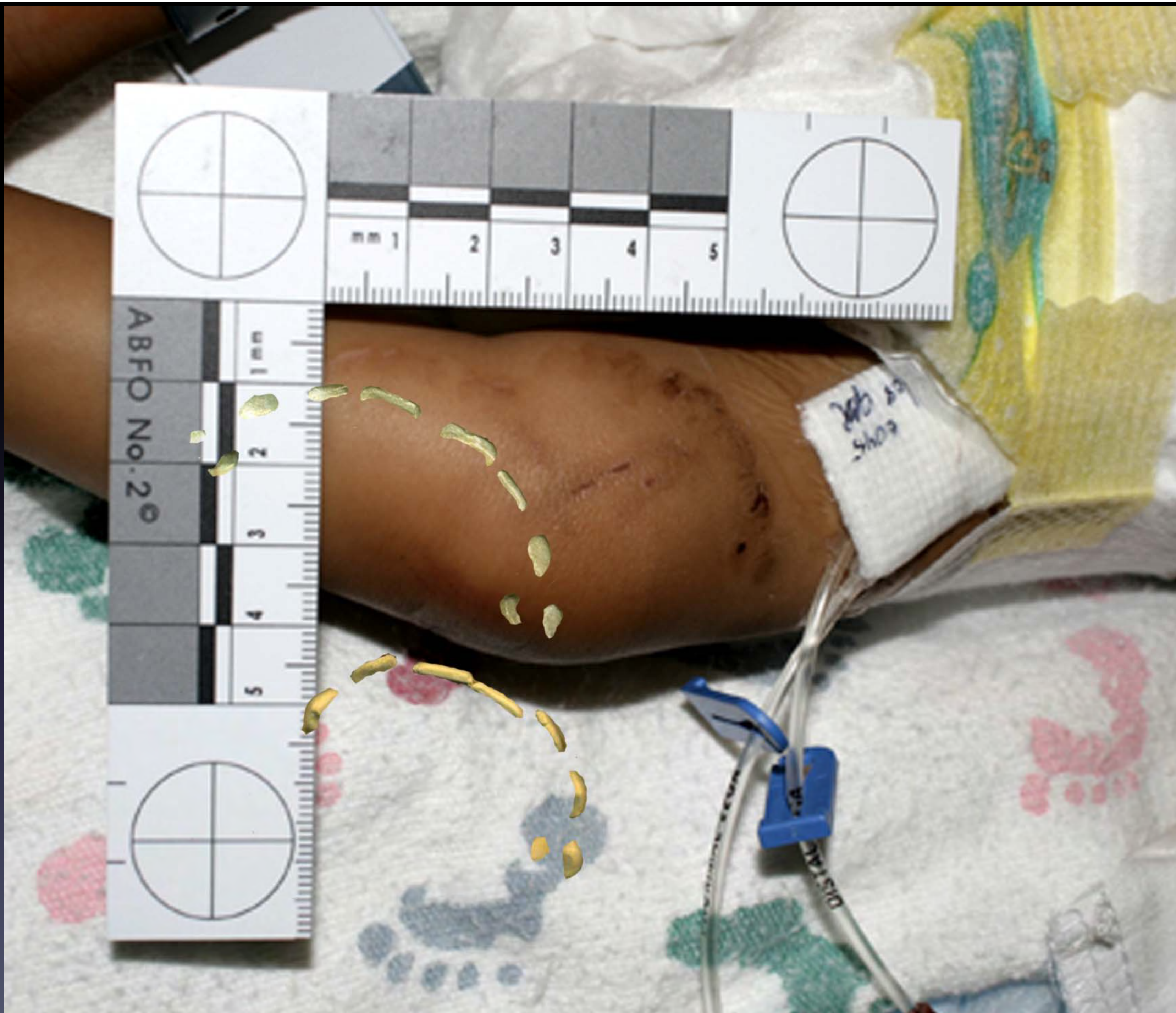
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1 mm 2 3 4 5


ABFO No. 2©


ABFO No. 2©
mm 1 2 3 4 5
David


ABFO No. 2©
mm 1 2 3 4 5
Da


mm 1 2 3 4 5
ABFO No. 2©


mm 1 2 3 4 5
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mm 1 2 3 4 5


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mm 1 2 3 4 5


mm 1 2 3 4 5
ABFO No. 2©

Opinion

- J[redacted] C can be eliminated as a suspect that generated the bitemarks on David C Jr.

- Ru[redacted] C can be eliminated as a suspect that generated the bite marks on David C Jr.

- Da[redacted] C ***cannot*** be eliminated as a suspect that generated the bite marks on David C Jr.

Bitemark Analysis is too important and valuable to the investigation and adjudication of certain crimes to be discounted or overlooked

David Senn

to National Academy of Sciences-2007

~~Not True~~ Partially True

Page 8, last paragraph, Page 9, first paragraph

Simply put, there is no science that confirms biting surfaces of teeth are unique… which is to say there is no science whatsoever which "confirm[s] the fundamental basis for the science of bite mark comparison."

Not True

What science there is, moreover, affirmatively disproves it.

By the way…

A DNA profile is not unique…

but the probability of two full forensic DNA profiles matching wrongly by chance is thought to be very low, less than one in a billion. The probability of a false match depends on the profiling system used.

FORENSIC GENETICS POLICY INITIATIVE
Setting Human Rights Standards For DNA Databases Worldwide

http://dnapolicyinitiative.org/resources/frequently-asked-questions/

DNA Analysis Errors

Lab error rates are typically regarded as being around 2%, although the labs do what they can to conceal errors (as well as avoid them).

Scientific Decision Making
University of Texas at Austin
Book for Bio301D
https://www.utexas.edu/courses/bio301d

DNA Analysis Errors

A) sample mixup. This is probably the most common source of false matches – the people in the lab mixed up the samples. Ultimately, every sample is handled by a person before it gets processed, and this step of human handling is the vulnerable one.

B) Sample contamination. Some cases are similar to sample mixup. In other cases, sample contamination occurs because an officer touches the material with his/her hands, or the contamination may occur when the sample is deposited (e.g., if a blood stain gets bacteria in it).

DNA Analysis Errors

C) DNA degradation. DNA degrades if it is not kept cold or dry. Thus, by the time the police arrive at a crime scene, the DNA in some of the samples may already be bad. Improper storage of samples also contributes to degradation. Degradation may lead to inaccurate DNA typing, though more so for the STR method than for the mitochondrial method.

D) Bad data analysis. The calculation of RMP may be straightforward in many cases, and some software automatically calculates it for each STR. However, unusual cases require a deep understanding of probabilities (and statistics), which if often lacking.

Dental Profile Databases

2D and 3D Dental Profile Databases for bite pattern studies are under development in at least three sites in North America, and in a combined effort among odontologists in Australia, Saudi Arabia, and the USA.

These databases do not (and will not) have the discriminatory power of nuclear DNA but can have a discrimination capability similar to that of mitochondrial DNA

Dental Profile Databases

A dental profile database already exists for dental identification studies (OdontoSearch) The databases are based on the work of Bradley J. Adams, PhD

Adams, B.J., 2003, *Establishing Personal Identification Based on Specific Patterns of Missing, Filled, and Unrestored Teeth.* Journal of Forensic Sciences, 48(3):487-496

Adams, B.J.. 2003, *The Diversity of Adult Dental Patterns in the United States and the Implications for Personal Identification*. Journal of Forensic Sciences, 48(3):497-503

Sample profile result used in the investigation for identification of WWII servicemen recovered in Tarawa

OdontoSearch

Odontosearch Results

Examiner's Name: Senn and D'Anjou

Case Number: HF-2015-028

Detail Coding / Universal Numbering

There were 0 pattern matches out of a comparison with 37955 records.

This suggests that the selected pattern would occur in 0.00263 % of the target population.

The percentage is calculated as (X+1)/(N+1)*100, where X is the number of pattern matches and N is the sample size.

Data Source: Combined_Data_1988_2004_Detailed

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
/	MODFL	MODL	MOD	OD	F	V	V	V	V	F	O	OD	MODFL	X	/
32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17
/	MOF	MODFL	OD	F	V	V	V	V	V	F	F	MOD	MODF	MOF	/

The Path Forward

for Bitemark Analysis and Bitemark Evidence

1. Promote the expression of conservative opinions
2. Publish more restrictive standards and guidelines
3. Accelerate validation of guidelines and standards
4. Accelerate development and population of dental profile databases
5. Implement proficiency testing
6. Promote and encourage research
7. Enforce ethics
8. Assist in responsible review of past cases

1. Conservative Opinions

The ABFO must have a consistent organizational culture that recognizes the limitations of bitemark analysis and requires conservative opinions based on validated standards, guidelines, and terminology

2. More restrictive standards and guidelines

The ABFO and the NIST/OSAC Odontology Subcommittee must work in concert to improve existing standards and guidelines for bitemark evidence

2. More restrictive standards and guidelines

Recommendation 1 – new bitemark definition

Bitemark definition Criteria:

A circular, or oval or curvilinear pattern or patterned injury consisting of either one arch or two opposing arches often, but not always, separated at their bases by unmarked spaces. Individual marks, abrasions, contusions, or lacerations may be found near the periphery of each arch. The marks present reflect the size, shape, arrangement, and distribution of the contacting surfaces of the human teeth that made the pattern.

2. More restrictive standards and guidelines

Recommendation 1- new bitemark definition

Bitemark definition criteria (continued)

Either the maxillary or mandibular arch, or both arches, can be identified and the midline of each arch visible may be determinable.

Some of the marks made by individual teeth can be recognized and identified based on their class characteristics and/or location relative to other features. The size and shape of each arch visible is consistent with the size and shape of the human dentition.

2. More restrictive standards and guidelines

Recommendation 2

New guideline defining evidentiary value

A human bitemark with sufficient evidentiary value to justify comparison to suspected biter information

Criteria:

In addition to the features indicating that this pattern is a human bitemark, this pattern or patterned injury contains additional information. The additional information may be in the form of an increased number or higher quality of identifiable class characteristic features such as distinctive arch detail or distinctive tooth mark detail. This other additional information may also be based on features indicative of the individual characteristics of the teeth

Recommendation 2
New guideline defining evidentiary value
Criteria: (continued)

These individual characteristic features may reveal indications of unusual, distinctive, or non-characteristic dental features.

These distinctive features may include, but are not limited to, patterns indicating the presence of tooth rotations, tooth malformations, missing teeth, chipped or broken biting surfaces, malposed teeth, tooth crowding, diastemata, arch malformations, and teeth that are not fully erupted or for some other reason approach or reach the occlusal plane.

Recommendation 2
New guideline defining evidentiary value
Criteria: (continued)

The accumulation of the class and individual characteristics reflected in this pattern elevate the evidentiary value of this pattern or patterned injury to a level that justifies the comparison of this pattern to suspected biter information.

3. Accelerate validation of guidelines and standards

The validation studies for bitemark evidence guidelines and standards must be continued. These studies must be completed appropriately, expeditiously, and with appropriate urgency

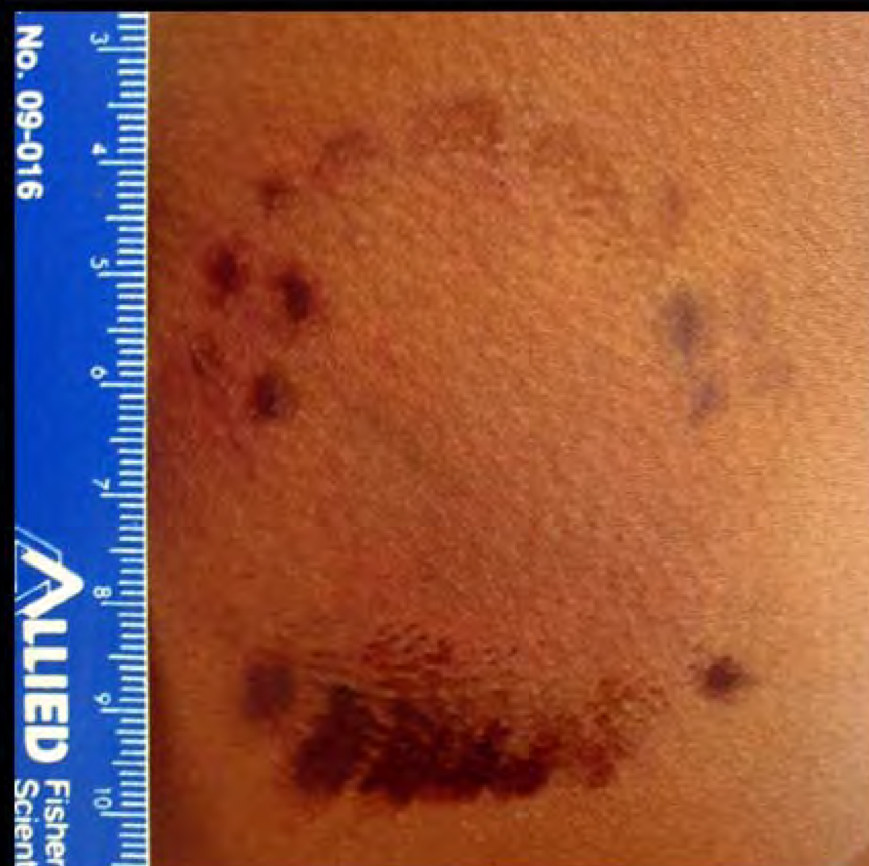
4. Accelerate development and population of dental profile databases

Funding must be found to continue the work initiated independently by Johnson et al., Bush et al., and others to develop appropriately-sized databases of profiles of the anterior human dentition.

These databases should include 2D and 3D profiles of all upper and lower teeth anterior to the permanent first molars for permanent and mixed dentitions.

(20 teeth, 10 upper and 10 lower)

Images below show high evidentiary value bitemarks that include marks made by all upper teeth anterior to the permanent first molars



5. Implement proficiency testing

- The ABFO should expedite the process already underway to introduce bitemark evidence proficiency testing for the forensic odontologists certified by the board.

6. Promote and encourage research

- The ABFO and its members must take urgent steps to acquire the funding to perform the research studies needed to validate the procedures performed by certified forensic odontologists.

7. Enforce ethics

- The ABFO must take all practical steps to make certain that the odontologists certified by the board understand and abide by the Code of Ethics.

8. Assist responsible review of past cases

Testimony given by ABFO certified forensic odontologists has contributed to erroneous convictions

The testimony given may or may not have conformed to the then-existing ABFO bitemark evidence standards and guidelines

It is professionally and morally unsupportable to give improper testimony…and devastating and disastrous if improper testimony leads to the erroneous conviction of an innocent person

The ABFO should encourage its members to assist with all responsible reviews of past cases that contain testimony linking individuals to bitemarks

Summary

- Bitemark Evidence can be useful in the investigation and adjudication of certain cases
  - Pattern evidence information must be of high quality
  - Evidence must be properly collected and analyzed
  - Sometimes the mere presence of a bitemark is important evidence, even when no comparison is possible
  - Odontologists must avoid making comparisons and forming linkage opinions for cases with insufficient evidence
  - Odontologists must take steps to inhibit bias
  - Odontologists must form conservative opinions and avoid overstating opinions in sworn testimony
  - Standards and Guidelines must be appropriate and appropriately followed
  - Odontologists should have and enforce the highest ethical standards
- If bitemark evidence is discounted or overlooked, or if the use of bitemark evidence is discontinued, children and others who are victims of violence and abuse will suffer.

Thank You

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July 22, 2015

Texas Forensic Science Commission
1700 North Congress Avenue, Suite 445
Austin, Texas 78701

Dear Commissioners:

Please accept this complaint, filed on behalf of our client, Steven Mark Chaney, and on behalf of the Innocence Project, Inc. We ask that the Texas Forensic Science Commission ("the Commission") exercise its statutory mandate to investigate and report on "the integrity and reliability" of bite mark evidence as used in criminal proceedings. Tex. Crim. Proc. Code Ann. § art. 38.01(4)(b-1)(1).[1]

The Innocence Project is a national litigation and public policy organization dedicated to exonerating wrongfully convicted persons through DNA testing and improving the criminal justice system to prevent future miscarriages of justice. To date, 330 people in the United States, including 18 who served time on death row, have been exonerated by DNA testing. One lesson to be drawn from these exonerations is that the misapplication of forensic sciences is one of the leading causes of wrongful conviction, contributing to the original wrongful conviction in approximately half of the DNA exoneration cases. Some forensic techniques are more problematic than others, however, and of those disciplines currently in use, it is bite mark comparison evidence that poses the most acute threat to the reliability and fairness of Texas's criminal justice system. Indeed, despite the relative rarity of its application, no less than 24 people have been wrongfully convicted or indicted on the basis of bite mark evidence,[2] including *at least*

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[1] Forensic odontology is not specifically enumerated as an accredited field of forensic science. *See* 37 Tex. Admin. Code § 28.145. However, it may be treated as a form of impression evidence, *see Milam v. State*, No. AP-76,379, 2012 WL 1868458, at *12-*13 (Tex. Crim. App. May 23, 2012) (unpublished opinion), which may thus be conducted out of an accredited laboratory, giving the Commission additional jurisdiction. *See* Tex. Crim. Proc. Code Ann. § art. 38.01(4)(a)(3).

[2] *See* Ex. B (Amanda Lee Myers, *Men Wrongly Convicted or Arrested on Bite Evidence*, ASSOCIATED PRESS, June 16, 2013, available at http://news.yahoo.com/men-wrongly-convicted-arrested-bite-evidence-150610286.html); Ex. C (Amanda Lee Myers, *Bites Derided as Unreliable in Court*, ASSOCIATED PRESS, June 16, 2013, available at http://news.yahoo.com/ap-impact-bites-derided-unreliable-court-150004412.html); *see also* Ex. D (List of Bite Mark Exonerations).

two in Texas to date.[3] That this technique is responsible for so many miscarriages of justice is not surprising. As this complaint outlines, no validated and reliable science remotely supports bite mark evidence, and what science there is affirmatively disproves even the most basic assumptions which underlie it. Bite marks, moreover, "often are associated with highly sensationalized and prejudicial cases, and there can be a great deal of pressure on the examining expert to match a bite mark to a suspect," *see* Ex. A at 175 (NATIONAL ACADEMY OF SCIENCES, Committee on Identifying the Needs of the Forensic Sciences Community, STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES: A PATH FORWARD (2009) ("NAS Report")). This, along with the fact that bite mark analysis is entirely subjective, greatly increases the risk of wrongful conviction in bite mark cases.

Given the complete lack of science supporting bite mark analysis, and the grave risk of wrongful conviction use of the technique poses, bite marks represent an ideal and critical opportunity for this Commission to bring to bear its statutory mandate to "advance the integrity and reliability of forensic science" in Texas. *See* Tex. Crim. Proc. Code Ann. § art. 38.01(4)(a-1). We thus ask that this Commission undertake a thorough investigation of bite mark evidence. Our request is that this investigation include retrospective and prospective components. Retrospectively, we ask that this Commission audit those cases in which bite mark comparison testimony was offered. Prospectively, we ask this Commission declare a moratorium on the continued use of bite mark comparison evidence in criminal prosecutions until such time as the technique has been scientifically validated and proven reliable. Doing so will not only advance this body's statutory mission, but also help ensure that no more innocent Texans are incarcerated as a result of this dangerously unreliable "science."

Bite Mark Analysis Has Never Been Validated or Proven Reliable

The use of bite mark comparison evidence in criminal trials rests on a series of unproven assumptions. First, bite mark comparison evidence assumes that the biting surfaces of teeth (i.e., the dentition) are unique. Second, it assumes that human skin is capable of accurately recording the dentition's unique features. Third, it assumes that forensic dentists can reliably associate a dentition with a bite mark. Finally, bite mark comparison assumes that, given all the foregoing, forensic dentists can provide a scientifically valid estimate as to the probative value of the association. But, as this letter will demonstrate, no science supports these assumptions, and thus no science supports the conclusion that a perpetrator can be identified from a bite mark in human skin.

The Dentition Has Never Been Scientifically Demonstrated to be Unique

The first assumption of bite mark comparison evidence is that the human dentition (i.e., the biting surfaces of teeth) is unique. But this proposition has never been demonstrated by science to be valid or reliable. In 2009, the National Academy of Sciences ("NAS")—an organization made up of the nation's most accomplished

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[3] For more on the exonerations of Calvin Washington and Joe Sidney Williams, and the probable wrongful convictions of Steven Mark Chaney and others in Texas, *see infra*.

Several Courts have ruled that the NAS report is not "authoritative"

scientists "charged [by an Act of Congress] with providing independent, objective advice to the nation on matters related to science and technology"[4]—undertook the first examination by an independent scientific body of bite mark evidence. After nearly four years of work, including thorough literature reviews and extensive testimony from a vast array of scientists, law enforcement officials, medical examiners, crime laboratory officials, investigators, attorneys, and leaders of professional and standard-setting organizations, the NAS issued its groundbreaking and authoritative report. While the report criticized the scientific foundation for many forensic disciplines, the NAS reserved its most pointed and devastating critique for bite mark evidence, concluding that the technique lacks scientific validity and has never been proven reliable.

In particular, the NAS rejected the first assumption of bite mark analysis as baseless, finding that "[t]he uniqueness of the human dentition has not been scientifically established." Ex. A at 175-76 (NAS Report). Recent scientific research published largely after the NAS Report suggests that not only has this uniqueness *not* been scientifically established, but that it *cannot* be. This research indicates that the limited features of the biting surfaces of teeth, which are likely to involve only one narrow surface of less than eight teeth within a bite mark (as opposed to 32 teeth with five sides for a typical adult), may not actually be unique.[5] Indeed, these studies have found there are "matches" between dentitions within certain populations.[6] *See* Ex. E at ¶¶ 8, 14-15 (Affidavit of Dr. Mary and Peter Bush ("Bush Affidavit")) ("Our results indicate that the biting surfaces of human anterior (front) teeth (i.e., the dentition) is not unique within measurement error. This is particularly true within a bitemark, in which only those anterior teeth may be involved.").

Even if the Dentition Were Unique, Human Skin Is Not Capable Of Accurately Recording Those Unique Features

Even if there were scientific support for the proposition that the dentition is unique, there is no support for the proposition that human skin is capable of accurately recording those unique features. The NAS Report found that this assumption, too, was unsupported, concluding that "[t]he ability of the dentition, if unique, to transfer a unique pattern to human skin and the ability of the skin to maintain that uniqueness has not been scientifically established . . . ." Ex. A at 175-76 (NAS Report).

Moreover, as with the supposed uniqueness of the dentition, a new body of science—much of which emerged after publication of the NAS Report—suggests that this ability will never be established. This peer-reviewed research indicates that due to its

[4] *See* National Academy of Sciences, available at http://www.nasonline.org/about-nas/mission/.
[5] Ex. F (Bush MA, Bush PJ, Sheets, HD. Statistical Evidence for the Similarity of the Human Dentition. J Forensic Sci 2011, 56(1):118-123 (observing significant correlations and non-uniform distributions of tooth positions as well as matches between dentitions)); Ex. G (Sheets HD, Bush PJ, Brzozowski C, Nawrocki LA, Ho P, and Bush MA. Dental Shape Match Rates in Selected and Orthodontically Treated Populations in New York State: A Two Dimensional Study. J Forensic Sci 2011, 56(3): 621-626 (finding random dental shape matches)); Ex. H (Bush MA, Bush PJ, Sheets HD. Similarity and Match Rates of the Human Dentition In 3 Dimensions: Relevance to Bitemark Analysis. Int J Leg Med 2011, 125(6): 779-784 (same)).
[6] *See supra fn.* 5.

anisotropic, viscoelastic, and non-linear properties, human skin cannot accurately record whatever uniqueness may be present in the human dentition.[7] *See* Ex. E at ¶ 8 (Bush Affidavit). This work demonstrates that skin's natural tension lines and tissue movement distort bite marks, often dramatically.[8] Bite marks from the same dentition may appear substantially different depending on the angle and movement of the body and whether the mark was made parallel or perpendicular to tension or Langer lines.[9] Other studies indicate that skin is so unreliable as a medium that similarly aligned dentitions may create indistinguishable marks. Even more concerning, this research also revealed that dentitions may appear to best match marks *they did not create*.[10]

Thus, current research strongly suggests that "even if the human dentition were unique . . . human skin is not capable of faithfully recording that uniqueness with sufficient fidelity to permit bitemark comparison." Ex. E at ¶ 23 (Bush Affidavit); *see also* Ex. A at 174 (NAS Report) ("[B]ite marks on the skin will change over time and can be distorted by the elasticity of the skin, the unevenness of the surface bite, and swelling and healing. These features may severely limit the validity of forensic odontology.").

Forensic Dentists Cannot Reliably Associate A Dentition With A Bite Mark

The third false assumption of bite mark analysis is that forensic dentists can reliably associate a dentition with a bite mark. But the NAS found that "[t]here is no science on the reproducibility of the different methods of analysis that lead to conclusions about the probability of a match. This includes reproducibility between experts and with the same expert over time." Ex. A at 174 (NAS Report). Indeed, "a standard for the type, quality, and number of individual characteristics required to indicate that a bite mark has reached a threshold of evidentiary value has not been established." *Id.* at 176. This is an especially acute problem in bite mark comparison because the manner in which skin heals or decomposes over time is not predictable, and therefore there is no methodology to account for the distortion of the injury caused by these processes. As a result, experts attempting to associate a particular dentition with a bite mark made on human skin can, at best, make educated guesses.

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[7] Ex. I (Bush MA, Bush PJ, Sheets HD. A Study of Multiple Bitemarks Inflicted in Human Skin by a Single Dentition Using Geometric Morphometric Analysis. Forensic Science International 211 (2011) 1-8); Ex. J (Bush MA, Thorsrud K, Miller RG, Dorion RBJ, Bush PJ. The Response of Skin to Applied Stress: Investigation of Bitemark Distortion in a Cadaver Model. J Forensic Sci 2010;55(1):71-76); Ex. K (Bush MA, Cooper HI, Dorion RBJ. Inquiry into the Scientific Basis For Bitemark Profiling and Arbitrary Distortion Compensation. J Forensic Sci 2010; 55(4):976-983); Ex. L (Miller RG, Bush PJ, Dorion RBJ, Bush MA. Uniqueness of the Dentition as Impressed in Human Skin: A Cadaver Model. J Forensic Sci 2009; 54(4):909-14) ("Miller, Uniqueness").

[8] Ex. M (Bush MA, Miller RG, Bush PJ, Dorion, RB. Biomechanical Factors in Human Dermal Bitemarks in a Cadaver Model. J Forensic Sci 2009 54(1): 167-176)).

[9] *Id.*

[10] *E.g.*, Ex. L (Miller, Uniqueness). For a real life example of how well an innocent person's dentition can appear to match a bite mark, *see* Ex. N at p. 46 (Amici Curiae Brief of Michael J. Saks, Thomas Albright, Thomas L. Bohan, Barbara E. Bierer and 34 Other Scientists, Statisticians and Law-And-Science Scholars and Practitioners In Support Of the Petition for Writ of Habeas Corpus by William Joseph Richards ("Scientists' Brief")) and *infra* on the wrongful conviction of Ray Krone.

Moreover, while the American Board of Forensic Odontology ("ABFO"), forensic odontology's only board certifying body, has issued "guidelines" for a range of conclusions concerning an association between a bite mark and a suspect, its members are not required to adopt the suggested terminology. Nor are they provided with any guidance on delineating between the various conclusions. More importantly, these guidelines were not arrived at scientifically but instead with nothing more than a show of hands of the members present at a meeting. *See* Ex. A at 174 (NAS Report) ("The [ABFO] guidelines, however, do not indicate the criteria necessary for using each method to determine whether the bite mark can be related to a person's dentition and with what degree of probability."). As the NAS found, "[e]ven when using the [ABFO] guidelines, different experts provide widely differing results . . . ." *Id.*

Ultimately, the NAS concluded that forensic odontologists lack "the capacity to consistently, and with a high degree of certainty, demonstrate a connection between evidence and a specific individual or source." *Id.* at 7; *see also id.* at 175 ("[T]he scientific basis is *insufficient to conclude that bite mark comparisons can result in a conclusive match*." (emphasis added)).

Even If Bite Marks Could Be "Matched," There Is No Evidence Of The Probative Value Of That Association

Even if there were science to support the notion that an association could reliably be made between a dentition and a bite mark, bite mark analysis still fails in its final assumption—that a scientifically valid estimate of the probative value of that association can be made. But as the NAS concluded, there is no way to determine the probability of a match because "there is no established science indicating what percentage of the population or subgroup of the population could also have produced [a] bite." *Id.* at 174; *see also* Ex. E at ¶ 28 (Bush Affidavit) ("[S]tatistical evidence for the likelihood of a random match is, as yet, unsupportable.").

This Commission recently took action regarding precisely the same type of scientifically invalid testimony in cases involving microscopic hair comparison. After the FBI acknowledged that its hair examiners had been making improper individualization claims and otherwise exaggerating the probative value of an association between a known and a suspected hair for decades, it, along with the National Association of Criminal Defense Lawyers and the Innocence Project, undertook an unprecedented review of thousands of cases to search for testimony that went beyond the bounds of science.[11]

The FBI also trained hundreds of state and local examiners to give similarly flawed testimony, and so the Commission has undertaken a case audit to "determine whether the issues identified by the FBI are also present in the testimony provided by state, county

[11] *See, e.g.,* Ex. A at 160 (NAS Report); Spencer Hsu, *U.S. Reviewing 27 Death Penalty Convictions for FBI Forensic Testimony Errors*, WASHINGTON POST, July 17, 2013, available at http://www.washingtonpost.com/local/crime/us-reviewing-27-death-penalty-convictions-for-fbi-forensic-testimony-errors/2013/07/17/6c75a0a4-bd9b-11e2-89c9-3be8095fe767_story.html.

and municipal laboratories."[12] This case audit will consider whether 1) "the report or testimony contain[ed] a statement of identification"; 2) "the report or testimony assign[ed] probability or statistical weight"; 3) "the report or testimony contain[ed] any other potentially misleading statements or inferences."[13] As the Commission has concluded, a hair

> examiner cannot provide a scientifically valid estimate of the rareness or frequency of [an] association. The examiner's testimony should reflect the fact that hair comparison cannot be used to make a positive identification of an individual. In other words, hair comparison can indicate, at the broad class level, that a contributor of a known sample could be included in a pool of people as a possible source of the hair evidence. However, the examiner should not give an opinion as to the probability or the likelihood of a positive association.[14]

These same limitations apply to bite mark evidence. *See* Ex. A at 176 (NAS Report). ("Bite mark testimony has been criticized basically on the same grounds as testimony by questioned document examiners and microscopic hair examiners."). Indeed, bite mark evidence is even more circumscribed, as the distorting properties of skin discussed above mean that bite mark comparison experts cannot even validly make an association between a mark and a dentition.

Bite Marks Are Prone to Serious Error

Given its lack of scientific basis, it is no surprise that bite mark comparison evidence is prone to serious error. Indeed, "error rates by forensic dentists are perhaps the highest of any forensic identification specialty still being practiced." Ex. N at 5 (Scientists' Brief). Devastating new research highlighting these profound error rates, conducted in part by the Vice President of the ABFO's own Executive Committee, has recently become public. This study, entitled *Construct Validity Bitemark Assessments Using the ABFO Bitemark Decision Tree* ("Construct Validity Study"), demonstrates that even the ABFO's most experienced forensic odontologists cannot agree on whether an injury is a bite mark *at all*, to say nothing of whether it was caused by a particular individual.

As part of the Construct Validity Study, photographs of 100 patterned injuries were shown to 103 ABFO board-certified Diplomates. They were asked to decide three questions: first, whether there was sufficient evidence to render an opinion on whether the patterned injury was a human bite mark; second, whether consistent with the ABFO decision tree, the injury was, indeed, a human bite mark, not a human bite mark, or

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[12] Texas Forensic Science Commission, *Statement Regarding Texas Hair Microscopy Review Texas Forensic Science Commission*, available at http://www.fsc.texas.gov/sites/default/files/Statement%20re%20Texas%20HM%20Review%20Final%20Draft%5B1%5D.pdf.
[13] *Id.*
[14] *Id.*

suggestive of a human bite mark (the three options the ABFO's guidelines currently provide); and third, whether, if a human bite mark, it had distinct, identifiable arches and individual tooth marks.[15] Thirty-nine Diplomates—accounting for nearly 40% of practicing ABFO Diplomates— finished all 100 questions, resulting in nearly 4,000 decisions. Drs. Pretty and Freeman did not examine the results for ground truth—i.e., whether the diplomates accurately determined what type of injury they were looking at—but rather, on an even more basic level, whether the diplomates agreed with one another. The results were shockingly poor. Determinations were wildly inconsistent across forensic odontologists on the vast majority of marks. As *The Washington Post* reported, on the question of whether the injury provided sufficient information from which to make a determination as to origin—"the most basic question a bite mark specialist should answer before performing an analysis"—

> the 39 analysts came to unanimous agreement on just 4 of the 100 case studies. In only 20 of the 100 was there agreement of 90 percent or more on this question. By the time the analysts finished question two — whether the photographed mark is indeed a human bite — there remained only 16 of 100 cases in which 90 percent or more of the analysts were still in agreement. And there were only 38 cases in which at least 75 percent were still in agreement. . . By the time the analysts finished question three, they were significantly fractionalized on nearly all the cases. Of the initial 100, there remained just 8 case studies in which at least 90 percent of the analysts were still in agreement.[16]

These failures are deeply disturbing. As a group of distinguished scientists reviewing the study's results concluded, "if dental examiners cannot agree on whether or not there is enough information in an injury to determine whether it is a bitemark, and cannot agree on whether or not a wound is a bitemark, then there is nothing more they can be relied upon to say." Ex. N (Scientists' Brief).

Given the lack of a scientific basis for bite mark comparison evidence, the Construct Validity Study's results are hardly surprising. Nor are they anomalous: a study published in the May 2013 Journal of Forensic Sciences largely presaged its findings.[17] As that study noted, "[w]hile most odontologists would suggest they can determine with a reasonable degree of certainty what is and what is not a bitemark, there is little evidence to support this claim."[18] Looking to close this gap, researchers asked fifteen Australian forensic odontologists—who comprised the majority of those practicing forensic odontology in Australia—to examine six images of potential bite marks, five of which

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[15] Ex. O (Radley Balko, *A Bite Mark Matching Advocacy Group Just Conducted A Study That Discredits Bite Mark Evidence*, WASHINGTON POST, April 8, 2015, available at http://www.washingtonpost.com/news/the-watch/wp/2015/04/08/a-bite-mark-matching-advocacy-group-just-conducted-a-study-that-discredits-bite-mark-evidence/).

[16] *Id.*

[17] Ex. P (Mark Page, et al., Expert Interpretation of Bitemark Injuries—A Contemporary Study , 58(3) J. Forensic Sci. 664, 664 (May 2013)).

[18] Id.

were of marks confirmed by living victims to have been caused by teeth.[19] The odontologists were then asked in narrative form whether the injuries were, in fact, bite marks. As with the Construct Validity Study, "conclusions between practitioners [were] highly variable."[20] Thus, "the qualitative data plainly verifie[d] the fact that there is a wide range of opinion expressed over even the most basic assumption in bitemark analysis: that of the origin of the mark itself."[21] The study further concluded that this "[i]nconsistency indicates a fundamental flaw in the methodology of bitemark analysis and should lead to concerns regarding the reliability of any conclusions reached about matching such a bitemark to a dentition."[22]

The inability of bite mark analysts to properly identify human bite marks as such in the first instance are only compounded when they are asked to make conclusions regarding the perpetrator. Study after study has demonstrated a "disturbingly high false-positive error rate" in bite mark comparisons.[23] For example:

- a 1975 study found that bite mark examiners made "incorrect identification[s] of . . . bites" on pig skin 24% of the time even when the bites were made "under ideal laboratory conditions" and 91% of the time when the bites were photographed 24 hours after being made;

- a 1999 American Board of Forensic Odontology Bitemark Workshop in which "ABFO diplomats attempted to match four bite marks to seven dental models" resulted in 63.5% false positives;

- a 2001 study of "bites made in pig skin" resulted in between 11.9 and 22.0% "false positive identifications . . . for various groups of forensic odontologists."[24]

These studies demonstrate that bite mark evidence simply cannot do what its practitioners purport.

Bite Marks Have Led to Many Miscarriages of Justice

Steven Mark Chaney

Simply put, there is no science that confirms biting surfaces of teeth are unique, that these unique features can be accurately recorded in human flesh, or that practitioners can objectively and systematically measure this uniqueness—which is to say there is no

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[19] *Id.* at 665.
[20] *Id.* at 671.
[21] *Id.* at 668.
[22] *Id.* at 670.
[23] Ex. Q (C. Michael Bowers, Problem-Based Analysis of Bitemark Misidentifications: The Role of DNA, 159S Forensic Sci. Int'l S104, S107 (2006)).
[24] *Id.* at S106.

science whatsoever which "confirm[s] the fundamental basis for the science of bite mark comparison." Ex. A at 175 (NAS Report). What science there is, moreover, affirmatively disproves it. *See* Ex. E at ¶ 30 (Bush Affidavit) ("The fundamental tenets of bitemark analysis are not supported by science. Our research, confirmed by the NAS report, suggests, moreover, that they cannot be."). The practice of bite mark comparison is also prone to high rates of serious error. Yet our client, Steven Mark Chaney, and others like him, languish in prisons and jails in Texas and elsewhere, often on the basis of little more than subjective speculation masquerading as science.

On December 14, 1987, Mr. Chaney was convicted of the murder of John Sweek and sentenced to life in prison. The primary driver of his conviction was the testimony of two forensic odontologists that Mr. Chaney's teeth matched an alleged bite mark on the body of one of the victims and that there was only a one-in-a-million chance that Mr. Chaney wasn't the source of the mark. The prosecution told the jury that it was on this evidence alone that they should convict:

> Most of all, we have the bite mark. I wouldn't ask you to convict just based on the testimony of the tennis shoe, of the statements [Chaney] made to Investigator Westphalen, or the statements [Chaney] made to . . . [the informant]. But, by golly, I'm going to ask you to convict on that dental testimony. . . . And [Dr. Hales] said to you that only one in a million people could have possibly made that bite mark. What more do you need?[25]

The prosecutor's exhortations had their intended effect; as one juror testified in a post-verdict colloquy, "Do you want me to tell what made my decision? […] The bitemark."[26]

Without the link provided by forensic odontology, the case against Mr. Chaney could not have been sustained. He was arrested in June of 1987, after the bodies of a drug dealer and his wife were found murdered in the apartment they shared in East Dallas.[27] John Sweek and his wife Sally had had their throats slit, and both suffered many additional stab wounds.[28] The Sweeks had been dealing cocaine from their apartment for at least two years prior to their deaths, and their family members immediately informed the police that the couple's drug suppliers had threatened to kill John in the past for non-payment.[29] The family believed these suppliers included a man named Juan Gonzalez, who they understood to be a member of the "Mexican Mafia" active in Dallas's drug trade. Gonzalez had apparently been looking for John just before the murders, and the family accordingly suspected his involvement.[30]

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[25] Tr. II 801-02.
[26] Tr. II Vol. 9, p. 6.
[27] *Chaney v. State,* 775 S.W.2d 722, 723 (Tex. Ct. App. 1989).
[28] *Id.*
[29] *E.g.,* First Trial Tr. ("Tr. I") 158-61, 167; Detective Westphalen Investigative Notes, Dallas Police Department File ("W. Notes") 150.
[30] *E.g.,* W. Notes 185.

While this information originally led police to suspect Gonzalez, Mr. Chaney, a regular client and friend of the Sweeks, was ultimately arrested after a friend and fellow customer of the Sweeks informed police that he believed that Mr. Chaney had a motive for the murders because he owed the Sweeks approximately $500 for drugs.[31] Though Mr. Chaney had nine alibi witnesses who broadly confirmed his whereabouts the day of the murders (and no criminal history apart from two misdemeanor marijuana convictions), the state proceeded to trial against him.[32]

As the prosecutor told the jury in closing, by far the most compelling evidence of Mr. Chaney's guilt was the testimony of two forensic odontologists, Drs. Jim Hales and Homer Campbell, both of whom also played key roles in the wrongful Texas convictions of Calvin Washington and Joe Sidney Williams. Drs. Hales and Campbell each testified that the alleged bite mark on John's forearm matched Chaney's dentition. *See* Ex. R (Hales Testimony) at 359, 368, 373, 375, 384, 389; Ex. S at 480, 482 (Campbell Testimony). Dr. Campbell testified that Chaney made the alleged bite mark to a reasonable dental certainty. *See* Ex. S at 462, 482–83 (Campbell Testimony). Dr. Hales also testified that there was a "[o]ne to a million" chance that someone other than Mr. Chaney could have left the bite mark. *See* Ex. R at 433 (Hales Testimony).

Today, we know that the bite mark evidence offered against Mr. Chaney was not worthy of belief and should never have been proffered to a jury. Indeed the testimony proffered by Drs. Hales and Campbell is exactly the type that the NAS has recognized as unreliable and baseless and that substantial scientific evidence has disproved. As an initial matter, the testimony purporting to "match" Mr. Chaney to the marks, or otherwise to identify him as the biter, is unsupportable as a matter of science. *See* Ex. A at 175 (NAS Report) ("[T]he scientific basis is *insufficient to conclude that bite mark comparisons can result in a conclusive match.*" (emphasis added)); Ex. N at 25 (Scientists' Brief) (noting that "the uniqueness assumption [regarding the dentition] has increasingly come to be recognized as unproved and unsound . . . ."); Ex. E at ¶ 29 (Bush Affidavit) (conclusions "that bitemark comparison evidence permitted an odontologist to determine that a particular dentition created a particular mark left in human skin (i.e., individualization) . . . are not supported by science. Indeed, we know from our research that the distorting effects of skin can result in random matches of non-biting dentitions to bitemarks").

Dr. Hales's assertion that there was a "[o]ne to a million" chance that someone other than Mr. Chaney made the mark further exemplifies the foundationless conclusions characteristic of bite mark testimony. *See* Ex. A at 174 (NAS Report) ("[T]here is no established science indicating what percentage of the population or subgroup of the population could also have produced the bite."); Ex. N at 22 (Scientists' Brief) ("Unfortunately, forensic dentists have very little information of the kind needed to make an informed assessment [as to the likelihood of a random match]. . . . Actual probabilities are not known because no population studies have been carried out to determine what

[31] *E.g.,* Second Trial Transcript ("Tr. II") 200-207; Tr. I 146-47; *Chaney* at 775 S.W.2d at 724.
[32] *E.g.,* Tr. II 530-41, 636-644, 644-58, 659-670, 711-723, 670-711, 740-46; 724-727; 727-730; *Chaney* at 775 S.W.2d at 724-25.

features to consider, much less the actual degree of variation in teeth shapes, sizes, positions, etc., that exist in the population." (internal quotation marks omitted)); Ex. E at ¶ 29 (Bush Affidavit) ("Dr. Hales's assertion that there was 'one to a million' chance that anyone other than Mr. Chaney created the mark has now been entirely discredited by our work and by the work of the NAS; there is simply no scientific support to offer that, or any other figure, regarding the likelihood of a random match."). This proffer of statistical evidence without sufficient foundation, is, moreover, exactly the same as the flawed hair microscopy testimony on which this Commission recently took action.

Mr. Chaney is currently in the process of challenging his conviction pursuant to Texas's new discredited science statute, Article 11.073. Whether or not Mr. Chaney ultimately obtains relief from the courts, it is clear that the continued incarceration of a person like Mr. Chaney on what we now know to be utterly unreliable testimony, without basis in science, is an injustice that this Commission can and should ensure that Texas avoids repeating.

Bite Mark Evidence Has Led to Many Wrongful Convictions

Bite mark evidence has also been directly responsible for the wrongful conviction or indictment of at least two dozen people. (A complete list of these known wrongful convictions is attached as Ex. D). Ray Krone's case is the paradigmatic example such a wrongful conviction. Mr. Krone was wrongfully convicted and sentenced to death after a bartender at a bar he frequented was kidnapped and murdered.[33] Police had a Styrofoam impression made of Mr. Krone's apparently distinctive teeth for comparison to injuries found on the victim's body; he thereafter became known in the media as the "Snaggle Tooth Killer" due to his crooked teeth.[34] Mr. Krone was convicted in two trials, both times largely on the testimony of Dr. Raymond Rawson, a board-certified ABFO Diplomate, that a bite mark found on the victim matched Mr. Krone's teeth. Mr. Krone served ten years in prison, some of this time on death row before being exonerated by DNA testing. This testing excluded Mr. Krone but inculpated another man, who had lived near the victim and who was then serving a sentence for an unrelated sexual assault.[35] A picture of the bite mark found on the victim along with Mr. Krone's dentition (appearing on page 46 of Ex. N (Scientists' Brief)) is a powerful demonstration of how well-matched an innocent person's dentition may appear to be to a mark in fact made by another person.

Robert Lee Stinson, too, served more than two decades in prison for the rape and murder of an elderly woman he did not commit. Mr. Stinson became a suspect after police officers, who had been informed by a forensic odontologist that the perpetrator

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[33] Innocence Project, *Know the Cases: Ray Krone*, http://www.innocenceproject.org/Content/Ray_Krone.php.
[34] Ex. D (List of Bite Mark Exonerations).
[35] Innocence Project, *Know the Cases: Ray Krone*, http://www.innocenceproject.org/Content/Ray_Krone.php.

was missing a tooth, told him a joke, causing him to laugh and expose his teeth.[36] Mr. Stinson's ultimate conviction rested largely on the testimony of a forensic dentist that bite marks found on the victim "had to have been made by teeth identical" to Mr. Stinson's. The dentist testified that there was "no margin for error" in his conclusion.[37] DNA later demonstrated that, despite the odontologists' certainty, Mr. Stinson was innocent.[38] Mr. Krone and Mr. Stinson's stories represent only a few of the injustices borne from the use of this so-called science.[39]

In addition to the decades stolen from innocent people, bite mark evidence has also been responsible for at least one needless death, after a real perpetrator was left free to rape and kill.[40] Levon Brooks was wrongfully convicted of the rape and murder of a three-year old girl after bite mark comparison not only wrongly included him, but also excluded the actual perpetrator, Justin Albert Johnson. After Johnson evaded punishment for this terrible crime, he raped and murdered another three-year old child.[41] After this second child was killed, bite mark evidence was used *again* to inculpate another innocent man, Kennedy Brewer. Mr. Brewer was convicted of capital murder and sexual battery and sentenced to death, based in part on testimony that the supposed bite marks found on the victim were "indeed and without a doubt" made by him.[42] DNA evidence ultimately proved Mr. Brewer's innocence and Johnson's guilt.[43]

is this true?
Did West compare evidence from and exclude Johnson?

[36] Innocence Project, *Know the Cases: Robert Lee Stinson*, http://www.innocenceproject.org/Content/Robert_Lee_Stinson.php (another dentist also testified that the bite mark evidence was "high quality" and "overwhelming").
[37] *Id.*
[38] *Id.*
[39] In addition to Ex. D, the Innocence Project's list of known bite mark wrongful convictions and indictments, more about other wrongful convictions can be found in Ex. T, the Washington Post's exhaustive four-part series on bite mark evidence. *See, e.g.*, Radley Balko, *How The Flawed 'Science' Of Bite Mark Analysis Has Sent Innocent People To Prison*, Washington Post, Feb. 13, 2015, *available at* http://www.washingtonpost.com/news/the-watch/wp/2015/02/13/how-the-flawed-science-of-bite-mark-analysis-has-sent-innocent-people-to-jail/. ("[T]he scientific community has declared that bite mark matching isn't reliable and has no scientific foundation for its underlying premises, and that until and unless further testing indicates otherwise, it shouldn't be used in the courtroom.").
[40] Innocence Project, *Know the Cases: Levon Brooks*, http://www.innocenceproject.org/Content/Levon_Brooks.php ("[I]t could be no one but Levon Brooks that bit this girl's arm."); Shaila Dewan, *New Suspect Is Arrested in 2 Mississippi Killings*, N.Y. TIMES, Feb. 8, 2008, http://www.nytimes.com/2008/02/08/us/08dna.html?_r=0 ("Mr. Johnson had been excluded in both cases by bite-mark comparisons.").
[41] *See* Innocence Project, *Know the Cases: Kennedy Brewer*, http://www.innocenceproject.org/Content/Kennedy_Brewer.php.
[42] *Id.*
[43] *Id.* In a similar story, Dane Collins was wrongfully charged with the rape and murder of his stepdaughter based largely on bite mark evidence. Though the state ultimately did not proceed against Mr. Collins, "the DA gave several public interviews stating that while there was not enough evidence to try the case, he believed Collins was guilty of the crime." Ex. D (List of Bite Mark Exonerations). Fifteen years later, DNA from a databank was found to match DNA left at the crime scene; the real perpetrator was already serving a sentence of life imprisonment for the kidnapping and rape of another woman. *See* Jeremy Pawloski, *Plea in '89 Slaying Eases Parents' Pain*, Albuquerque Journal, August 14, 2005, available at http://abqjournal.com/news/state/380765nm08-14-05.htm.

Wrongful Convictions in Texas: Calvin Washington and Joe Sidney Williams

Texas has not escaped the scourge of wrongful bite mark convictions. Calvin Washington and his codefendant, Joe Sidney Williams, were exonerated after spending years in prison for a murder they did not commit. On March 1, 1986, the body of Juanita White[44] was discovered beaten, raped, and murdered in her home. A bite mark was found on her body.[45] The prosecution produced evidence that Mr. White and Mr. Williams were in possession of Ms. White's car the day after the murder and had sold some of her belongings the night she was killed.[46] Originally, forensic odontologist Jim Hales told police that Mr. Washington made the mark, but by the time of trial, another forensic odontologist, Homer Campbell, had concluded that Mr. Williams was the source of the mark.[47] Campbell testified at both trials that Mr. Washington's teeth were consistent with the mark found on Ms. White's body, thus linking both men to the crime.[48]

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[44] Ms. White was also the mother of David Wayne Spence, another person possibly wrongfully convicted and executed in Texas on the basis of bite mark evidence. *See* Michael Hall, *The Murders at the Lake*, Texas Monthly, April 2014, http://www.texasmonthly.com/story/investigating-the-lake-waco-murders?fullpage=1 (Hall, *Murders*). Mr. Spence, along with three co-defendants, was convicted in 1985 of the murders of three teenagers in Waco, Texas. *Id.* The prosecution's theory was that Muneer Deeb, the 23 year-old operator of a convenience store, had hired Mr. Spence and brothers Tony and Gilbert Melendez to kill an employee on whom, like all his employees, he had taken out a life insurance policy. The state theorized that Mr. Spence killed another woman by mistake, along with two other teenagers who had witnessed the crime. *See* National Registry of Exonerations, *Muneer Deeb,* https://www.law.umich.edu/special/exoneration/Pages/casedetail.aspx?caseid=3168 (Deeb Registry). The state's major evidence of guilt was the testimony of Dr. Homer Campbell that "Spence was 'the only individual' to a 'reasonable medical and dental certainty' who could have bitten the women." Hall, *Murders supra.*

Mr. Deeb and Mr. Spence were both convicted at trial in 1985, with Mr. Spence sentenced to death; the Melendez brothers pleaded guilty. In 1992, Texas Criminal Court of Appeals overturned Mr. Deeb's conviction on the basis of improperly admitted informant testimony; he was then acquitted on retrial. *See* Deeb Registry *supra.* Despite substantial doubts about his guilt, Mr. Spence was executed in 1997. *See* Bob Herbert, *The Wrong Man*, N.Y. TIMES, July 25, 1997, available at ("Mr. Spence was almost certainly innocent. This is not a hypothesis conveniently floated by death-penalty opponents. Those who believe that David Spence did not commit the crime for which he died include the lieutenant, now retired, who supervised the police investigation of the murders; the detective who actually conducted the investigation, and a conservative Texas businessman who, almost against his will, looked into the case and became convinced that Mr. Spence was being railroaded."). Both Gilbert Melendez and Mr. Deeb have since passed away from natural causes. Tony Meldenez, who remains incarcerated, has recently sought and obtained DNA testing on, among other items, shoelaces used to tie up the victims; results of these tests have yet to be made public. *See* Cindy V. Culp, *Evidence From Lake Waco Murders Case To Be Sent To Arkansas Lab,* WacoTrib.com, April 4, 2013, available at http://www.wacotrib.com/news/courts_and_trials/evidence-from-lake-waco-murders-case-to-be-sent-to/article_fd971525-8adf-5375-b683-d0ab1b7717bf.html.

[45] Innocence Project, *Know the Cases: Calvin Washington*, http://www.innocenceproject.org/cases-false-imprisonment/calvin-washington.

[46] *Id.*

[47] Hall, *Murders, supra note* 44.

[48] *Id.*

In 1992, the Texas Court of Criminal appeals set aside Mr. Williams's conviction, determining that alleged statements by Mr. Washington were improperly admitted at Mr. Williams's trial. The charges against Mr. Williams were ultimately dismissed, and he was released in 1993.[49] Mr. Washington, who remained imprisoned, continued to seek DNA testing. In 2001, he obtained tests which proved that blood on a shirt found at his home was not the victim's, as the prosecution had claimed at trial. Later DNA tests excluded both Mr. Washington and Mr. Williams from semen found inside the victim; DNA in the semen was matched to an original suspect in the crime, who committed a similar crime shortly after Ms. White was killed.[50]

The Need for This Commission's Intervention

Bite mark evidence is unscientific and unreliable, and thus grossly unfit for use in criminal proceedings. *See* Ex. E at ¶ 30 (Bush Affidavit) ("Unless and until these premises [regarding the uniqueness of the dentition and the ability of human skin to record that uniqueness] can be scientifically demonstrated, bitemark comparison evidence should not be admitted in criminal proceedings."); Ex. N at 45 (Scientists' Brief) ("[T]he foundations of bitemark identification are unsound."). It thus presents a perfect opportunity for this Commission to exercise its statutory mandate to evaluate and report on the discipline's "integrity and reliability." Tex. Crim. Proc. Code Ann. § art. 38.01(4)(b-1)(1). A thorough review of the state of bite mark science and an audit of the cases premised upon it would ameliorate some of the damage this technique has already done to the Texas criminal justice system; a moratorium on its use would prevent it from doing any further harm. *See* Tex. Crim. Proc. Code Ann. § art. 38.01(4)(b-1)(3) ("the investigation may include the preparation of a written report that contains: . . . other recommendations that are relevant, as determined by the commission"); Tex. Crim. Proc. Code Ann. § art. 38.01(4)(a)(3).

Not only is such a report and audit well within this Commission's statutory authority, but action by an independent body like this one may well be necessary to ensure that bite marks are no longer used to convict innocent people in Texas. A series of articles published earlier this year by *The Washington Post* (appended as Ex. T) revealed the ABFO's longstanding pattern and practice of suppressing dissent and punishing scrutiny. The articles reveal that most recently, the ABFO sought to silence one of its most prominent critics, Dr. C. Michael Bowers, by filing a retaliatory ethics complaint against him in front of the American Academy of Forensic Sciences ("AAFS"). *See* Ex. T at 27-38. In addition to this "transparent attempt to purge someone who has been a problem for [the ABFO]," *id.* at 29 (internal quotation marks omitted), *The Washington Post* stories also reflect efforts by the ABFO to silence Dr. Mary and Peter Bush, who have conducted the most substantial (and indeed, largely the only) scientific research into the fundamental assumptions underlying bite mark analysis. *Id.* at 27-38. *The Washington Post* reveals that the Bushes' basic research was welcomed and supported by the ABFO until they "began to come back with results that called the entire discipline

[49] National Registry of Exonerations, *Joe Sidney Williams*, available at https://www.law.umich.edu/special/exoneration/Pages/casedetail.aspx?caseid=3748.
[50] *Id.*

into question. . . ." *Id.* at 38-46. Once the Bushes' results made plain that there is no scientific basis for bite mark comparisons, the forensic dentistry community undertook "a nasty campaign to undermine [their] credibility." *Id.* at 40. These campaigns by bite mark adherents to silence their critics and suppress science showing the invalidity of their claims are all the more reason for this Commission, as an independent body not subject to capture or intimidation, to intervene.

What?

On behalf of Mr. Chaney and others like him, we ask that this Commission take action and reverse the damage bite mark comparison and its disciples have done to the integrity of criminal justice in Texas. By conducting an investigation and audit, and in calling for a moratorium, this Commission can not only take a stand for reliability and integrity in forensic science in Texas, but also ensure that wrongful convictions like those of Calvin Washington and Joe Sidney Williams remain things of the past.

Very Truly Yours,

DP

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December 21, 2015

An open letter to
Drs. Gary Berman, Mark Bernstein, Adam Freeman, Iain Pretty, and Frank Wright

Gentlemen,

Toward the end our discussion on November 29 I agreed to draft a letter to be reviewed and edited by this group. The plan was to send the edited letter to ABFO Diplomates to encourage them to participate in a follow up study to the earlier Freeman-Pretty Survey I. (FPS1)

The new study, Bitemark Assessment Survey II (BAS2) is under development and the plans discussed include a different survey design but similar methodology for collecting data when compared to FPS1.

The concept discussed included developing a very restrictive bitemark definition, then surveying ABFO Diplomates to assess their levels of agreement whether patterns viewed were bitemarks. The planned restrictive definition is different than the definition currently in the ABFO Diplomates Reference Manual and different from those used in the so-called beta studies done following AAFS-Orlando 2015.

ABFO Diplomates would again be invited to view online images of 100 cases. They would have the same options to download the images to view and analyze them using their own preferred software. Of the 100 cases 50 would be new cases and 50 would be cases that were included in FPS1. Each case may include multiple images.

The strategy for this follow up survey seems to be to create a very restrictive definition of a bitemark. Using this restrictive definition, participating odontologists are to opine whether each target pattern or patterned injury seen in the 100 cases represents a bitemark that meets those restrictions.

The investigators would then analyze the data to determine the level of agreement among the participants.

The study hypothesis appears to be;
Forensic odontologists with similar training, experience, and credentials who critically view images of cases from their peers' casework, will have high levels of agreement on which patterns or patterned injuries in the cohort are bitemarks and which are not when using specified criteria. The null hypothesis is, of course, that they will not have high levels of agreement.

While I am still committed to the concept of a follow up survey, during my attempts to create a draft of a letter based on the bullet point suggestions received from the ad hoc group, some questions and concerns have arisen.

This letter details my attempt to explain my thoughts about each of those questions and concerns.

1. **Artificiality 1**

    If we use the proposed very restrictive definition of bitemark and get "high' levels of agreement…

    Won't the critics of bitemark evidence merely point out the obvious:

    - "Of course they agree, the criteria are so restrictive that disagreement would require blindness, ignorance, or incompetence."
    - "They designed a study that could not fail so that they would appear to know what they are doing."

2. **Artificiality 2**

    If we use the proposed restrictive definition and the results of the study generate less than "high" levels of agreement those same critics will view us as:

    - Blind
    - Ignorant
    - Incompetent

3. **False Negatives**

    - The current survey design requires that those cases that include images of patterns that actually are bitemarks but do not meet the proposed restrictive criteria should (must?) be determined to be NOT bitemarks
    - These false negatives would negate the value of those cases for which the mere presence of a bitemark has significance.
    - This will likely generate confusion among some potential participants and possibly again distort the results
    - Perhaps there is an alternative (see 8)

4. **Problems still existing considering concerns about FPS1**

    In a February 27, 2014 email to the Bitemark Committee, with the subject line <u>RE:ABFO Bitemark Analysis and Comparison Decision Tree,</u> BM Chair Dr. Freeman first reached out to the BM Committee noting in this first email on the subject (to my knowledge) the plans for assessing validity, including the statement in italics below:

    > *It is therefore proposed that a total of 100 patterned injuries are assessed by a minimum of 60 experienced examiners (we may wish to restrict this to ABFO DIPS in the first instance).*

    It is not clear when it was decided (or by whom) that 38 was an acceptable number of responses and close enough to the stated minimum of 60. I do not recall discussions by the Bitemark Committee on whether or not the number of participants was adequate.

On April 1, 2014 Dr. Freeman sent all ABFO Diplomates an email with the subject ABFO Patterned Injury Validation Study. In this email Dr. Freeman made the 3 statements in italics below: (portions in red highlighted by me)

> *As you may be aware we are undertaking a validation study of the new ABFO Patterned Injury Decision Tree, which is attached to this email. We are working with Professor Iain Pretty to ensure that the research is considered independent and vigorous, however the Bitemark Committee will review and approve the protocol.*

I am not certain that the Bitemark Committee was fully informed and fully engaged in approving the evolving protocol for FPS1. (It is possible that I may not be correct about this issue since, although I am on the bitemark committee, I could have missed some emails during that period.) Instead it seems to me that only a few people (including me) actually developed the protocol.

> *None of the images will be used for any other purpose, and all submissions will be anonymous. We will not maintain a record of who sent in what image nor will we retain records of how each individual answered the questions in the study.*

While I do not know if a record of who sent what image was maintained, I do know that he records of how each individual answered the questions in the study were, in fact, retained, at least for a period of time.

After the study was completed and during the 2015 AAFS meeting at which the results were presented, Dr. Pretty was able to call, text, or email Manchester from Orlando and in a short period of time procure and compare the survey answers for Drs. Freeman, Senn, and Wright to illustrate, to the dismay of some, the lack of agreement between them.

This indicates that not only Dr. Pretty, but also someone else in Manchester had (and may still have) access to the answers for individuals for whom anonymity was promised.

This raises a question of ethical research practices and indicates the remote possibility that an attorney, perhaps an Innocence Project attorney, could subpoena the specific results for any of the 38 FPS1 participants.

> *Please be assured that these images will only be used for the study, only shown and be available to the research participants and will not be used in any other way. If you wish to include any contextual details on the injury – please send these in the body of the email. Once the study has been completed the images will be destroyed.*

It is obvious that the images were not destroyed. The proposal for BAS2 is to use up to 50 of those same images. As recently as Monday, December 21, 2015 I was able to go to the website http://www.fds-consult.co.uk/abfo/ and view the images of 100 cases at least some of which were from the (completed?) FPS1 study.

Although the determination of when FPS1 is considered completed is subject to discussion, for some, this raises a further question of ethical research practices.

This issue and that of the number of participants are less worrisome than the issue of retaining records of how each participant answered the survey questions, but broken agreements erode confidence.

5. **Confidence in the Researchers**

Although I have not talked to all ABFO Diplomates about this issue, a number of ABFO Diplomates to whom I have spoken do not have confidence that Dr. Pretty and Dr. Freeman acted a] in their best interest, b] in the best interest of the discipline of bitemark analysis, c] in the best interest of science, or d] in the best interest of justice in carrying out FPS1.

Some stated that they suspect that Dr. Pretty may have a hidden agenda and that Dr. Freeman may agree or may have been influenced by that agenda. Some are suspicious of their motives for a second survey and doubtful of their ability to properly and impartially carry out a second survey.

Others stated that FPS1 was "confusing" and "not a good study" appearing to be hastily and improperly designed, managed, and conducted.

There are additional issues relating to ownership of the data from FPS1 and the manner used by Drs. Pretty and Freeman to justify releasing the data to persons or entities outside the ABFO. The allegations include that Drs. Pretty and Freeman used the explanation that releasing the data to ABFO Diplomates, who as such were co-owners of the data, meant that they could not refuse to release the data to other individuals who just happen to be bitemark opponents. (Chris Fabricant? Radley Balko?). While I have heard accounts from several different persons and positions, I have been unable to determine a definitive answer regarding this issue.

6. **Non-participation**

The above concerns and others may cause a significant number of ABFO Diplomates to be hesitant to participate in the BAS2 survey. What would the effect be, if, despite our best efforts to convince ABFO Diplomates that it would be in their best interest to participate, they decline?

Participation by only a small number of Diplomates would mean the survey would not reliably indicate an answer to the research question.

Nevertheless, both Dr. Pretty and Dr. Freeman have made it clear in conversations how they will proceed if there are low levels of ABFO Diplomate participation.

In discussions in the Worthington Hotel bar in Ft. Worth following the TFSC Bitemark hearing (Freeman, Pretty, Senn, Wright), Dr. Freeman and Dr. Pretty explained how they would deal with large-scale non-participation.

They stated that if only a small number of ABFO Diplomates participate, they would still present and publish the results. They indicated that they believed low participation could have very negative implications for Diplomates, for the ABFO, and for the discipline of bitemark analysis, especially since the TFSC showed interest in the second study during the hearing.

This approach could be interpreted as a not-so-veiled threat…participate or suffer the consequences. The consequences would impact participants of FPS1, potential participants or non-participants of BAS2, the Diplomates of the ABFO, and the ABFO as an organization.

These threats, real or perceived indicate the need for IRB or Research Ethics Committee oversight.

7. Institutional Review Boards (IRB), Research Ethics Boards (REB), and Research Ethics Committees

More than one ABFO Diplomate asked whether IRB approval had been sought for FPS1. Apparently, there was no communication with a Research Ethics Board, Research Ethics Committee or an Institutional Review Board seeking information or guidance for Freeman-Pretty Survey 1. There is no indication that an application for ethical review was made for FPS1.

During discussions on Sunday, November 29, 2015, among five of us (Berman, Bernstein, Freeman, Pretty, Senn) during a recorded GoToMeeting conference, Dr. Bernstein asked if it would be a good idea to apply for IRB oversight for BAS2. Discussion followed and Dr. Pretty responded that he would look into the issue. He then made several comments explaining why seeking ethical review for FPS1 had *not* been needed. On Monday, November 30 he sent the email copied below to the Secretary of the Research Ethics Committees, at the University of Manchester, Dr. Timothy Stibbs. (red highlights by me)

From: *Iain Pretty*
Sent: *30 November 2015 07:28*
To: *Timothy Stibbs*
Subject: *Ethics Advice*

Dear Tim
I do apologise, we seem to be bothering you a lot at the moment.
I wonder if I could ask your view on the following project?

> *This is an online survey that is being conducted between myself and an American dentist, Dr Adam Freeman. It concerns the assessment of bite marks and a defined group of professionals views on the injuries. The group is called the American Board of Forensic Odontology (ABFO) and comprises of those forensic dentists with the highest levels of training and experience.*
> *The online survey presents a number of images provided by the ABFO and these are then rated anonymously by participants who will be invited to participate voluntarily. The results will be published. The work is in essence the evaluation of a "Service" the ability of trained examiners to indicate a bite mark or not – a service provided to police and other criminal justice actors.*
>
> *I know that online surveys of professionals is a bit of a grey area, but I don't think ethical approval will be needed for the following reasons:*
>
> *The population involved does not include any of those listed on the UoM REC section of the website (http://www.manchester.ac.uk/research/environment/governance/ethics/urec/) I.e as professional dentists within the ABFO*
> *Looking more broadly at the research ethics advice in relation to online surveys its seems that "the essential issue is concerned with u**nderlying intention**: if the intention is evaluation of a service or product and there is no experimentation, e.g. a trial involving two or more research arms each receiving different products or services, then **no review is necessary.** In most cases it is not normal to seek formal written consent, indeed given that most surveys are completed anonymously, written consent will have the paradoxical effect of compromising anonymity. The usual position is that a positive response from a respondent is, in itself, evidence of consent."*
> *As always we are happy to apply for ethical approval if you think indicated, but I did want, as always, to check and get your expert view.*
> *Best wishes*
> *Iain*

The following day, Tuesday December 1, Dr. Pretty forwarded an email from Dr. Stibbs, Secretary of the Research Ethics Committees that included the following statement:

> *I have given some thought to this and agree that this does not need ethical approval from our point of view. You are asking questions within the participants' professional competence and the responses are anonymous anyway.*

Dr. Freeman noted in a follow up email that same day that the matter was settled:

> *Please find below the IRB decision at the University of Manchester. As Iain stated during our meeting, he did not think he would need it and that has now been confirmed.*

I am not as confident as Dr. Freeman that this is sufficient. In contrast to what Dr. Stibbs wrote in his email, the survey responses may not be anonymous. If BAS2 has a protocol similar to FPS1, Dr. Pretty and a member or members of his staff will know the identity of the responders and be able to access their responses.

The following is copied from the University of Manchester's StaffNet website at http://www.staffnet.manchester.ac.uk/services/rbess/governance/ethics

> Research Ethics is a world-wide set of principles governing the way any research involving interaction between the researcher and other humans or human tissue or data relating to humans, is designed, managed and conducted. Those same principles apply to you the researcher, whether you are an untrained undergraduate or an internationally recognised scholar in your field.

Under the same website's "Does Your Research Require Ethical Approval?" tab there appears a paragraph that seems to be the basis for Dr. Pretty's argument and Dr. Stibbs' opinion regarding the need for ethical review for the proposed BAS2 study.

> **Research Involving Interviews with Participants on Subjects Deemed to be Within Their Professional Competence:** Although this is a grey area, if the researcher is not asking the participant to reveal personal, confidential or sensitive information and the subject matter is well within the professional competence of the interviewee, formal ethical review is usually not needed.

Depending on the definition of "interviews" the paragraph above seems to support Dr. Pretty's position and Dr. Stibbs cursory evaluation that ethical approval is not needed. Whether a study or survey of this type that requires participants to view and evaluate evidence and record their responses by means of a website is considered an interview can be argued.

However, in consideration of the nature of the security of the information in FPS1, the responses may NOT be anonymous.

Consequently, as it is not clear that a study requiring participants to view one hundred cases accessed on a website, download and assess multiple images for most cases, and develop opinions based on published criteria can be considered to be an "interview". Furthermore one or more researchers for this study will have access to personal, confidential, and sensitive information just as they did in FPS1.

For the reasons discussed above, I think making formal application for ethical approval for BAS2 is imperative and important to protect ABFO Diplomates as well as to protect Dr. Pretty and Dr. Freeman.

To further clarify this issue I have communicated with eight forensic odontologists associated with universities in the USA and Canada about this specific issue. These ABFO certified odontologists are knowledgeable about research ethics and IRB or REB procedures. There is general agreement among these odontologists that formal application for ethical oversight by an IRB or REB is needed for BAS2 to protect the participants and the investigators. The IRB or REB may decide that the study is exempt or qualifies for expedited review, but the formal application should be made.

While Dr. Pretty, following Dr. Bernstein's suggestion, requested information on the necessity for what we in the USA would refer to as IRB approval for BAS2, neither he nor Dr. Freeman sought the same kind of information (as far as I know) for FPS1.

This omission raises these additional questions:

- Do the principles of Research Ethics require that researchers at least seek information indicating that their research is exempt from ethical oversight?
- Do editors and reviewers for peer-reviewed publications inquire about IRB approval for papers submitted for publication?
- Does this lack of application, approval or exemption have an effect on the suitability of the FPS1 research for peer-reviewed publication?
- Does the fact that the anonymity of the participants in FPS1 is at least in doubt mean that the anonymity of participants in BAS2 could also be in doubt?

Before I discuss my opinions on where I think we can or should go from here I would like to make a few observations that are very personal:

> I have had spirited, sometimes very spirited, discussions about issues involving FPS1 with both Dr. Freeman and Dr. Pretty.
>
> They have decided to make BAS2 their personal project not connected to the ABFO but using ABFO Diplomates.
>
> After all our discussions and after reading this open letter they may very well decide to dismiss me from participation in THEIR study.
>
> Dr. Pretty told the TFSC panel that I was the reason the follow-up study had not been done.
>
> Dr. Freeman has written in recent emails that I am a big part of the problem and implies that I am more or less just an old has-been who only wants to obstruct implementation of his superior vision for the ABFO and bitemark evidence.
>
> Dr. Freemans's November 20, 2015 verbatim recommendations:
>
> - *I would suggest that we move forward without David.*
> - *It is his generation of the ABFO who has stymied the process*
> - *Last study he wanted a beta test. Then another larger one.*
> - *His thinking is why we are here.*
> - *David is not in the leadership of the ABFO*
> - *After the study is done he can mark it with red green and blue underlines in what he agrees which are lies and so forth.*

- *Iain I would suggest that you mock up study and then we will as a courtesy show it to Mark and Gary. (red highlights mine)*

While some of these comments, and others he has made are insulting and are personally painful to read and hear from a valued colleague and long-time friend, what is of greater concern to me is Dr. Freeman's concept of leadership for the ABFO and his judgment in designing, managing, conducting, and reporting research that has important implications for forensic odontology.

- Does he plan to be a leader for only certain "generations" of the ABFO membership?
- Were the beta tests he decries and disparages useful or not useful for developing and evaluating a methodology for moving forward?
- Should a study similar to the proposed BAS2 or other "beta-type" tests have been done first, prior to rushing to complete and report FPS1?
- How will he convince a significant number of ABFO Diplomates to participate in BAS2 considering his management of FPS1?
- Does it matter to him if participation is robust or meager?
- I assume that his red-green-blue underlining dig means he did not agree with my assessment of the contents of the Innocence Project's complaint to the TFSC that was, by the way, specifically requested by Dr. Kessler, the chair of the TFSC bitemark panel.
- Will his plan to "as a courtesy" share the intended design of the BAS2 study with the ABFO's current President and current Chair of the Bitemark Committee be sufficiently courteous to convince them to urge ABFO Diplomates to participate in BAS2?

OK, enough of my personal angst. If you have read this far you may actually want to know if and how I think we can proceed from here in a positive manner.

8. **Where can we go from here?**

These are my ideas and mine alone

a. A follow up study to FPS1 is important and needed.
   The study should <u>not</u> be a product of just two men, (or of four, five or six men selected by two men) but with sponsorship and oversight by the ABFO and sufficient participation.
   As Dr. Freeman stated during the November 16, 2015 TFSC hearing:
   DR. FREEMAN: -- if you're asking the ABFO to participate in a study, right, you still need their --you need their buy in. You need them to

participate. If we did it again, and there was such political disarray that people didn't agree – and instead of getting 38, we got 5, that isn't a real study.

The study should be carried out by a properly appointed group of ABFO Diplomates and possibly others. The group would implement a mechanism for appropriate oversight working with the investigator(s). The investigators would be responsible to an IRB as well as to the ABFO's EC, BOD, and ultimately to the entire membership. There are capable and talented Diplomates who can contribute.

b. The artificiality of the current design for BAS2 should be addressed.

Decreeing that ***only*** patterns that meet the new very restrictive criteria are bitemarks is wrong. ABFO Diplomates would not, in my opinion, accept this definition and accompanying criteria as a guideline. Nor would positive results coming from a study based on such criteria be convincing to forensic science commissions or gatekeepers, or bitemark opponents for the reasons stated above.

Instead, perhaps we could accept and embrace what we have learned from FPS1. Accept that without appropriate, specific, approved, and clearly understandable criteria there will be high levels of disagreement among odontologists about whether patterns are bitemarks. This is the system under which we have been operating since 1976, and FPS1, despite its flawed history, reflects that.

There could and should be restrictive criteria for developing the opinion that a pattern is a bitemark. Those criteria, IMHO, should not be as restrictive as BAS2 currently proposes.

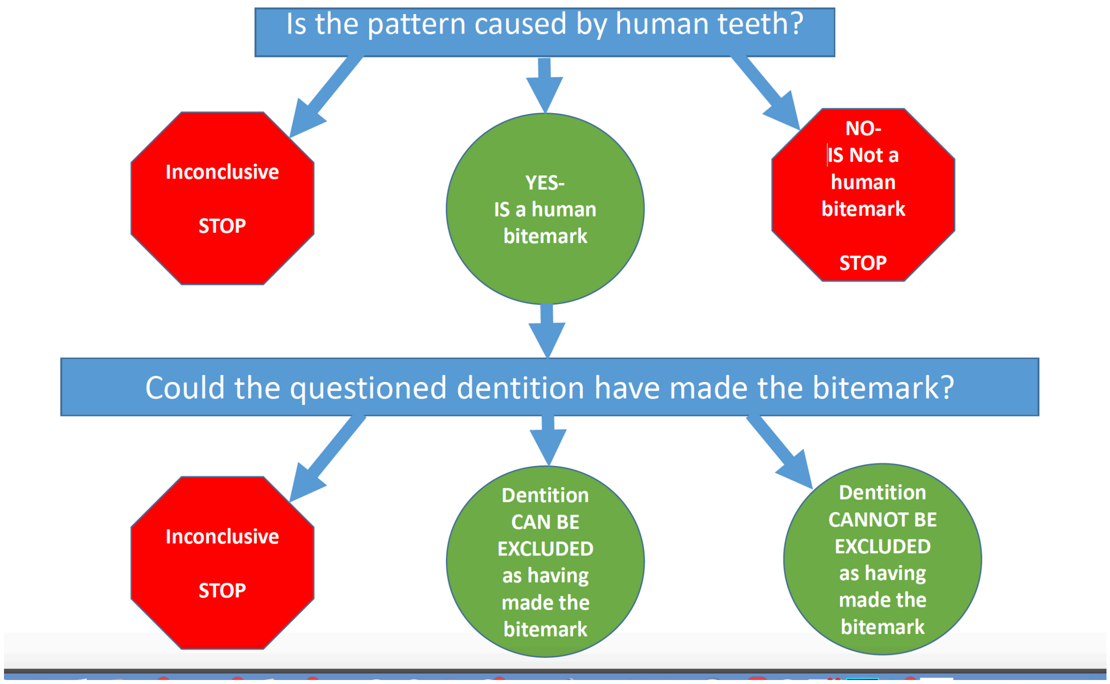
The not yet defined new criteria for bitemark should allow the inclusion of some patterns that would not meet the more restrictive criteria required for those patterns to be suitable for comparison, but certainly still be restrictive enough to eliminate or greatly inhibit the types of unacceptable cases that we have seen in the past, including but not limited to, cases with patterns with only two or three diffuse contusions or cases with unclear marks on areas difficult to reliably assess such as fingers, toes, ears, or penises.

This system could still allow for providing investigators and protective services with information that may be important but have nothing to do with identification of a perpetrator. This change should at least partly address the false negative issue.

The most important and urgent goal should be to develop more comprehensive guidelines and standards that as completely as possible ensure that no person is put at risk of being convicted of a crime based, even partly, on dental evidence that does not meet very restrictive criteria.

The very restrictive criteria idea proposed is sound but, again IMHO should be applied to deciding whether a pattern or patterned injury contains sufficient evidence to allow for comparisons to suspected biters.

BAS2 could be revised to fit that model using or modifying the already proposed changes to the guidelines being considered by the NIST/OSAC Odontology Bitemark Task Group as well as the ABFO Bitemark Committee. Dr. Metcalf (the [then] Chair of the Bitemark Committee) sent proposed changes to the guidelines and decision tree algorithm to the EC and BOD in October.



The bitemark guidelines and standards could be applied to the blue bar questions of the proposed algorithm, the appropriately restrictive criteria to the top blue bar question and the very much more restrictive criteria to the lower blue bar question.

A revised BAS2, once approved, could be conducted fairly quickly using the mechanisms already developed by Dr. Pretty but with appropriate ABFO participation, following approved protocol, and with IRB oversight.

If successfully completed, the revised BAS2 study could report whatever levels of agreement are attained.

Embracing and building on the results of FPS1, that study should then be repeated using the modified criteria (less restrictive than those for BAS2 but more restrictive than those for FPS1)

There will never be perfect agreement among odontologists.

c. Seeking and procuring IRB approval for BAS2 and all future studies, including appropriate ABFO participation, and strictly following protocols should address most of the holdover problems from FPS1 discussed in item 4 above. Precisely following those protocols and thereby protecting the anonymity of the participants, their responses, and the data along with appropriate ABFO participation should generate higher levels of confidence for ABFO Diplomates in the research and the researchers.

d. Leadership.
Dr. Freeman is an intelligent, organized, caring, and extremely generous man. He has strong views on many subjects and a highly developed philosophy regarding forensic odontology and bitemark evidence.
As a leader he has shown that, when people agree with him, he can be an inclusive and effective leader. The email below he sent to Dr. Metcalf after he reviewed the Metcalf-led bitemark committee's plans for revising the bitemark guidelines and decision tree is indicative of that type of leadership

> *August 29, 2015 email to Dr. Metcalf and BM Committee*
> *Bravo roger. This is almost identical to what Dr frank Wright and I have been discussing for NIST. Bold thinking grounded in science is what we need to move this field forward. I do think we will need to create a definition of what a bitemark is to get diplomates to agree on what a bitemark looks like and that we stick to using those of the highest quality for comparison. You have my full support and will next year while I am president*

Dr. Freeman has more difficulty leading when dealing with people who do not agree with him. As with many intelligent people, he has little patience for what he views as wasting time. His tendency when faced with dissent is to try to convince, convert, or overwhelm dissenters, and failing that, to bypass those who disagree with him so that he can get the job done. This works well for him in certain settings but not so well in others.

His leadership style is similar to Plato's concept of the philosopher-king but because of his impatience and a short-fused temper his style is more like that of a benevolent dictator. Both of these strong leader/dictatorial styles seem more efficient to those who espouse them but they almost always fail.

A more democratic approach with consideration and respect for all, including those who disagree with or challenge leadership, is slower and messier and often more frustrating but better in the long run.

I believe both Dr. Freeman and Dr. Pretty are honorable men who are trying their best to do what is right. While their concepts of what is right may differ from others they have both worked very hard for reform. Dr. Pretty, who is not a member and has no duty or allegiance to the ABFO worked with members of the ABFO to try to delay or soften the blow of the results of FPS1 by presenting the study in Orlando in a manner that many considered most favorable to the ABFO. He did this voluntarily but with an expectation of a timely follow-up study.

Like each of us, Dr. Freeman and Dr. Pretty are not perfect and although neither will easily admit it, they make mistakes. Mistakes were made in the design, management, and reporting of FPS1.

It is my opinion that if Dr. Freeman and Dr. Pretty are willing to accept changes, not necessarily the changes that I offer here, but changes that the ABFO leadership AND Diplomates agree are in the best interests of forensic odontology, they can capably lead and complete the studies needed.

Thoughts on the glacial pace of change in the ABFO

Dr. Pretty stated in his presentation at the TFSC hearing in Ft. Worth that the ABFO's slow-paced processes for proposing, discussing, and implementing change were not serving the ABFO well. He said that the discipline of bitemark analysis could be obliterated by its opponents while the ABFO discusses bylaws, policies and procedures, debates the proper way to propose changes, argues over whether the proposals were submitted before a certain deadline, and thereby causes votes on critical issues to be pushed forward to the next annual meeting which may be more than a year away.

I agree with Dr. Pretty's assessment. The ABFO leadership must revise the by-laws and policies and procedures to expedite the ability to make changes more expeditiously. Changes must allow votes on important issues without having to wait extended periods of time for face-to- face annual meetings. Sensible proposals should be able to be made at any time. These proposals could be properly vetted and after practical waiting periods, lead to online or other types of electronic voting. The ABFO must be able to act year-round, not just on one night each year. This is certainly possible in the 21st century. Change is good.

Of course, Dr. Freeman and Dr. Pretty can ignore my histrionics and choose to go forward with BAS2 as their personal project as planned. They may believe they will be able to convince a significant number of ABFO Diplomates to participate.

If this is their decision, I cannot assist with the effort to convince others in the ABFO to participate.

Summary of recommendations:

- ABFO President to appoint a committee or task group to design and implement a follow-up study to FPS1. Dr. Freeman, if he chooses, should be a part of that group. That group to decide how to proceed including whether to include Dr. Pretty
- The follow-up study to apply the very restrictive criteria in relation to new proposed guidelines that in turn relate to the proposed new algorithm's second blue bar question, "Could the questioned dentition have made the bitemark?"
- Later, another follow-up study could repeat FPS1 to investigate the validity of the guidelines regarding the first blue bar question, "Is the pattern caused by human teeth?" This study would use improved methodology and new criteria that are more restrictive than before but less restrictive than the criteria for suitability for comparison.
- Formal application for IRB approval (or exemption) to be made for all research going forward
- The leadership of the ABFO to take immediate steps to update and modernize the bylaws and policies and procedures to allow for more efficient and responsive operations.

Respectfully submitted,

David R. Senn

David Senn

The National Academies

Committee on Identifying the Needs of the Forensic Science Community

Forensic Odontology
Bite Marks

David R. Senn, DDS, DABFO

National Academy of Science
Lecture Hall
Washington, DC

April 23, 2007

Questions from the Committee

1. What is the state of the art?
2. Where is research conducted?
3. Where is it published?
4. What is the scientific basis that informs the interpretation of the evidence?
5. What are the major problems in the scientific foundation, methods, and practice?
6. What research questions do you think need to be answered?

What is the state of the art?

What is the state of the art?

Definition: Bite mark analysis is the investigation of marks made by teeth on human skin or other objects. The analysis is accomplished by combining the science and art of dentistry and a forensic discipline that encompasses aspects of anatomy, pathology, oral medicine, physiology, histology, chemistry, and physics (especially mechanics) and tooth mark pattern analysis.

What is the state of the art?

- Forensic Odontologists understand the anatomy and function of teeth and the dynamic mechanics of biting.

- A competent, skilled Odontologist can produce biter profiles from bite patterns that exhibit sufficient information to have evidentiary value.

What is the state of the art?

- Competent Forensic Odontolgists will conform to the American Board of Forensic Odontology Bitemark Methodology Guidelines for:
  - Bitemark Evidence Collection
  - Bitemark Evidence Comparison
  - Bitemark Forensic Report Writing
  - Ethics

State of the Art

The State of the Art is Defined by Forensic Odontologists who:

- Are capable of using all known evidence collection and comparison modalities

- Select those modalities appropriate for the case in question
- And..

State of the Art

- Employ blinding techniques to inhibit bias (observer effects)
  - Evidence collection
  - Evidence analysis
  - Dental lineups
- Seek 2nd opinions from independent, blinded, competent forensic odontologists.
- And…

State of the Art

- Engage in continuing study and research to improve themselves and Forensic Odontology
- Recognize and abide by the Code of Ethics and Conduct

State of the Art

- Understand the scientific method
- Use the scientific method in tests and procedures to the greatest extent possible

Where is research conducted?

Where is research conducted?

Odontology Research Consortium Associates

www.orca-forensic.org

ORCA Mission Statement

It is our goal to stimulate mutual research co-operation and to enhance the scientific credibility of the discipline by encouraging and supporting scientific rigor in forensic odontology research.

Where is research conducted?

Forensic Odontology research is conducted by individual Odontologists and by Odontologists at Institutions and Universities Worldwide

Go to www.orca-forensic.org for complete listing of ORCA associates

Where is research conducted?

Institutions and Universities

University of Alabama, School of Dentistry, Birmingham, Alabama, USA

University of British Columbia, Vancouver, BC, Canada

15 Institutions Worldwide

University at Buffalo, The State University of New York, Buffalo, NY, USA

Catholic University at Leuven, School of Dentistry, Leuven, Belgium

15 Institutions Worldwide

Columbia University School of Dental Medicine, New York, NY, USA

Louisiana State University School of Dentistry, New Orleans, LA, USA

15 Institutions Worldwide

University of Manchester, Dental School, Manchester, England, UK

Marquette University, Milwaukee, WI, USA

15 Institutions Worldwide

McGill University, Montreal, Quebec, Canada

University of Melbourne, School of Dental Science, Melbourne, Australia

15 Institutions Worldwide

University of Nevada Las Vegas, School of Dental Medicine, Las Vegas, NV, USA

University of Oslo, Faculty of Dentistry, Oslo, Norway

15 Institutions Worldwide

National Board of Forensic Medicine, Stockholm, Sweden

University of Texas Dental Branch at Houston, USA

15 Institutions Worldwide

University of Texas Health Science Center at San Antonio, Dental School USA

Where is it published?

- The Journal of Forensic Sciences
- Forensic Science International
- American Journal of Forensic Medicine and Pathology

(list attached)

What is the scientific basis that informs the interpretation of the evidence?

What is the scientific basis that informs the interpretation of the evidence?

Although forensic odontologists have significantly improved the scientific basis for <u>collecting and analyzing</u> evidence (digital analysis, improved exemplars, light microscopy, SEM, improved metric analysis, etc)…

What is the scientific basis that informs the interpretation of the evidence?

….there has been no significant improvement in the scientific basis for interpreting the evidence to reach a truly objective conclusion.

What is the scientific basis that informs the interpretation of the evidence?

- Forensic Odontology, like other forensic identification modalities, relies on the education, ability, and experience of the practitioners

- Interpretation of bite mark evidence must be tempered with a recognition of the limitations of the discipline.

What is the scientific basis that informs the interpretation of the evidence?

- Forensic Odontology provides important information that can assist judges and juries to understand situations involving bite marks.

- But…

What are the major problems in the scientific foundation, methods, and practice?

Major problems

- The uniqueness of the human dentition has not been scientifically established.

Major problems

- The ability of the dentition, *if unique*, to transfer a unique pattern to human skin and maintain that uniqueness has not been scientifically established.

Major problems

- A clear statement of the type, quality, and number of class and individual characteristics or other features required to indicate that a bite mark has reached a threshold of evidentiary value has not been established.

Major problems

- Forensic Odontology certifying organizations have not created or administered bite mark analysis proficiency tests for their board certified members.

Major problems

- The ability to analyze and interpret the scope or extent of distortion of bite mark patterns on human skin has not been demonstrated.

Major problems

- The effect of that distortion on comparison modalities is not fully understood and has not been quantified

What research questions do you think need to be answered?

Research Questions

- Is the dentition of each human unique?

- Do teeth transfer their distinctive characteristics to human skin and maintain and express the uniqueness?

Research Questions

- Are the currently recommended analysis and comparison methods sufficient?

Research Questions

- What new analysis methods are most likely to lead to significant improvement in the comparison procedures?

Research Questions

- What are the features of a bite mark that distinguish one with evidentiary value from one without?

- Can those features be listed and quantified?

Research Questions

- Can new and potentially better methods of comparing bite patterns and the teeth that may have created them be developed?

Research Questions

- What are the most promising of these potential new methods?

Big Research Question

- What are the potential sources for funding for this research?

Conclusions

- Bite Mark Analysis is too important and valuable to the investigation and adjudication of certain crimes to be discounted or overlooked.

- The use of bite mark analysis to exclude suspects is powerful and important.

Conclusions

- The scientific basis for associating unknown biters to tooth marks or bite marks must be established.

- Currently, the association of one individual in an open population to a bite pattern on human skin to a reasonable dental, medical, or scientific certainty based on pattern analysis alone cannot be scientifically supported.

THE UNIVERSITY OF TEXAS HEALTH SCIENCE CENTER AT SAN ANTONIO

Conclusions

- In closed or limited population cases it may be possible to associate a biter and the bite mark(s) with reasonable dental, medical, or scientific certainty *for that limited population*.

- Forensic Odontology certifying bodies should properly test and periodically re-test their certified members for proficiency in bite mark analysis

Thank You

David R. Senn, D.D.S.
Vice President-American Board of Forensic Odontology
Director-Center for Education and Research in Forensics
University of Texas Health Science Center at San Antonio
senn@uthscsa.edu

EXHIBIT E

Texas Forensic Science Commission

Bitemark Comparison Review Panel

November 16, 2015

Franklin D. Wright, DMD, D-ABFO

Forensic Dental Consultant,
Hamilton County Coroner's Office
Cincinnati, Ohio
frankwright@msn.com

Appropriate Use, Role and Limitations

Bitemark Evidence- 4 steps

- Examination and analysis of the injury
- Examination and analysis of potential biters
- Comparison- if evidence supports moving to a comparison
- Opinion

Appropriate Use and Role

- Adult bites versus child bites
- Animal bites versus human bites
- Sourcing for biter DNA
- Multiple bites in various stages of healing

Appropriate Use

- Child bite vs adult bite

Bitemarks mom found on her child from daycare

Hospital ER admission child abuse victim

Bitemark Evidentiary Value

Mom left 17 yr old stepbrother in charge of this 7 year old child and his 4 year old brother.

Mom returned home to find this 7 year old badly beaten and bitten. The 17 year old said the two younger brothers got in a fight while he was outside.

Police asked if the bitemarks were made by the 4 year old.

Bitemark Evidentiary Value

- Animal bite vs human bite

-badly beaten child admitted to hospital

-this injury was reportedly inflicted by one of seven dogs that live in the home

Bitemarks

Previous slides showed bitemark evidence and analysis but no attempt at biter identity or exclusion- all appropriate use of bitemarks

National Resource:

- Kempe Center, Aurora, Colorado

The Kempe Foundation
The Gary Pavilion at The Children's Hospital
Anschutz Medical Campus
13123 E 16th Ave B390
Aurora, CO 80045

(303) 864-5300

questions@kempe.org

Same child

Different ages of injuries

Different locations

…those that survive and those that don’t


Protein Hydrolysate Formula with IRON
NeoSure


Hospital Formula System

Two child abuse victims


FALCON
AUBURN, MAINE
MADE IN U.S.A.


FALCON

Appropriate Use

- Part of the evidence in cases involving person on person crime where biting occurs
- Best cases involve limited numbers of suspected biters with significantly distinctive dentitions and bitemark(s) of high evidentiary value
- Vast majority of cases involving bitemarks have limited forensic value
- Often best used to exclude suspected biters

Bitemark Analysis/Comparison

- Bitemarks of high evidentiary value in a <u>defined population</u> of suspected biters (n=2 or 3), each of whom present with significantly different dentitions, may be analyzed for discriminate inclusion/exclusion of a specific biter

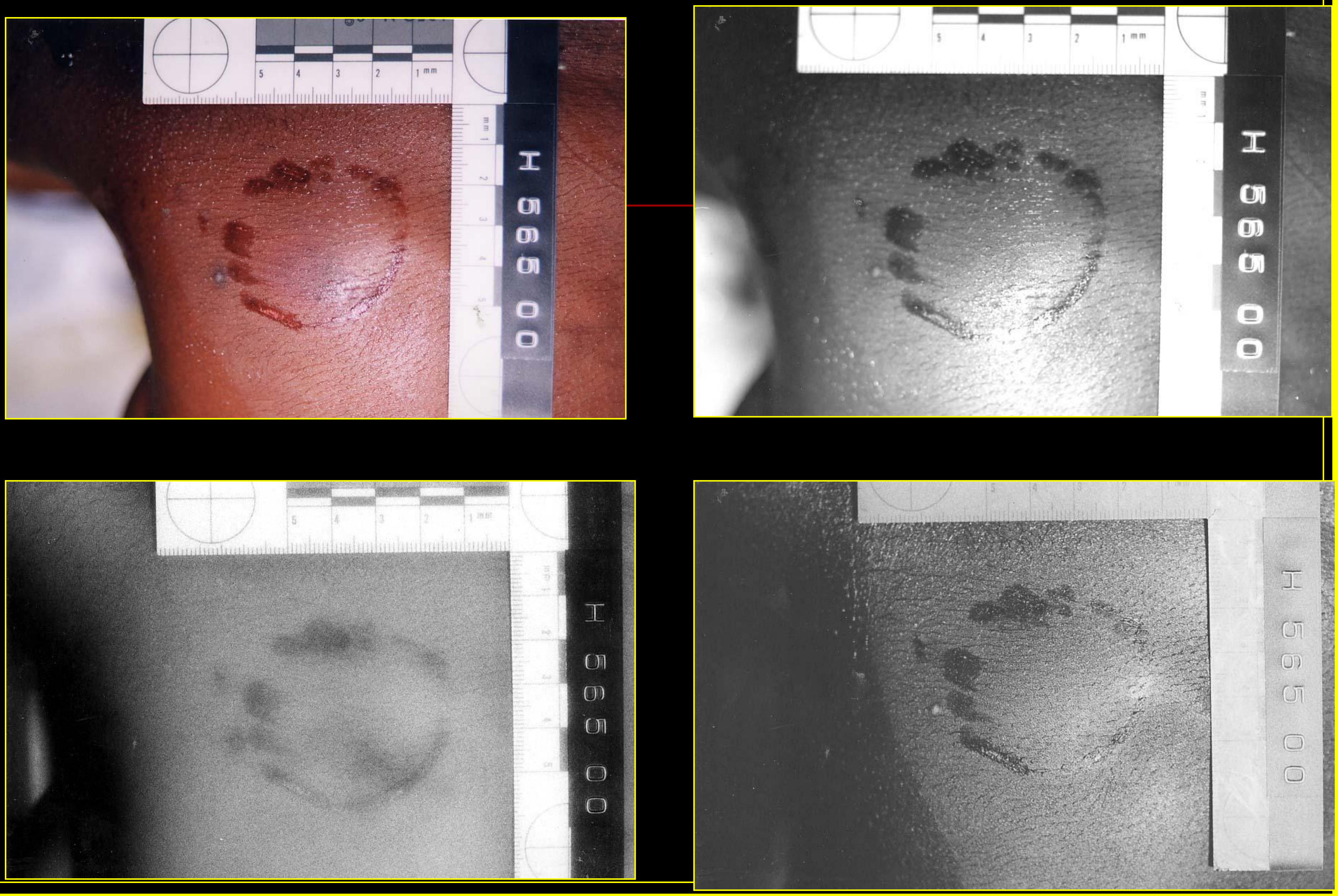
STEP TWO- defined population of biters' dentitions

[redacted]

Suspect A

Upper Teeth

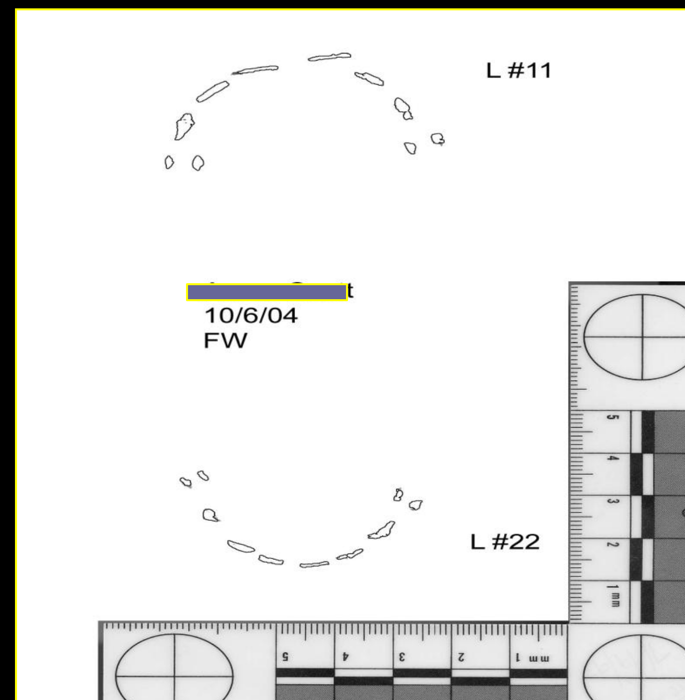

Suspect B
[redacted]
Upper Teeth

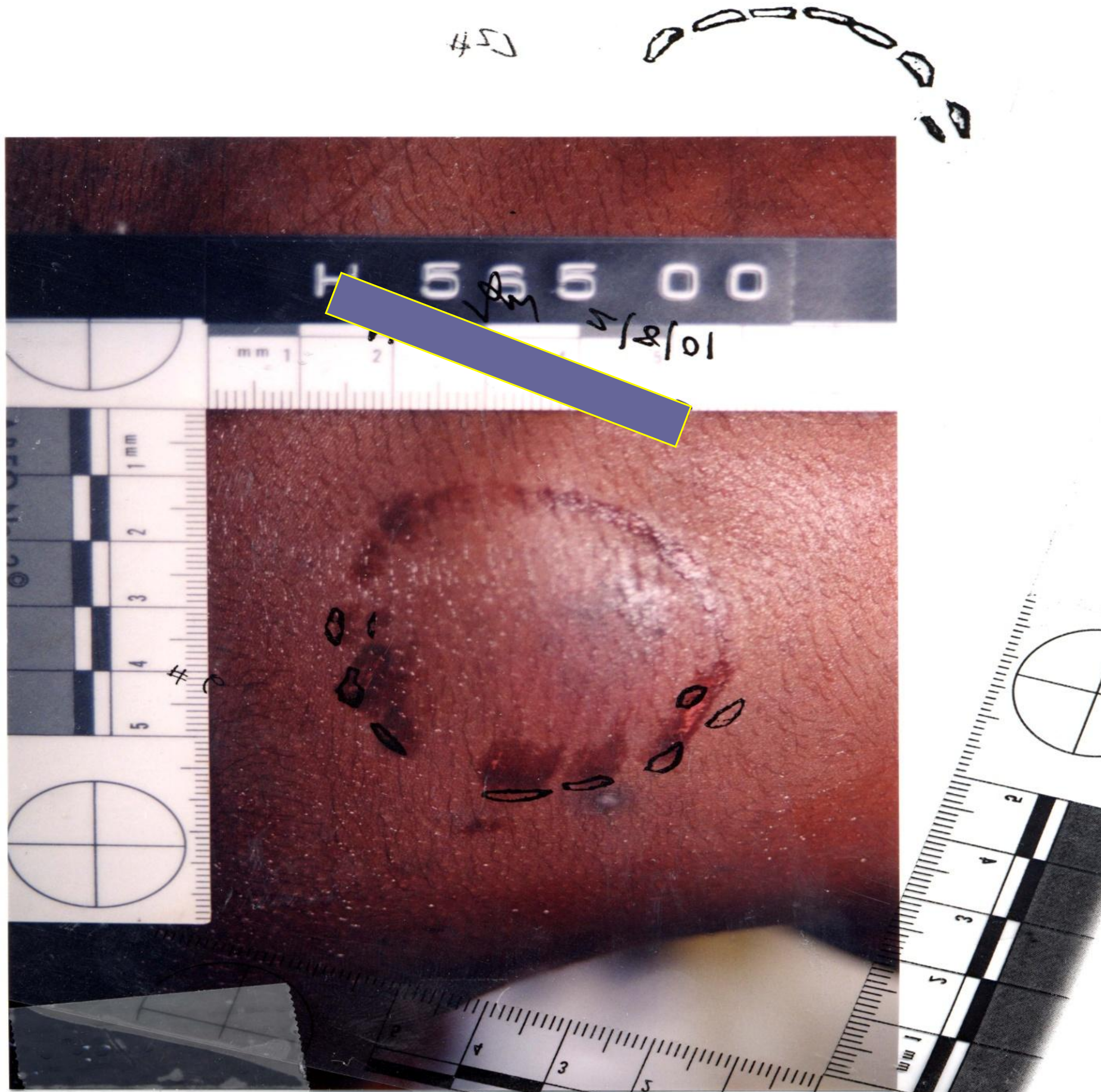


IR

UV

Models and the overlay

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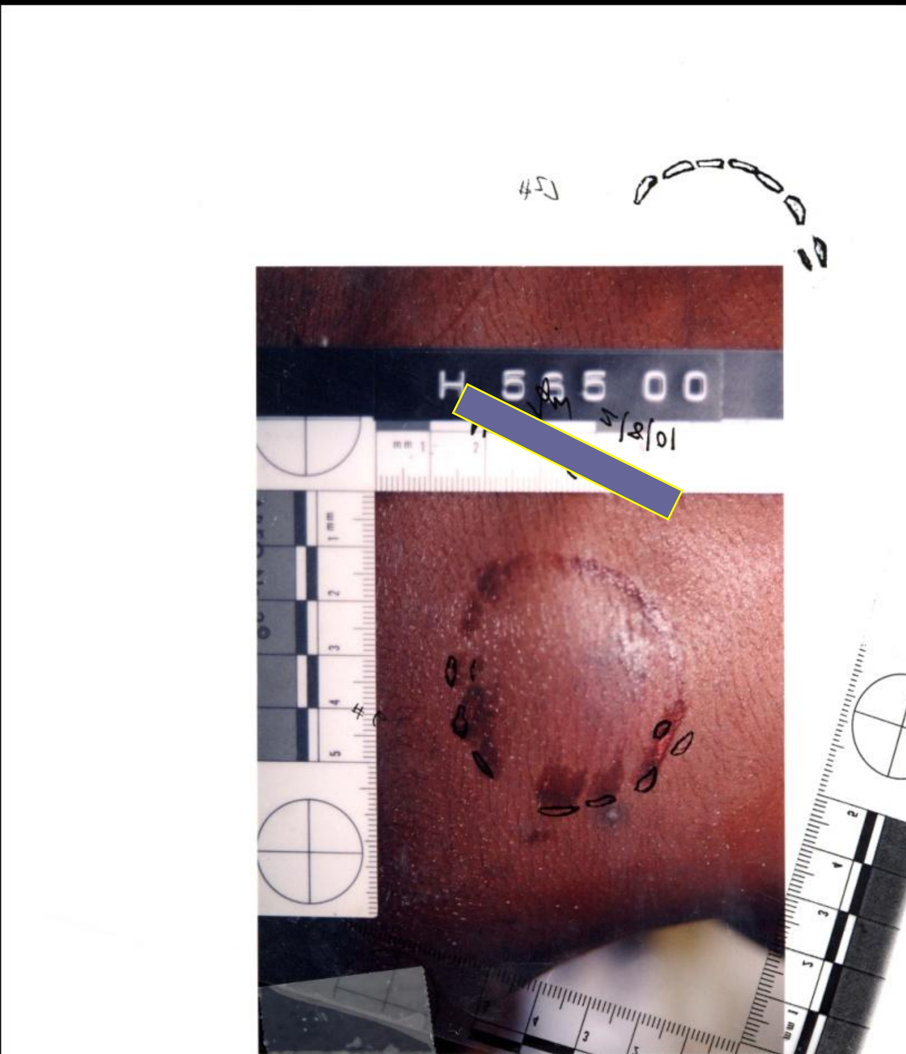
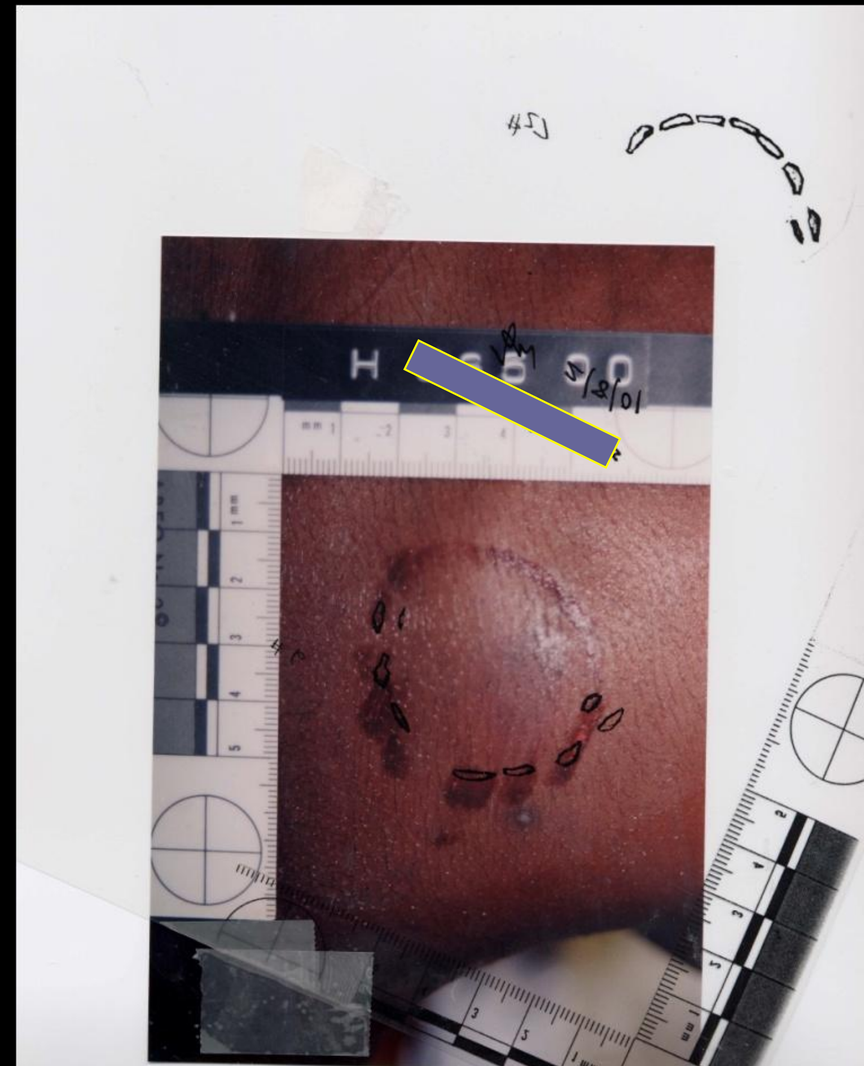
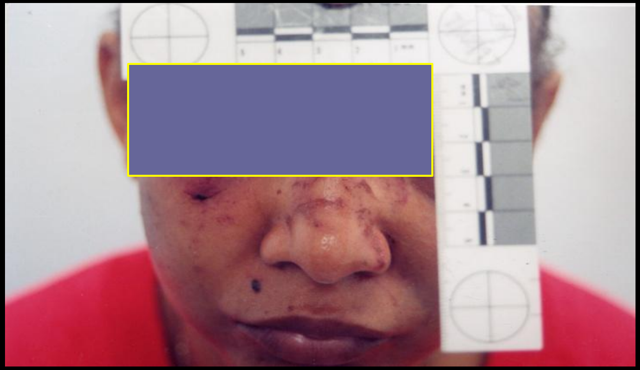
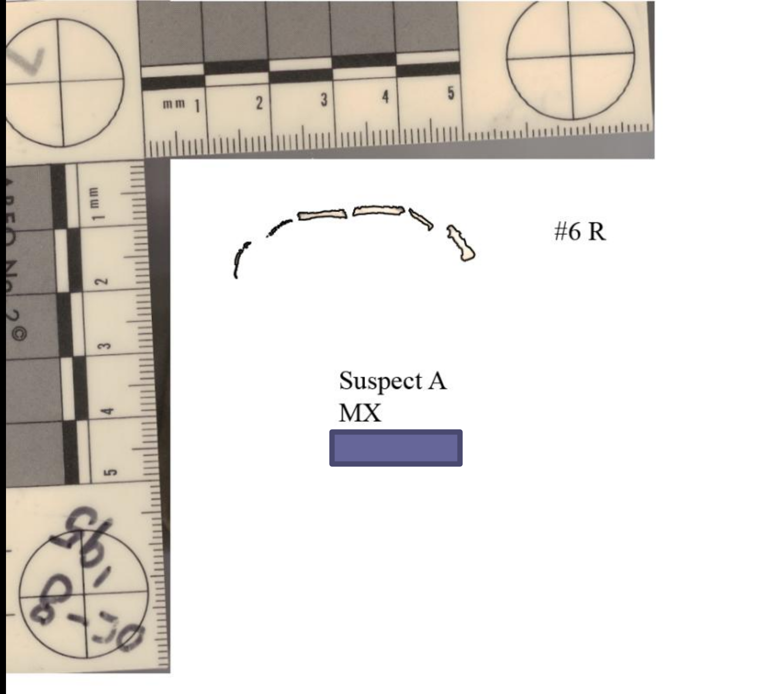
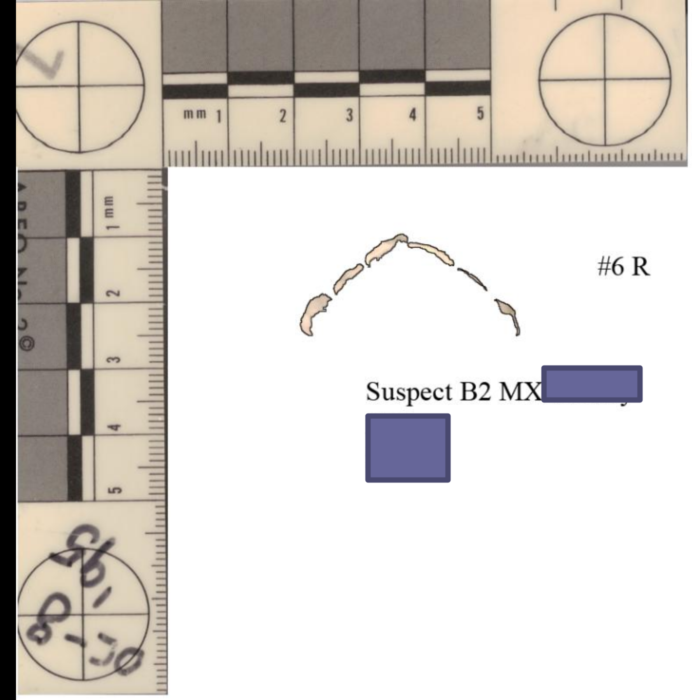




7 hour attack and rape, 37 bites




#6 R
Suspect A
MX
[redacted]
ABFO No. 2©

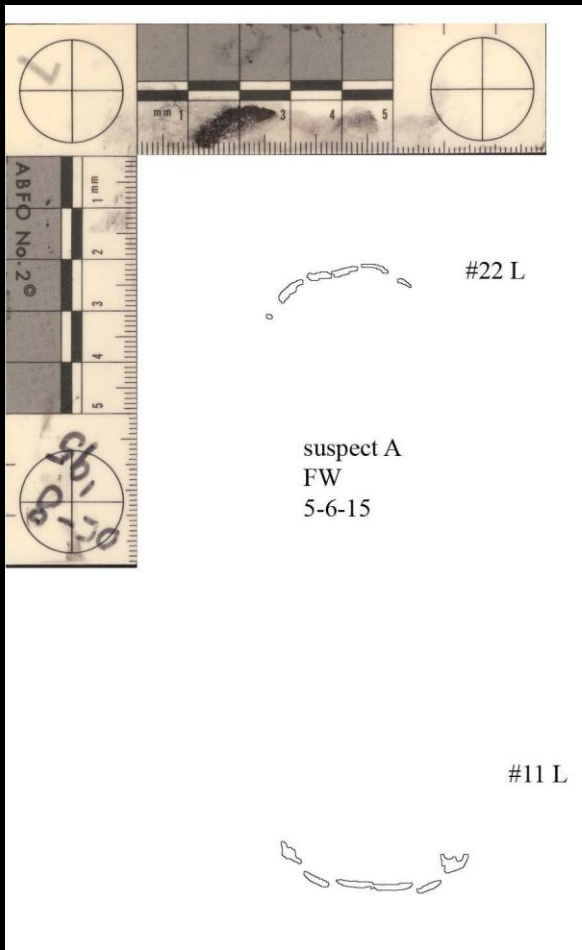

#6 R
Suspect B2 MX [redacted]
[redacted]

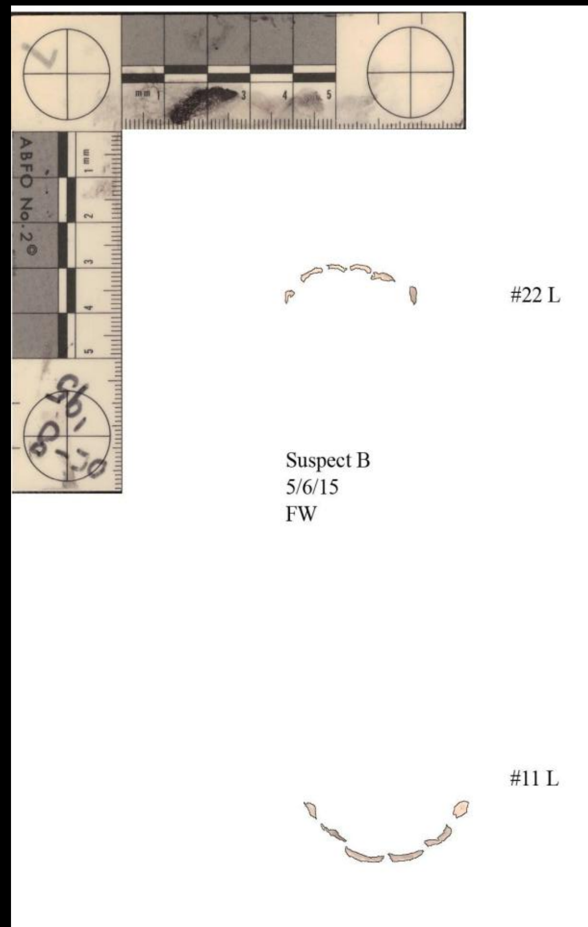

ABFO No. 2©
[redacted]

Limitations in the use of Bitemarks

- Undefined biter population
- Bitemarks of low forensic value
- Biters with similar arrangements of teeth
- Poor quality evidence collection

Bitemark case


ABFO No. 2©
#22 L
suspect A
FW
5-6-15
#11 L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#22 L
Suspect B
5/6/15
FW
#11 L


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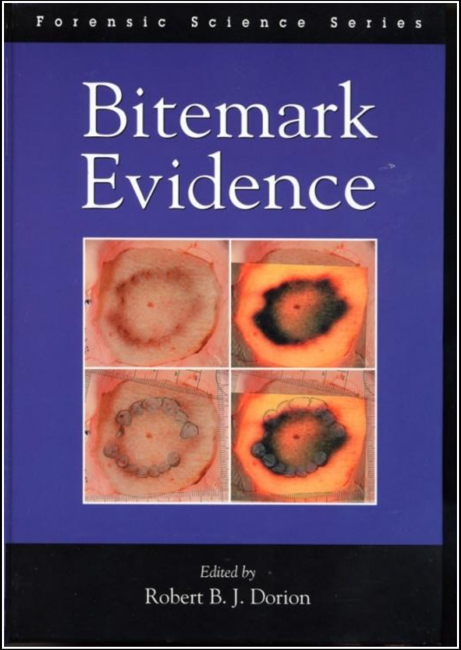
ABFO No. 2©

- "The research suggests that bitemark evidence, at least that which is used to identify biters, is a potentially valid and reliable methodology. It is generally accepted within the scientific community …"



Iain Pretty in _Bitemark Evidence,_ 1st edition, edited by Dorion, pg 543

Perspective on Research

- Human skin as an impression medium
- Uniqueness of the human dentition

Human Skin and Bitemarks

- Three research sources:
  - Anesthetized pig skin
  - Human Cadaver (dead) skin
  - Living human skin

	TOOTH PATTERNS IN SKIN				
	Cadaver Skin		Vital Human Skin		Vital Pig Skin
pain receptors activated	NO		YES		NO
bite mechanism	FIXED HINGE TOOL		HUMAN TMJ		FIXED HINGE TOOL
vital response	NO		YES		YES
bleeding under skin	NO		YES		YES
biting interval	13-19 SECONDS		1-2 SECONDS		???
tooth patterns in skin	GONE IN MINUTES		DAYS OR WEEKS		DAYS
skin temperature when bitten	MAYBE 18 C		37 C		39 C
"fear factor" and movement	NO		YES		NO
induced distortion or injury pattern	DISTORTION		INJURY		BOTH
bite infliction	SLOW AND STEADY		QUICK AND BRIEF		???

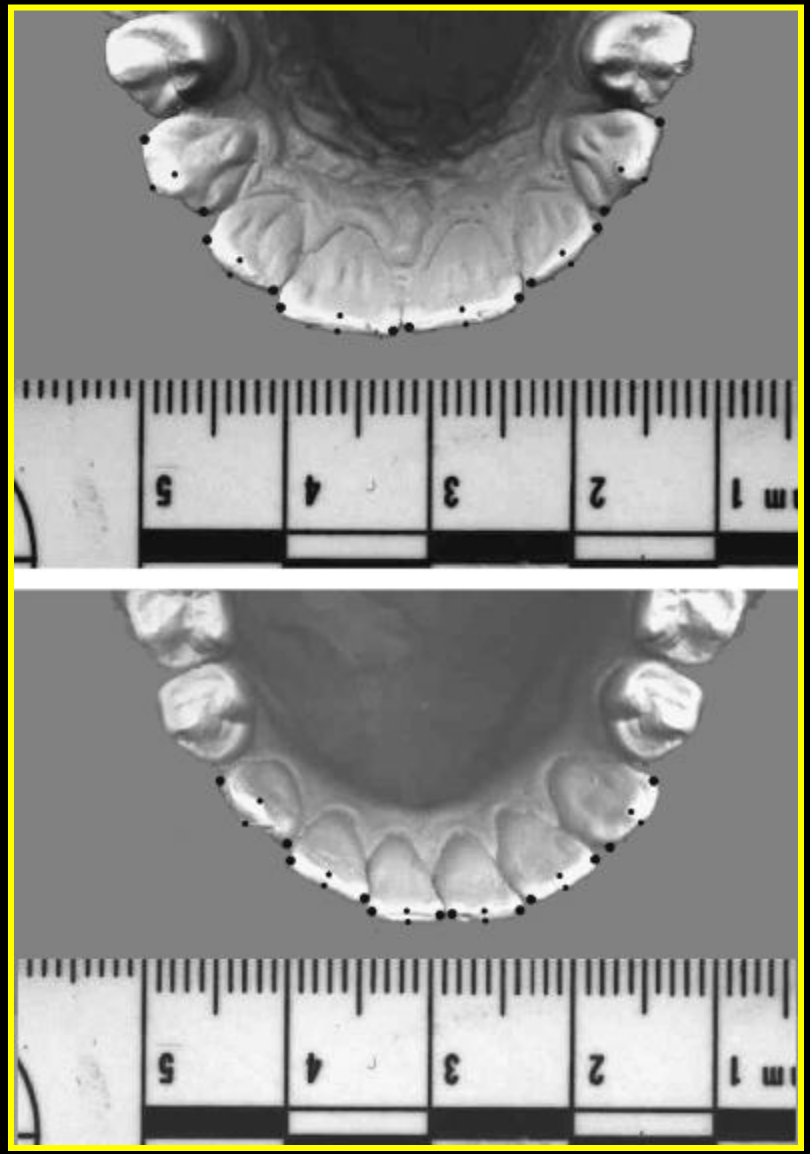
State of Ohio v Prade

- "While the Court appreciates Dr. Bush's efforts to study the ability of human dentition to transfer unique patterns to human skin, the Court finds the premises and methodology of her studies problematic."

-Judge Judy Hunter, January 31, 2013

Uniqueness of the Human Dentition

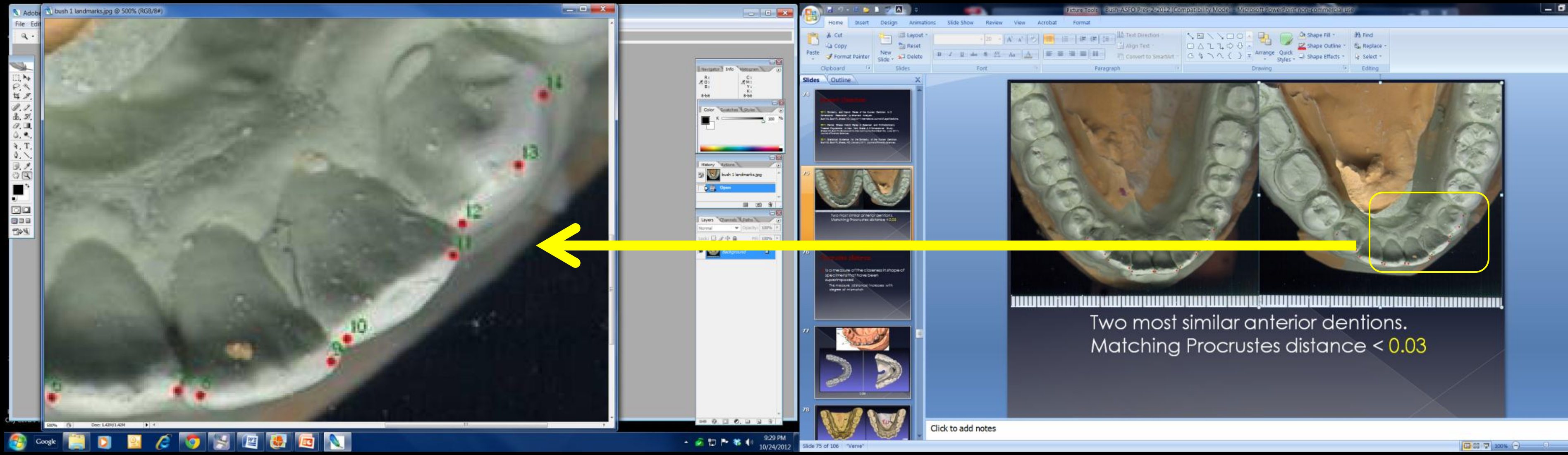
- As a population study, have little relevance in bitemark cases
- Limited populations of biters' dentitions in bitemark cases must be distinctly different



-No specimens had concordant landmarks; the dentition is unique.

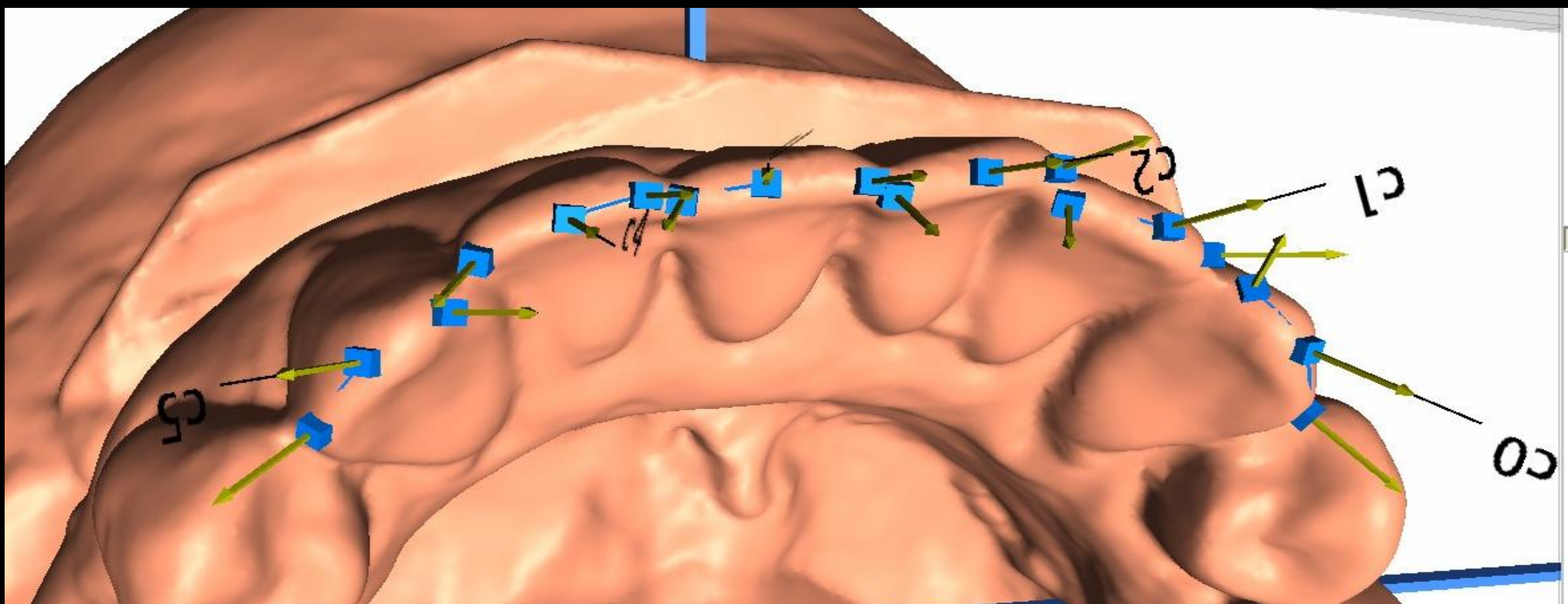
Arbitrary placement of landmarks- 2D –studies Un. at Buffalo

"…so similar they were indistinguishable…"



According to the 2000 and 2002 Procrustes studies by Robinson, et. al improper placement of landmarks "will result in false representations of shape"

3D Studies- Un. at Buffalo



-Are the landmarks within 1 pixel of the anatomical edge?

-How is the 3D model oriented to insure it’s in the right position?

	Uniqueness of the Human Dentition				
	Bush 2D		Kieser 2D		Bush 3D
Dentition Orientation at Image Capture per Robinson et al	NO		YES		N/A
Proper Placement of Landmarks	NO		YES		NO
Study Sample Size	>1000		82		>1000
Actual Specimens Compared when Procrustes predicted a match	NO		NO		NO
Number of Landmarks per tooth	2/3		4		2/3/10
Image type	JPEG		JPEG		computer animation
reproducible orientation for landmark placement	YES *		YES		NO
human dentition unique	NO		YES		NO

Patterned Injury Analysis

- Pretty Freeman et al Study
- ABFO Bitemark Committee Exercise

ABFO Bitemark Committee Exercise

- Follow up beta test to the Pretty –Freeman study
- Used new terminology
- 10 cases presented to twelve persons; 9 participated

- Human teeth created the pattern; other possible sources were considered and excluded; the pattern displays features that reflect the class characteristics of human teeth.
- **Criteria:**
- A circular, or oval or curvilinear pattern or patterned injury consisting of either one arch or two opposing arches often, but not always, separated at their bases by unmarked spaces. Individual marks, abrasions, contusions, or lacerations may be found near the periphery of each arch. The marks present reflect the size, shape, arrangement, and distribution of the contacting surfaces of the human teeth that made the pattern. Either the maxillary or mandibular arch, or both arches, can be identified and the midline of each arch visible may be determinable. Some of the marks made by individual teeth can be recognized and identified based on their class characteristics and/or location relative to other features. The size and shape of each arch visible is consistent with the size and shape of the human dentition.

beta test #	2	4	6	8	1	3	5	7	9
case 1 step 1	no	no	no	no	no	no	no	no	no
case 1 step 2	-	-	-	-	-	-	-	-	-
case 2 step 1	yes	no	no	no	no	no	yes	yes	mo
case 2 step 2	no	-	-	-	-	-	yes	no	-
case 3 step 1	yes	yes	yes	yes	yes	yes	yes	yes	yes
case 3 step 2	yes	yes	yes	yes	yes	yes	yes	yes	yes
case 4 step 1	yes	no	no	no	yes	yes	no	yes	no
case 4 step 2	no	-	-	-	no	no	-	no	-
case 5 step 1	no	yes	no	no	no	no	no	no	no
case 5 step 2	-	no	-	-	-	-	-	-	-
case 6 step 1	yes	yes	yes	no	no	yes	yes	yes	yes
case 6 step 2	yes	no	no	-	-	no	no	yes	no
case 7 step 1	yes	yes	yes	no	yes	yes	yes	yes	yes
case 7 step 2	yes	yes	yes	-	yes	yes	yes	yes	yes
case 8 step 1	yes	yes	yes	yes	yes	yes	yes	yes	yes
case 8 step 2	yes	yes	yes	yes	yes	yes	yes	yes	yes
case 9 step 1	yes	yes	yes	no	yes	yes	yes	no	
case 9 step 2	yes	yes	yes	-	yes	yes	yes	-	
case 10 step 1	yes	yes	no	no	no	no	no	no	yes
case 10 step 2	yes	no	-	-	-	-	-	-	yes

Next Steps:

- Continue experimentation on living human skin for creating and studying bitemarks
- Proficiency testing and certification

Final Comments

Innocence Project and this complaint

NAS report citation in complaint

Media as source of support in complaint

-Mr. Radly Balko, Washington Post

-Ms. Amanda Meyers, AP

EXHIBIT F

JOURNAL OF FORENSIC SCIENCES

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PAPER

ODONTOLOGY

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Patterns of Variation and Match Rates of the Anterior Biting Dentition: Characteristics of a Database of 3D-Scanned Dentitions

ABSTRACT: An understanding of the variability of the anterior human dentition is essential in bitemark analysis. A collection of 1099 3D laser scans of paired maxillary and mandibular arches were studied using geometric morphometric methods. Analyses were performed without scale (shape only) and with scale (shape and size). Specimens differing by no more than experimentally obtained measurement error were counted as matches, or as indistinguishable. A total of 487 maxillary (396 size preserved), 131 mandibular (83 size preserved), and one paired dentition (two size preserved) matches were found. Principal component analysis and partial least squares revealed interpretable patterns of variation and covariation in dental shape, principally dominated by variation in dental arch width. The sensitivity of match rate to assumed degree of measurement error was also determined showing rapid increases in match rate as measurement error increased. In conclusion, the concept of dental uniqueness with regard to bitemark analysis should be approached with caution.

KEYWORDS: forensic science, forensic odontology, bitemarks, dental uniqueness, geometric morphometric analysis, three-dimensional analysis

There have been a number of concerns raised about the discipline of bitemark analysis (1–5). It rests on the dual assumptions that the arrangement of the teeth that produce a bitemark is unique and that skin records sufficient detail to support statements of certainty about the relationship of the anterior dentition to a given bitemark (1).

The entire issue of uniqueness as a testable concept in forensic science is contentious (6–8). In forensic odontology, the definition of uniqueness can vary depending on whether it pertains to victim identification or bitemark analysis. In victim identification, the combinations of restored (five surfaces possible), unrestored, and missing patterns of 32 teeth, coupled with root morphology and trabecular bone configuration variation, combine to provide a powerful set of evidence for identification.

Typically in a bitemark, only the six anterior teeth of the maxillary and mandibular dentition leave an impression in skin, and thus, many of the descriptors used in victim ID are not applicable (9). When the evidence is restricted to the biting surfaces of the anterior dentition, there is a tremendous reduction in the amount of information available. Even if all the characteristics of the biting dentition are preserved in a bitemark, there is still far less basis for comparison than in a case where X-rays and other evidence of dental treatment of the entire dentition is available. Simple extension of methodology and logic of the parameters and evidence used in victim identification to study uniqueness with respect to bitemarks is thus inappropriate, given the drastic difference in the amount of evidence available.

There have been few studies examining the claim of dental uniqueness with regard to bitemark analysis based on systematic collections of specimens. Many of these have lacked a formal statistical approach or have had a very limited sample size (10,11). Other studies have explored the idea of dental similarity rather than uniqueness and have defined an approach to describe a cutoff point in which dentitions may be mathematically indistinguishable from one another (i.e., sufficiently similar) (12–16).

The guidelines on bitemark analysis currently listed on the website of the American Board of Forensic Odontology (ABFO) (17) indicate that a bitemark analyst should state conclusions in a case as belonging to one of the following categories: The Biter, The Probable Biter, Not Excluded as the Biter, Excluded as the Biter, or Inconclusive with "all opinions stated to a reasonable degree of dental certainty." The first of these categories does imply a strong identification of a particular biting dentition to a particular bitemark.

One substantial concern raised when examining the ABFO criterion is whether or not there is a chance that two different individuals could produce a bitemark so similar that they could both be placed into the first category: The Biter. Clearly, if there were two individuals within this category in a given investigation, there is a substantial potential for a miscarriage of justice. In some sense, this is not a question of uniqueness per se, but of the ability to effectively identify measurable differences between two very similar individuals.

The criteria and terminology chosen for this project are that two dentitions are said to "match" if the differences between them are no larger than the differences which might occur if one of the dentitions was measured repeatedly by the same operator,

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the repeated measurement error (10,12–16). If the difference between the two is within the expected range of error in the measurements involved, then one cannot claim that there is any meaningful, measurable difference between the two biting dentitions (although it may be possible that differences exist in the rest of the dentition, the posterior teeth, not recorded in a bitemark).

The pragmatic definition used here of the term "match" does not concur perfectly with the terminology used in the ABFO guidelines, but it provides a working definition of what a "match" is, specifically that there are no measurable differences between the two sets of teeth given the measurement methods available. If there are no individualizing characteristics detectable between dentitions at some measurement resolution, then there seems little possibility of assigning one and only one individual to the singular category of The Biter. The limitations of measurement would suggest that an analysis of a bitemark could result in the identification of more than one individual as The Biter.

The goals of this study were first to expand an existing database of 497 paired three-dimensional (3D) scans by over 600 additional specimens, to observe the impact of increased sample size on match rate (14). In the earlier study of 3D-scanned data, the comparison methods used did not take size into account, but rather removed all size differences. In this study, both size-preserving and size-removing methods were used to determine the impact of including size information on the match rate (13,16).

Second, the increase in match rate according to loss of measurement resolution was examined in order to understand the sensitivity to increase in measurement error. There is a second factor in bitemark analysis, that of transfer of the dental pattern to skin. Distortion in the transfer is inevitable, such that precise replication of dental shape will not be attained in the tissue (13). This factor has the effect of reducing resolution and increasing measurement error, potentially allowing many more dental matches to occur. This study explores that concept by demonstrating the number of matches that occur when measurement error threshold is increased.

Third, we examined several measures of size variation in the data set, both the familiar arch width and the centroid size measure common in geometric morphometrics (18,19). Correlation structures between the two measures, and between the maxillary and mandibular dentition were examined.

Last, a range of statistical tools were used in conjunction with landmark methods to produce a summary of the variation present in this large data set, as an approach to understanding shape variation present in the population of dentitions. The same types of methods were used in studying patterns of variation in bitemarks and in 2D dentitions to allow systematic comparisons of patterns appearing in both types of data (13). A database of this size allows a more robust understanding of the types of variation that are possible in the dentition and subsequently bitemarks.

Materials and Methods

All necessary Human Subject Institutional Review Board protocols were completed for this project and exemption was granted. A collection of 1106 paired sets of 3D-scanned maxillary and mandibular dentitions were obtained from a commercial dental laboratory, which produced these scans for the production of occlusal guards (night guards). The 3D virtual models that made up this data set were produced by laser scanning dental stone models that had been mailed to the commercial laboratory. The nominal spatial resolution of the laser scanner was 100 microns. Of these 3D models, 497 pairs were taken from an earlier data set (14) and 609 pairs were newly measured for this study.

After initial matching studies, seven of these specimens were identified as being repeated scans of the same individuals, which were removed, leaving 1099 distinct individuals. This was an interesting early result, as these blind repeats indicated the ability of the shape comparison process to detect identical dentitions and thus to serve as internal controls.

The dental models provided to the dental laboratory for 3D scanning were from private practice patients from dental practices across the United States. All patient identifying information was stripped from the data prior to any additional processing. This was a sample of convenience and contained a wide range of alignment patterns, from relatively straight to fairly malaligned.

Shape Measurement

Landmark measurements (LM) were taken on the 3D-scanned dentitions by placing 10 data points along the incisal edge of each of the six anterior teeth, using the Landmark digitizing program (20). The dentitions were rotated in 3D space within the software as landmark points were placed along the incisal edges using changes in 3D perspective to verify accurate landmark placement. This resulted in 60 total points along the incisal edges of the anterior teeth of both the maxillary and the mandibular arches, recording a wide range of geometric information including mesial to distal width, midpoints, angulation, incisal edge shape of each tooth, malalignment patterns, relative tooth heights and positions within the arch. It is emphasized that throughout this study, the measurements refer strictly to the six anterior teeth in the maxilla and mandible as this is the relevant portion of the dentition with regard to bitemarks.

Procrustes and Procrustes Size-Preserving Superimposition

When comparing shapes represented as sets of landmark data, it is first necessary to superimpose the sets of data. Much of the work in geometric morphometrics has focused on separating the shape of the object from the size of the object, so that the Procrustes method used in this field superimposes the data by removing all differences attributable to size. For most forensic work, size is regarded as a highly important aspect of the data, and so a variant superimposition method, called Procrustes Size-Preserving (Procrustes-SP) was used in this project as well as Procrustes.

Procrustes methods and Procrustes-SP (also called "size and shape analysis") have been discussed extensively in numerous other publications (11,13–16,18,19,21–23). Both methods simply minimize the summed squared distances between corresponding landmarks on two or more specimens by translating and rotating the specimens to match one another as well as possible. The Procrustes method used also requires that the centroid size of the two specimens be scaled to one, so that the size of the two specimens also matches.

The use of a least squares criteria for the quality of this match is a feature shared with many other statistical procedures including simple regression models for example, so that the procedure, while somewhat complex, is not outlandish by statistical standards. The least squares approach also allows for the computation of a distance metric, a standard descriptor of how different two shapes are, called the Procrustes distance, or the Procrustes-

SP distance, depending on whether or not the size information is preserved. These distance measures can be used either to characterize variability of measurements, to characterize a data set, or to understand the measurement resolution of a system.

There is a wide range of methods of working with shape statistics (19,21,22), the Procrustes method used here is technically termed a Partial Procrustes method, which is the generally preferred one of several alternative forms (21,23).

Match Criteria-Repeated Measures

Use of the match criteria that there are no measurable differences between specimens requires that we understand the variability possible in repeated measurements of a single specimen. This variation sets the limits of useful resolution in a measurement system. The total "error variance" may be expressed as the sum of contributions to the measurement error from a series of sources: operator error in placing landmark, inter-operator error because of differences between operators, error owing to the variability of taking a dental impression (including different materials and methods at this stage), error caused by the casting of the impression (including variations in casting material) and variation introduced by the 3D-scanning process, including that because of the mount of the cast in the scanning apparatus. The total variance may thus be expressed as the summed random contributions of each of these terms.

$$\sigma^2_{\text{total}} = \sigma^2_{\text{operator}} + \sigma^2_{\text{among operators}} + \sigma^2_{\text{impression}} + \sigma^2_{\text{casting}} + \sigma^2_{\text{scanning}} \quad (1)$$

Not included in this model are systematic biases in any of these terms, as such factors may be detected and removed. In this study, all digitization was by a single operator, and thus, the inter-operator term is zero. Multivariate analysis of variance methods are generally used to decompose the total variance into the contributions from each term, by systematically analyzing repeated measurements in each category of the factors contributing to variation. As we were working with scans obtained from a commercial laboratory intended for dental treatment, we did not have the ability in this study to measure the contributions of the impression, casting and scanning terms, which would have required a series of repeating impressions, casts and scans of several dentitions to estimate the contributions of these terms. We do believe that these terms are relatively small relative to the digization term ($\sigma^2_{\text{operator}}$), but it is clear that by neglecting the impression, casting and scanning variances, we are underestimating the total variability in the measurements, so that our estimates of match rates will be an underestimate of the true match rate obtained by considering all sources of variance.

To determine the measurement resolution ($\sigma^2_{\text{operator}}$), the scans of three maxillary and three mandibular specimens were digitized 10 times each by the same operator, and the scatter of Procrustes distances and Procrustes-SP distances of each specimen about the mean measurement of that specimen was determined. From these distances, the average root mean square (RMS) distance scatter of repeated measurement specimens about the mean was determined (σ_{operator}). This value characterizes the measurement resolution obtained in the study, expressed as a Procrustes or Procrustes-SP distance. The RMS scatter is analogous to a standard deviation, although it is not measured in the same way, nor does it have the same statistical properties. However, experiments have empirically indicated that 93–96% of repeatedly digitized specimens lie within twice the RMS scatter level.

In dimensionless Procrustes units, the RMS scatter in this data was 0.02 for both the maxillary and the mandibular dentition, so the matching criteria were twice this, 0.04. As Procrustes landmarks are scaled to the centroid size, this measurement indicates our typical total error in measuring all 60 landmarks was about 2% of the total size of the dentition.

When using Procrustes-SP methods, the RMS scatter per LM point was roughly 0.2 mm, still roughly 2% of the centroid size, which is consistent with a broad definition of 1 mm width of the incisal edges. A maximum error of ±0.4 mm per point would still leave each LM on the incisal surface in all cases. There may of course also be a lateral component, a sliding of points along the top margin of the tooth contributing to this RMS scatter as well. The RMS scatter summed over all 60 points (all six anterior teeth) in the mandibular dentition was 3.1 mm and 4.28 mm in the maxillary dentition, and thus, the net error was 2% of total size. Simply expressed, placement of LM points on the incisal edges was precise, and the placement error was small.

The substantial difference between the two arches is because of the increased size of the maxillary structure. The error as a *percentage* of size was similar. In considering this error, it is important to note that the RMS scatter reflects only the error in repeatedly placing landmarks on a single specimen, not errors appearing in retaking a dental cast, or in reproducing the 3D scan of that cast. Future work should ideally include an estimate of the contribution of these error sources as well.

Arch Width and Centroid Size

The typical measure of size used in geometric morphometrics is centroid size, the square root of the summed squared distances of landmarks from their centroid, or average (18,19). Centroid size is effectively a measure of how scattered the points in the system are about their average and is advantageous in many calculations in that all landmarks are treated equally, none carrying more weight than others in the calculations. However, centroid size is difficult to conceptualize, so arch width was also calculated, measured from the central point of opposing canine for each specimen from the landmark coordinates. The mean, minimum, maximum, standard deviation, and coefficient of variance of both arch width and centroid size for the maxillary and the mandible was calculated. Also correlation of arch width with centroid size in the maxillary and mandible was calculated, as was the correlation between maxillary and mandible in these two variables.

Principal Component Analysis Patterns of Variation

Principal component analysis (PCA) is a mathematical way of displaying the strongest independent patterns of variation in a multivariate data set (24). These methods have a long history of use in various forms of biometry and are typically used to determine patterns of variation in a complex data set (22). When used with shape data, the resulting principal component (PC) axes may be displayed as patterns of shape differences in the data set. These axes are often drawn as deformation grids for 2D data (22,23), showing the differences interpolated across the entire structure (18). Plots typically show the changes in shape associated with positive scores on the PCA axis, negative scores imply the opposite or inverse patterns of changes. In 3D data, it is easiest to simply plot the landmark positions of the mean shape and the PC axis.

PCA is a method of organizing data, rather than a statistical test (24). It arranges the data into conveniently interpretable variables (PCA scores) along each PC axis. A large score indicates a large difference from the mean form, along the pattern of shape difference depicted by the deformation grid plot, or 3D landmark plot of the change in shape along the axis. A negative score indicates a set of changes opposite to those depicted by the deformation grid. Each PC axis explains some percentage of the total shape variation in the data set, ordered by decreasing percentages of the total variance.

Partial Least Squares Patterns of Covariation

The partial least squares (PLS) method is a way of studying the covariation of two blocks of multivariate data measured on the same individuals (25). The method employs a singular value decomposition of a covariance matrix calculated between the two blocks of data (26). The result is a set of PLS axes which explain or express covariation in much the same way the PC axes express variation (27–30). The PLS method results in paired PLS axes, one for each block. In this study, the two blocks are the 60 landmarks measured on the incisal edges of the maxillary and mandibular dentitions of the individuals in the collection.

Much like PCA, specimens have scores along each PLS axis, and the scores along each axis have maximum possible covariation between the two blocks. In other words, the PLS scores in one block are the best possible predictors of the scores (and thus the shapes) in the other block. This approach is very similar to a regression model, except that regression models typically assume that one variable is predicted by the other. PLS methods explain covariation, not causal, predictive relationships as appear in regression models.

As PLS axes are ordered by the covariance explained, methods have been developed to use permutation methods to determine how many of the PLS axis are statistically meaningful (25). In some cases, the axes may be statistically meaningful (i.e., nonrandom), but explain so little covariation as to be meaningless.

Results

An initial determination of matches indicated five matches based on Procrustes and seven matches based on Procrustes-SP. Careful examination of the data indicated that seven of the specimens in these matches were among repeated 3D scans of the same individuals, so these repeated scans were removed prior to the final analysis, leaving 1099 specimens in the data set. Interestingly, the 3D scans of one particular individual were taken a year apart and were still within twice the repeated measurements RMS scatter range, indicating that in this case at least, the differences because of the intervening time, retaking of the cast and rescanning of that cast were still within the measurement error. This is some indication that the digitization process is the largest contribution to the total variance and that the matching procedure does work on real data.

The matching rates based on Procrustes and Procrustes-SP superimpositions were determined, and a substantial number of matches were found for the maxillary dentition as compared to the mandible. This rate further decreased when matches were searched between the maxillary and mandibular sets (Table 1). There was one remaining match in both maxilla and mandible of two different specimens under the Procrustes protocol. This was the same pair seen in an earlier study using the same data set (14). Under the Procrustes-SP procedure, there were two matched pairs of different specimens, for a total of four individuals with a match. The two pairs under Procrustes-SP were not the same individuals who matched under Procrustes.

TABLE 1—*Match rates in the maxillary and mandibular dentitions, and in both combined, based on Procrustes and Procrustes-SP superimpositions. The matching criterion used was twice the RMS scatter of repeatedly measured specimens.*

	Procrustes		Procrustes-SP	
	Number of Matches	Number of Individuals	Number of Matches	Number of Individuals
Maxilla	1691	487	763	396
Mandible	129	131	75	83
Both	1	2	2	4
	(603, 351 total comparisons, 1099 individuals)			

RMS, root mean square; Procrustes-SP, Procrustes Size-Preserving.

The exploration of the dependence of match rate on measurement error is summarized in Table 2. Clearly, the rates of matches in this large population increases rapidly as measurement resolution or repeatability decreases, as represented by the increased RMS errors used to calculate this table.

The characteristics of the observed ranges of the measurement of arch width and the centroid size are shown in Table 3. A plot of the relationship between the maxillary and mandibular arch width is shown in Fig. 1. The correlations between arch widths and centroid sizes are listed in Table 4.

Patterns of Variation

The PCA, based on Procrustes superimposed data, reveals the predominant patterns of variation in the anterior dentition of both the maxillary and the mandibular arches. Plots of the measured landmarks for the first six PC axes are shown in Figs 2 and 3. The figures show the data in two distinct views: along the incisal edges of the dentition (occlusal view) and in frontal view. These views are shown in Fig. 4 with representative 3D scans. The data in Figs 2 and 3 for the PC axes are shown as floating gray crosses. The average dentition over the entire set is shown as a series of black dots connected by solid lines along the incisal edges. The crosses indicate the pattern of differences for specimens with positive scores along the axis; specimens with negative scores would have the reversed pattern. The PC axes are independent axes that attempt to summarize variation; any real specimen could have a complex mixture of two or more of these patterns of variation.

The patterns shown in Figs 2 and 3 are readily interpretable, representing easily explained patterns of variation in the data as presented in Table 5. It should be noted that the data shown in Figs 2 and 3 are 3D in nature and that rotation in 3D space permits a better understanding of the shape variance.

Partial Least Squares: Decomposition of Covariance

The PLS method displays patterns of covariation of two sets of measurements, much in the way PCA displays patterns of variation. The PLS results reported here are thus describing patterns of correlated or covarying departures of individuals from the mean shape of both the maxilla and the mandible. Permutation tests of the singular values and of the correlations between PLS axes scores indicated that the first 11 PLS axes explained more

TABLE 2—*This table shows the dependence of the number of matches and number of individuals matching in this data set, under both criteria, for the maxilla and mandible, and both, as a function of increasing RMS scatter level, or decreased measurement resolution. The percentages are of the actual repeated measure scatter, so 125% represents a 25% increase in measurement error (603,351 total comparisons, 1099 individuals).*

	Fraction of RMS Scatter							
	100%		125%		150%		175%	
	Matches	Individuals	Matches	Individuals	Matches	Individuals	Matches	Individuals
Procrustes								
Maxilla	1691	487	21,358	873	85,282	1007	184,407	1061
Mandible	129	131	3119	500	18,543	769	5497	925
Both	1	2	526	246	6826	579	30,056	813
Procrustes-SP								
Maxilla	763	396	9660	826	39,854	1001	93,091	1059
Mandible	75	83	1658	451	9510	759	29,308	931
Both	2	4	166	144	2056	502	20,217	773

RMS, root mean square; Procrustes-SP, Procrustes Size-Preserving.

TABLE 3—*Characteristics of the distribution of arch widths and centroid sizes in this population. Dimensions are in mm. The coefficient of variation is the standard deviation divided by the mean and allows comparison of the variability despite differences in the mean or scale of the data.*

	Mandible		Maxilla	
	Arch Width	Centroid Size	Arch Width	Centroid Size
Maximum	35.3	93.2	42.2	127.0
Minimum	19.7	54.8	25.3	76.8
Mean	24.8	69.5	33.7	97.4
Standard deviation	2.0	5.0	2.4	6.5
Coefficient of variation	0.080	0.071	0.071	0.067

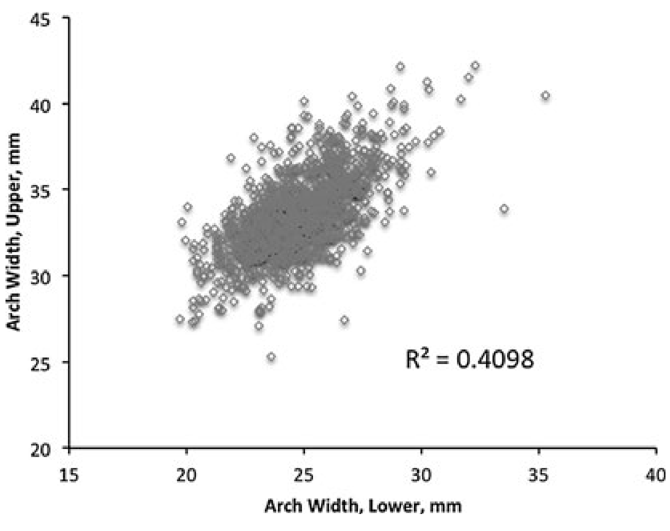

FIG. 1—*Arch width in the maxilla versus arch width in the mandible. The* R^2 *value is 0.4098.*

covariation than 95% of randomly permuted versions (25) of the data set did. The first four PLS axes appear to be easily interpreted and explained a total of 81.9% of the total covariance between the maxillary and mandibular measurements.

The PLS axes thus produced are shown in Fig. 5 and may be interpreted in the same manner as the PCA axes (Table 6). Perhaps not surprisingly, the first PLS axes (65.4% of covariance) describes the same pattern as seen in the first PC, a contrast between wide and narrow arches. The PLS analysis indicates this pattern is strongly shared between the maxilla and mandible.

TABLE 4—*Correlations between size measurements (arch width and centroid size[CS]) in the maxilla and the mandible.*

Variables	Correlation (R^2)
Maxillary arch width—mandibular arch width	0.4098
Maxillary CS—mandibular CS	0.4525
Maxillary arch width—maxillary CS	0.8958
Mandibular arch width—mandibular CS	0.8871

Discussion

Initial inspection of the matching results revealed that there were seven duplicate scans within the data set. This unexpected finding served to demonstrate and validate the ability of the matching process to identify the same individuals. The duplicates served as a useful (if inadvertent) internal control for the study.

A principal effect of database expansion was the large number of matches when the maxillary dentition was viewed separately from the mandibular, a number that increased significantly from the earlier study (14). However, the number of matches in the combined data set did not increase when considering Procrustes superposition. There was only one matching pair, which had already been seen in an earlier study (14). The use of Procrustes-SP methods (13,16,21), which had not been available in the earlier study, produced two matching pairs, of four individuals total, which did not include the individuals matching under the Procrustes criterion. The individuals matching under Procrustes but not under Procrustes-SP evidently differed in size. The matches under Procrustes-SP but not under Procrustes must have been virtually identical in size, so that the increased variance because of the uncertainty in size measurements overcame the dissimilarities in shape that allowed us to distinguish them under the Procrustes (shape only) procedure.

The effects of including the third dimension in analysis can be seen as these are relatively low match rates, compared to those seen in 2D data (12,15). It is difficult to make particularly strong statements about the effectiveness of Procrustes methods relative to Procrustes-SP based on these observed matches, owing to the limited number of total matched pairs. Detailed 3D data did reduce the match rate relative to that seen in 2D data, whether scale information was included or not. The effect of including

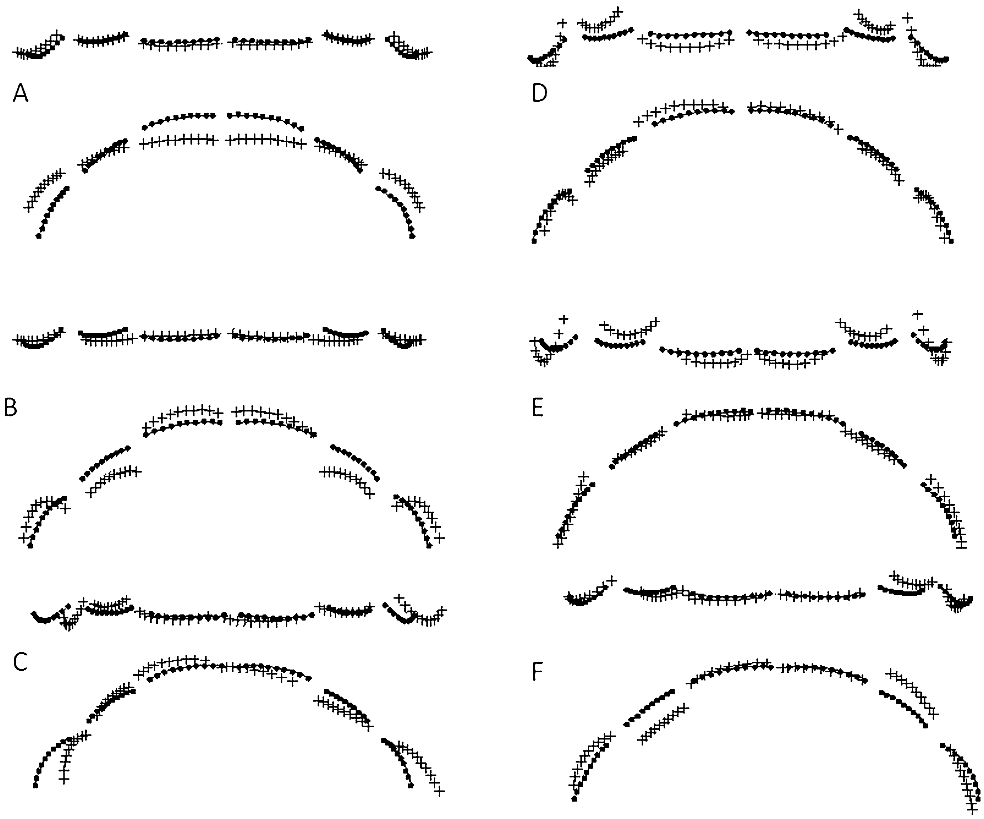

FIG. 2—*Principal component (PC) axes 1–6 (A–F) of the maxillary dentition in frontal and occlusal views. The data for the PC axis variation are shown as floating gray crosses. The average dentition over the entire set is shown as a series of black dots connected by solid lines along the incisal edges. The crosses indicate the pattern of differences for specimens with positive scores along the axis; specimens with negative scores would have the reversed pattern. It should be noted that the data shown in Figs 2 and 3 are 3D in nature and that rotation in 3D space permits a better understanding of the shape variance.*

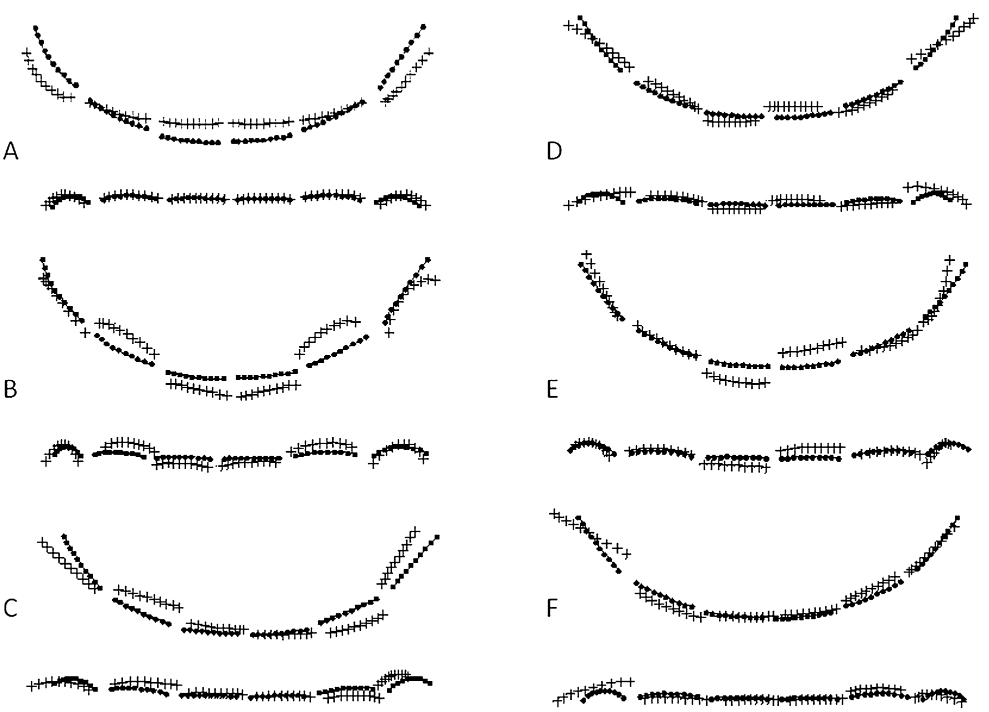

FIG. 3—*Principal component 1–6 (A–F) for the mandibular dentition, in occlusal and frontal view.*

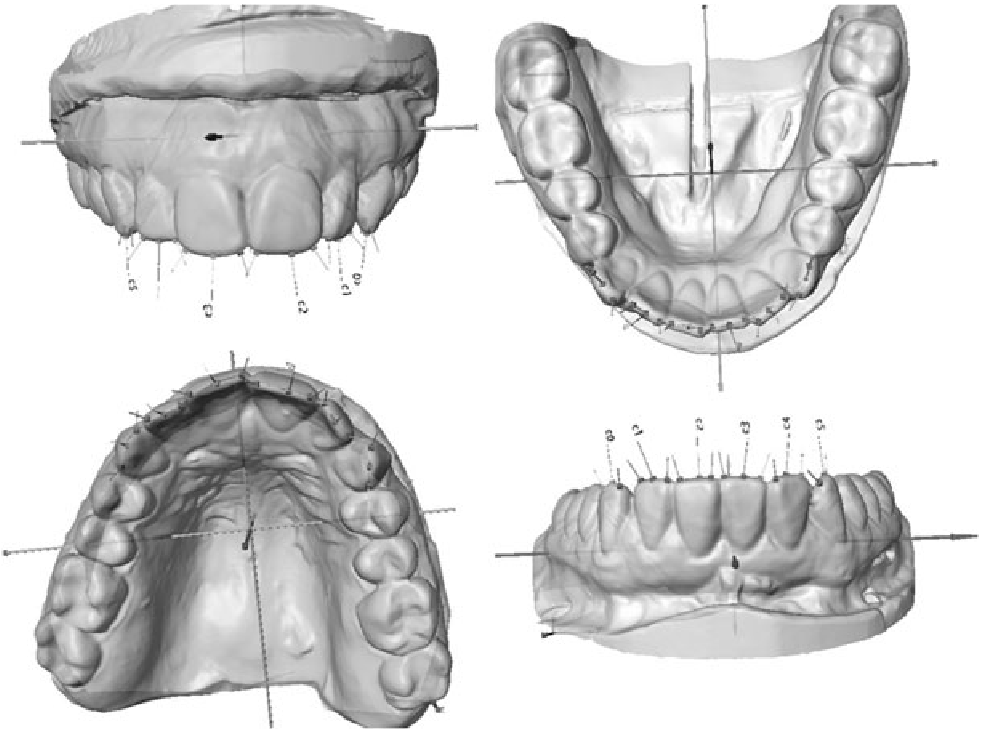

FIG. 4—*Views of representative 3D scans in the same orientation as the data presented in Figs 2 and 3.*

TABLE 5—*Results of PCA of maxillary and mandibular anterior dentition.*

PCA Axis	Percentage of Variance	Pattern Implied by the Axis
1	Mandible: 54.0 Maxilla: 39.8	Arch width; positive scores indicate a relatively wide arch, negative scores indicate a relatively narrow arch, in both maxilla and mandible
2	Mandible: 8.8 Maxilla: 12.6	Positive scores indicate a labial displacement of both central incisors, relative to a lingual displacement of both lateral incisors, with a slight labial shift of the canines in the maxilla
3	Mandible: 6.7 Maxilla: 7.0	This axis implies a pattern of left–right asymmetry in both maxilla and mandible, although the specific details of the asymmetry differ. In the mandible, there is a "bulge" of all teeth to one side, whereas in the mandible, all four incisors shift in a line relative to the canines
4	Mandible: 4.2 Maxilla: 5.2	Asymmetry in the location of the central incisors in the mandible. One shifted lingually and the other labially, while the adjacent lateral incisors shift in the opposite directions. In the maxilla, this is a different pattern, a labial shift of one central incisor with an accompanying lingual shift of the lateral incisor and canine
5	Mandible: 3.9 Maxilla: 4.8	In the mandible, this axis implies opposing lateral and lingual shifts of the central incisors, while in the maxilla, this axis describes outward shifts of both canines
6	Mandible: 3.6 Maxilla: 3.8	Opposing lingual–labial shifts of the canines and lateral incisors appear in the maxillary, while asymmetric lingual–labial shifts appear in the two lateral incisors of the maxilla, with some changes in the orientation of one canine

PCA, principal component analysis.

Note that the descriptions are stated in terms of positive scores, negative scores simply reverse the pattern.

size in the analysis did not have as large an effect on the matching rate as might have been expected from first principles.

The total number of matches did not increase quite as much as expected, when the sample size was more than doubled relative to the earlier study. As the number of possible pairwise comparisons in a data set is roughly proportional to the number of specimens squared (N(N−1)/2), the expectation would have been that the number of matches should quadruple, which was not seen. This probably indicates that the sample size is still not large enough for us to obtain a robust estimate of the underlying match rate at the maximum resolution obtained for this data. Lower resolutions of course drastically increased the match rates, putting a premium on measurement resolution in studying the human dentition. Estimation of optimal sample size may be elusive, as this was an empirical study and it is thought that match rate is dependant on the population studied. Attempts to use fitted statistical models to estimate the optimal sample size are certainly possible, but difficulties do arise in finding an appropriate distributional model when working with complex multivariate data. In light of this, we used only empirical approaches.

This study did work with a population of convenience, and one that may be expected to be biased toward relatively high levels of dental care given the source of the scans. It also did not consider the effect of missing teeth on match rate, or indeed attempt to determine the rate of incidence of missing teeth in a general population, both of which are clearly important in assessing the utility of bitemark analysis.

The rate of increase in the number of matches as the matching distances was increased (corresponding to progressive loss of measurement resolution, or incorporation of estimates of the other sources of measurement variation) shown in Table 2 is informative about the relationship between Procrustes and Procrustes-SP. These results show that Procrustes-SP methods do produce about 15% fewer matches than the Procrustes methods,

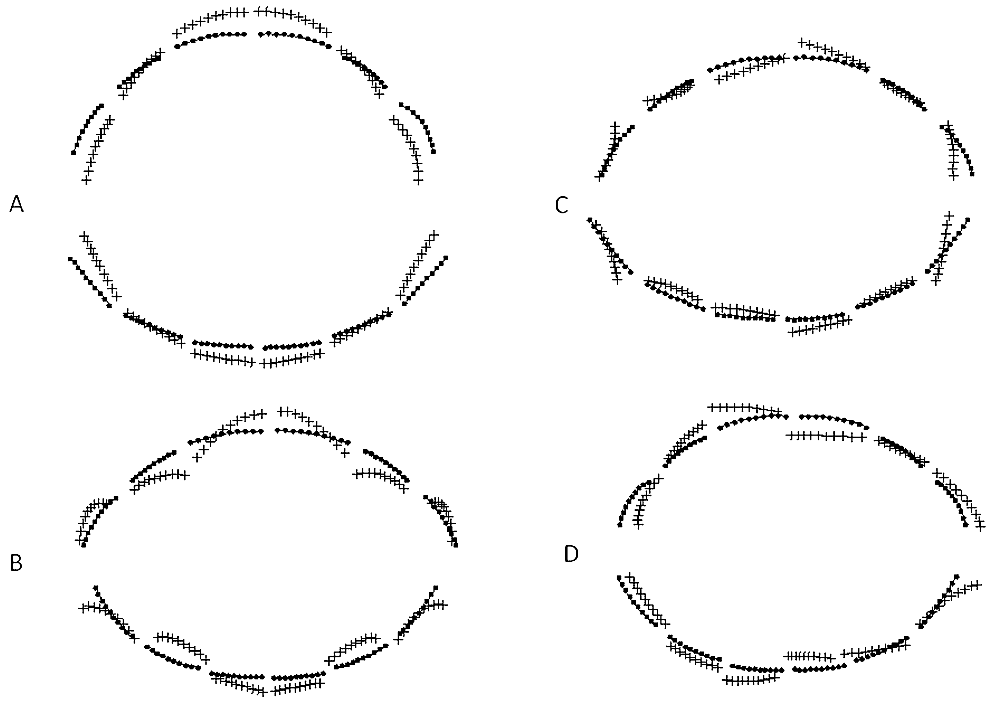

FIG. 5—*First four partial least squares axes (A–D), showing patterns of covariation in the maxillary and mandibular dentition (occlusal view with maxilla at top).*

TABLE 6—*Results of PLS analysis of maxillary and mandibular anterior dentition.*

PLS Axis	Percentage of Covariance	Pattern Implied by the Axis
1	65.4	A contrast between wide and narrow arches
2	7.2	Strong labial displacement of both central incisors of both the upper and lower dentition
3	5.0	Strong left–right asymmetry pattern
4	4.3	Opposing tilts of the central incisors and lateral incisors of both maxilla and mandible, and minor amounts of rotation of the canines

PLS, partial least squares.

Note that the descriptions are stated in terms of positive scores, negative scores simply reverse the pattern.

so that the incorporation of size information is important in this data set, although the contribution of size is not as dominant as one might initially expect. This indicates that the counterintuitive increase in match rate discussed earlier was probably simply a chance event because of the very low probability of matching. This table also indicates that match rates rise rapidly, a 25% increase in the measurement error resulted in a change from two matching individuals to 246 under Procrustes and from four to 144 under Procrustes-SP. This indicates that small changes in measurement resolution are critical to the ability to discriminate between specimens in this data. A 25% increase in measurement error has dramatically limited the ability to distinguish individuals from one another.

The arch widths seen in this data set appear similar to those reported elsewhere (31,32). The correlation of the less familiar centroid size with the commonly used arch width is relatively high in both the maxilla and the mandible (Table 4). These results are reported largely to help characterize this data set, allowing comparison with data sets in other studies. Neither arch width nor centroid size correlates well between the maxilla and the mandible. Not surprisingly, the coefficient of variation in the mandible was higher than in the maxilla for both arch width and centroid size, reflecting the higher structural variance in the mandible. Centroid size also displayed less variability (based on the coefficient of variation) than appears in the arch width. Centroid size incorporates all 60 landmarks in the study, averaging out localized variation, while arch width uses only two, so that tilts or malalignments in the canines contribute additional variation to this size measure.

Correlation of arch width or centroid size between the upper and lower dentition was small. This effect may be because the measurements are all along the incisal surfaces of the six anterior teeth, which is simply not capturing enough information about the dentition as a whole to see the expected strong size correlation. Studies comparing whole dentition patterns with those seen here on the anterior dentition might prove quite informative. Correlation of centroid size with the measured arch width was much higher, indicating that both measures of size were reflecting highly similar differences in the population.

The results of the PCA and PLS analysis were readily interpretable and appeared to indicate general patterns in the population, suggesting that the sample size was large enough that stable patterns (beyond the first and second PCA axes) were emerging in these analyses. Thus, the large sample size in this study produced PCA and PLS axes that may be interpreted very cleanly as distinct patterns of dental characteristics and malalignment patterns. At smaller sample sizes, one or more outlier specimens may heavily influence one or more of the PC or PLS axes. The patterns in both PLS and PCA are straightforward and simple to interpret because of the limited influence of outliers in such a large data set. The first PCA and PLS axes both show the contrast between relatively wide and narrow arches and indicate that this is the dominant shared pattern between maxillary and mandibular incisal edges. Interestingly, this pattern is large percentage of covariation (65.4%) but a lesser percentage of variation in the mandible (54%) and particularly in the mandible (39.8%). This seems to indicate that the two arches strongly share an overall pattern of wide or narrow structure, but other characteristics are not as strongly shared between the two, as the percentage of covariance explained by subsequent PLS axes drops more rapidly than the percentages of variance along the PCA axes do.

In conclusion, precise dental shape measurement of a large population permits conclusions concerning shape variation and match rates to be drawn. An earlier study showed the principal variation in multiple bitemarks inflicted with the same dentition on cadaver skin was in arch width and that size of bitemarks varied by a range of roughly 24% (13). The dramatic increase in match rate encountered when measurement error was increased by a similar amount in this study must be considered a cautionary finding for investigators seeking to make statements of individualization to a "reasonable degree of dental certainty."

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Texas Forensic Science Commission
Bite Mark Investigation Panel
November 16, 2015

Empirical Research

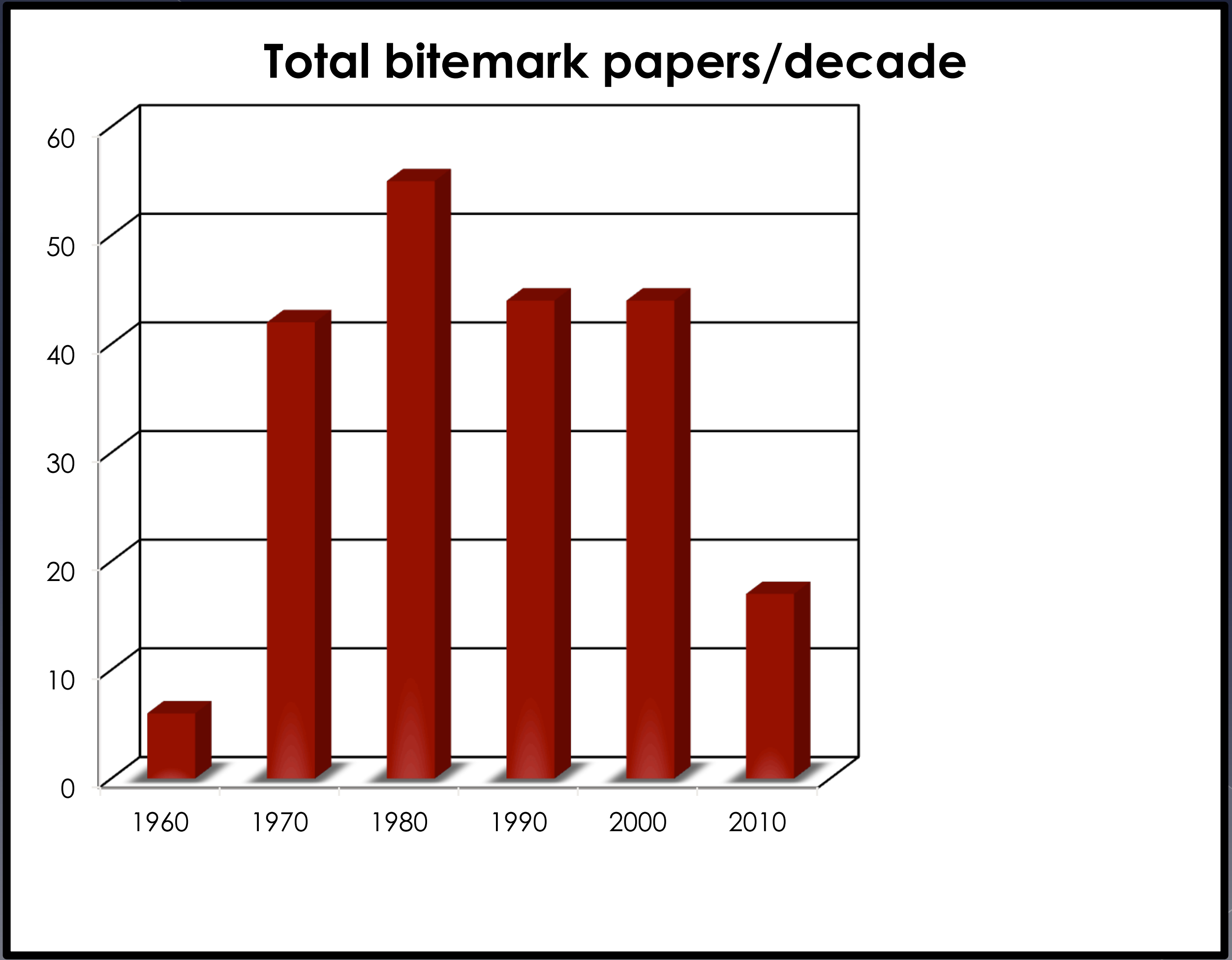
- Peter J. Bush *
- Mary A. Bush

SUNY at Buffalo

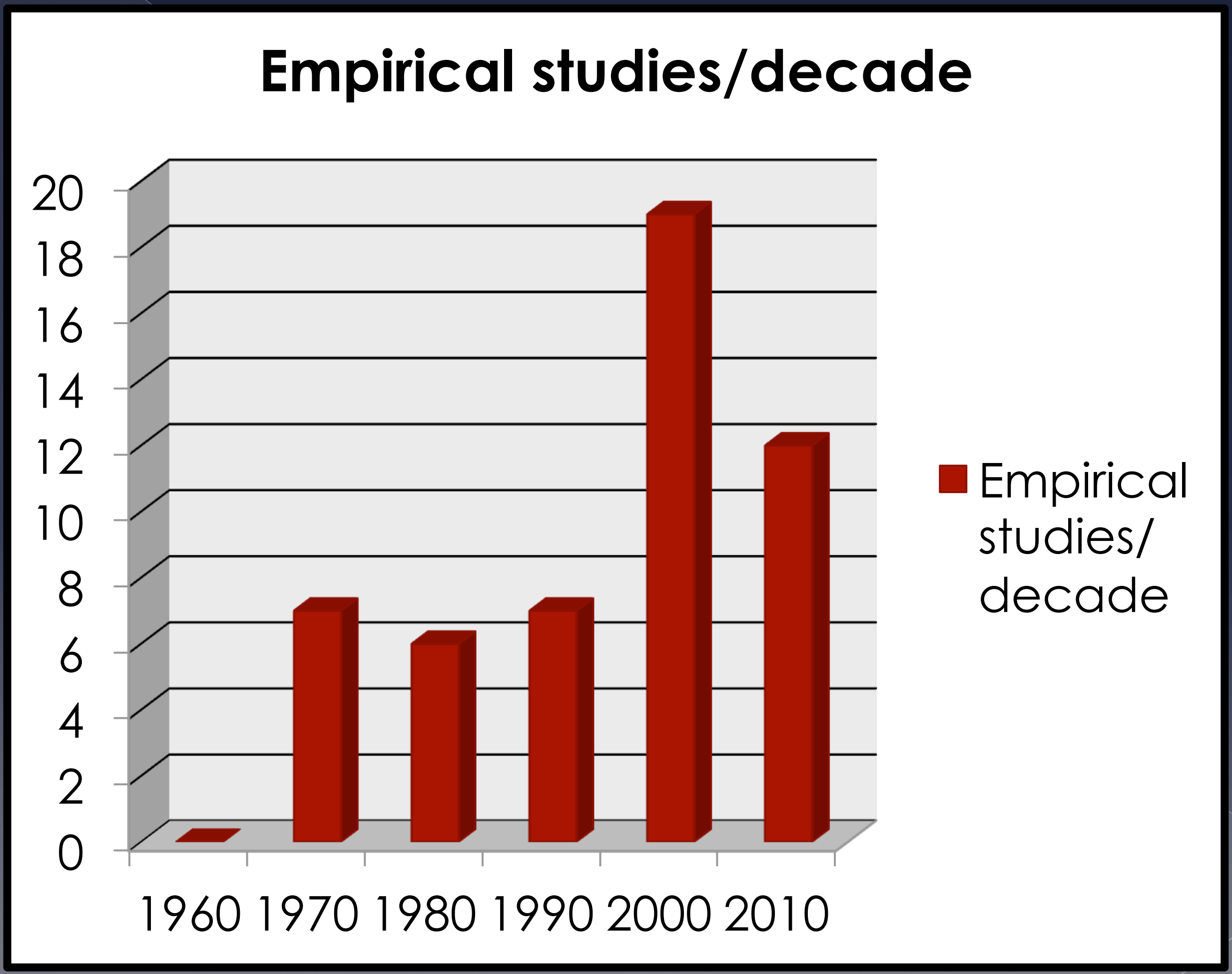
Premises of bitemark comparison

- The arrangement of the biting surfaces of the front teeth is unique
- Skin accurately records this dental pattern
- Reliable Identification can be made

Scientific Literature



Scientific basis



Scientific Basis?

- No scientific studies support the validity and reliability of bitemark analysis
- Most heavily criticized in the 2009 NAS report
- Foundational premises remain unproven

Early studies in skin

- Devore 1971 - distortion in skin
- Harvey 1973 - distortion in skin
- Whittaker 1975 - distortion in skin

DeVore 1971

- 1971 DeVore DT. Med Sci Law; 11(3):144-5 Bitemarks for identification? A preliminary report.
  - Placed ink marks on living volunteers
  - Photographs were taken in several body positions.
    - 60% linear expansion
  - Paper concludes there is a large margin of error using bitemark photographs and unsecured excised skin.
  - The exact position of the body when bitten must be known and replicated

DeVore 1971

- *"Techniques where comparisons are made by measuring spaces, teeth widths, arch curvature etc. on models of the alleged assailant and comparing them by any superimposition technique to size and shape of photographs taken of bite marks on the victim have been shown by this study to be invalid."*

Study replicated Oct 2015

Harvey 1973

- 1973 Harvey et al. Int J leg Med; 1973;(8):3-15. Bite-marks the clinical picture; physical features etc.
  - Discussed stress/strain curve for skin.
    - "Both the directional variations in skin properties and their alteration on movement have serious implications in bitemark matching"
  - biting experiment on live volunteer with tissue samples taken for histological evaluation.
    - Appearance of the bites changed dramatically within the first 24 hrs
  - *Found that each bite, though made by the same person, looked different!*

Whittaker 1975

- 1975 Whittaker DK. Int Dent J; 25(3):166-71 Some laboratory studies on the accuracy of bitemark comparisons.
  - Compared pig and wax bites
  - Found that pig skin bites were less reliable than wax in terms of biter identification.

Whittaker 1975

- 1975 Whittaker DK. Int Dent J; 25(3):166-71 Some laboratory studies on the accuracy of bitemark comparisons.
  - 25% of bites could not be correctly identified even under ideal laboratory conditions immediately after the bite
  - 1 hour after biting the accuracy fell further to 35% and after 24 hours to 16%

Whittaker 1975

- "It may be that bitemarks in human flesh are more readily matched with a suspects teeth than those in the skin of a pig but it appears likely that variations in quality of bite, variations in tissue bitten, and subsequent bruising and oedema would render bitemark comparisons an unsatisfactory means of identification in many cases"

LT Johnson, DDS

Replication of Known Dental Characteristics in Porcine Skin: Emerging Technologies for the Imaging Specialist

NIJ 2010-DN-BX-K176
Award period October 1, 2010 – September 30, 2013

Award amount, $715,000, three year period

LT Johnson, DDS

- 50 dentitions, 4 bites each on 25 pigs, 200 bites
- Only 50% of bitemarks made were of sufficient quality for analysis
- Measured position of four front teeth in bitemarks
- Compared to measurements of 469 dental models

LT Johnson, DDS

Conclusion of $715,000 study

In more than 20% of the Samples in this study, the Distance Metric Model found the Target within the closest 5% of the sample population. In more than 6% of the Samples, it found the Target within the closest 1% of the Population.

LT Johnson, DDS

Conclusion of $715,000 study

In other words, 80% of the bites were not close to the biting dentition.

94% of bites could not be matched within 1% of the biting dentition.

LT Johnson, DDS

Conclusion of $715,000 study

- The largest and most expensive bitemark study yet performed on living organisms *shows that bitemark analysis is notoriously unreliable*.

Models

- Cadaver model: HSIRB restrictions
  - Proper anatomical form
  - Biomechanical properties retained for some time
  - Cadaver models used for over 150 years as model for this type of testing
    - Well established model, extensive literature base

  Examples: skin, connective tissue research, biomedical engineering dermatology, plastic surgery

Discussion

- It is acknowledged that experimentation on cadavers results may be different than on live skin
- HSIRB restrictions may mean that aspects of bitemarks may never be analyzed on the living

Cadaver

Living subject

Exhibit M

- Biomechanical factors in human dermal bitemarks in a cadaver model. Bush MA, Miller RG, Bush PJ, Dorion RBJ. J Forensic Sci. 2009; 54(1):167-76.
- Accepted May 2008

Skin Literature

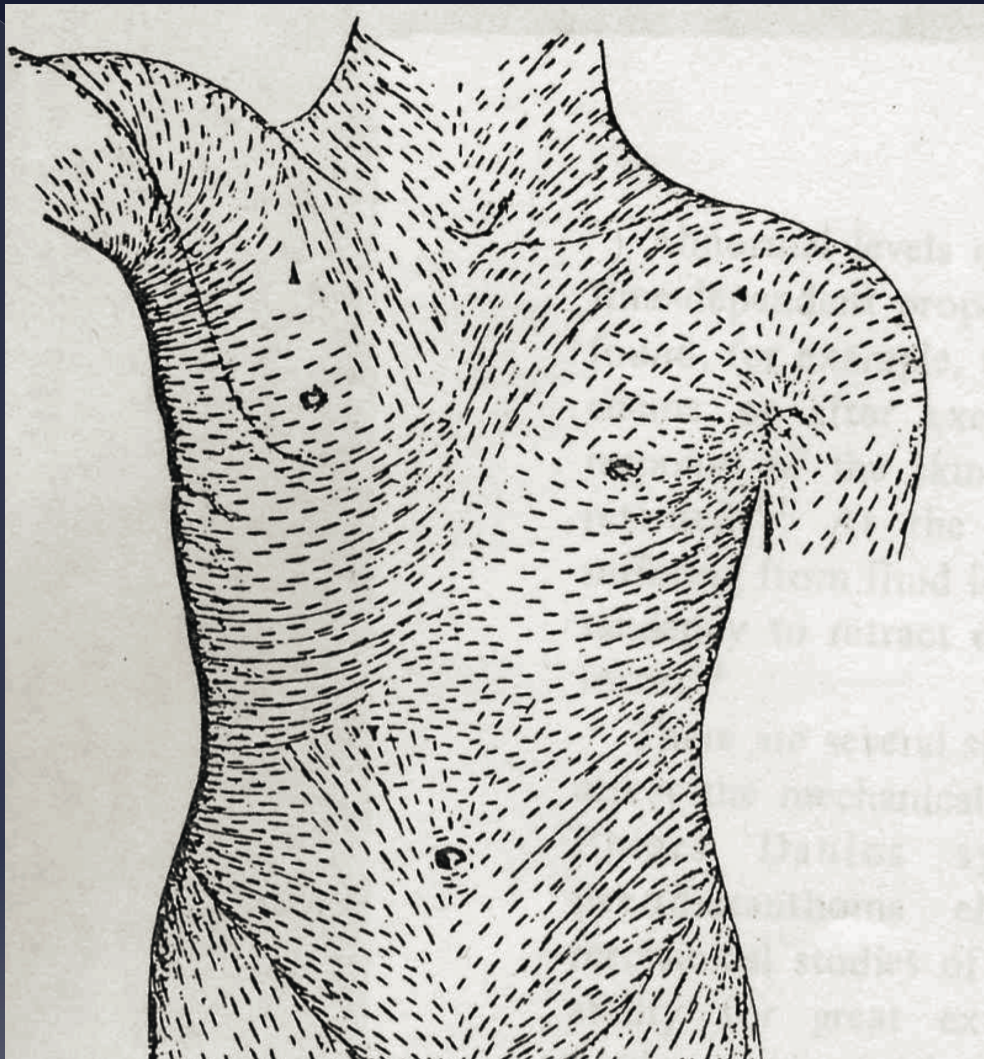
- Skin properties
  - Visco-elasticity
  - Anisotropy
  - Non-linearity
  - Hysteresis

Visco-elasticity

- Elastin
- Collagen
- Ground Substance

Anisotropy

- Directional variation in skin
- Dictated by skin tension lines
- Alters with movement
- Described by Karl Langer---Langer Lines



Karl Langer 1861

Courtesy of: Langer, K. On the anatomy and physiology of the skin. I. The cleavability of the cutis.

Perpendicular to tension lines

Parallel to tension lines

Empirical research

Observation and Results:

- No two bites were identical in appearance
- Not measurably the same – metric study
- Marked variations seen
- Anisotropy was a determinant factor in distortion

Distortion Range in skin

- Measured ranges -
- Tooth width: 34%
- Jaw width: 51%
- Angulation: 161%

Reasonable conclusion

- Based on measurements and observation using a new model
- Confirms Harveys 1973 observation

Exhibit L

- Uniqueness of the dentition as impressed in human skin: A cadaver model. Miller RG, Bush PJ, Dorion RBJ, Bush MA. J Forensic Sci 2009; 54(4):909-14.
- Accepted Oct 2008

Hypotheses

- If we make bites with specific dental alignments, can they be distinguished?
- Can other dentitions appear to “fit” better?

Methods

- 100 models compared to bitemarks
- Only lower jaw bite impressions analyzed
- Dental shapes grouped into common alignment patterns
- Bites compared within groups and to all models

Results

- Multiple false positives and false negative matches found
- Dental 'lineup'

NAS REPORT:

(2) The ability of the dentition, if unique, to transfer a unique pattern to human skin and the ability of the skin to maintain that uniqueness has not been scientifically established.

Results

Numbers of models that "fit" the indentation

bite number	"Fit" within group	"Fit" all models
1	6 out of 7 (86%)	12 out of 100 (12%)
2	2 out of 9 (22%)	3 out of 100 (3%)
3	5 out of 10 (50%)	11 out of 100 (11%)
4	8 out of 12 (75%)	16 out of 100 (16%)
5	5 out of 8 (62%)	7 out of 100 (7%)
6	1 out of 9 (11%)	6 out of 100 (6%)
7	6 out of 8 (75%)	12 out of 100 (12%)
8	4 out of 21 (19%)	4 out of 100 (4%)

Exhibit J

- The Response of Skin to Applied Stress: Investigation of Bitemark Distortion in a Cadaver Model. Bush MA, Thorsrud K, Miller RG, Dorion RBJ, Bush PJ. J Forensic Sci 2010;55(1):71-6.

- Accepted Jan 2009

Hypotheses

- At a specific force/unit area, skin should lacerate
- Knowing the laceration force, we should be able to make some statement about a given bitemark

Methods

- 4 sets of models from 1 individual:
  - Measured force
  - teeth systematically removed, varying stress
  - Force needed to lacerate the skin
- 46 bites perpendicular to tension lines

Results

- Bite appearance unpredictable
- Laceration unpredictable
- Missing teeth appeared in bitemark
- Tissue type important variable


ABFO No. 2©

Exhibit K

- Bitemark Profiling and Arbitrary Distortion Compensation Examined: Inquiry into Scientific Basis. Bush MA, Cooper HI, Dorion RBJ. J Forensic Sci 2010; 55(4):976-83.

Hypotheses

- Given current data, is it reasonable to profile a biter?
- Is it possible to predict a dental arrangement?
- Is it correct to make global scale alteration to correct distortion?

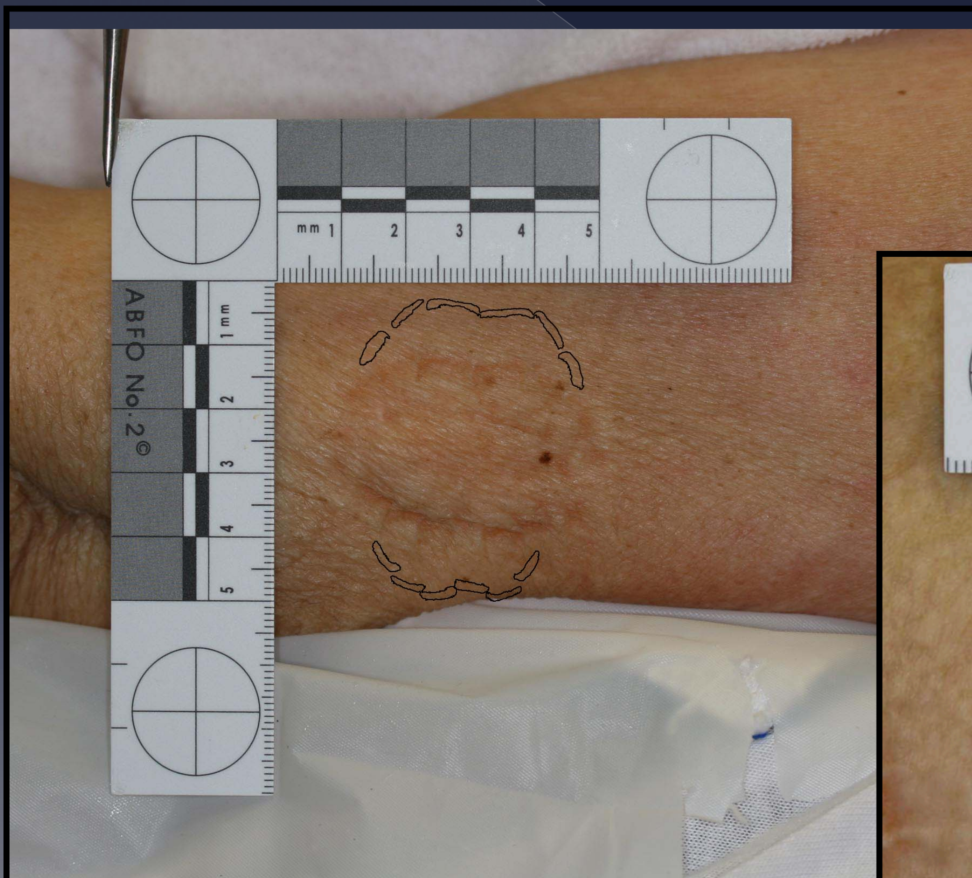
Results

- In a significant number of bites, misleading features were evident
- Universal distortion correction is not viable

Discussion

- Stipulating in advance what may/may not be present in a perpetrator's dentition can lead to
  - Bias
  - Inaccurate scenario account
  - Misdirection

Distortion in skin



- Of the 66 bites, 25 (38%) showed a feature or combination of features that could be misleading if profiled
- Global distortion correction cannot be made *because skin is anisotropic*

Type of Distortion Pattern	Number
Flattening of the Arch	6
Constriction of the Arch	5
Significant deviation in overall alignment	4
Missing tooth appears in the bite	3
Significant rotation of teeth	2
Significant buccal/lingual displacement of teeth	2
Questionable orientation of bitemark	2
Diastema appears when no diastema is present in biter's dentition	1

Science advances in increments

- Measurement of dental arrangement
- The Question of Dental Uniqueness

Uniqueness studies

- Rawson 1984 - uniqueness of the dentition
- Keiser 2007 - uniqueness of the dentition

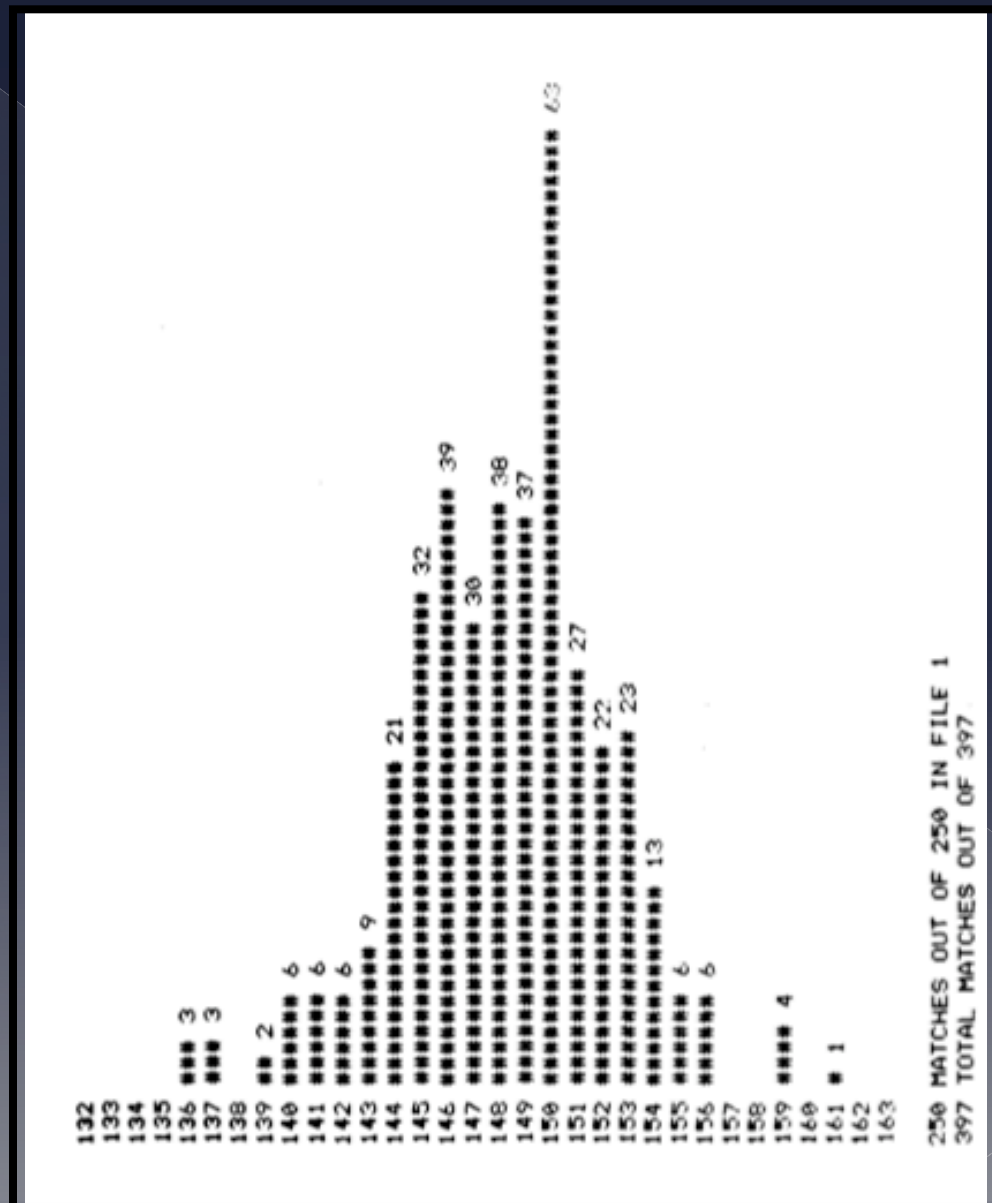
Rawson 1984

- Statistical evidence for the individuality of the human dentition. Rawson RD et al. 1984J Forensic Sci 1984;29(1):245-53
  - Used a single center point and angle to represent tooth position
  - Measured 397 dentitions

Rawson 1984

- Assumed no correlation of tooth position
- Assumed that tooth positions are evenly distributed
- Used the product rule to calculate probability
- Did not report any matches

X-axis centerpoint of tooth #6



Rawson 1984

- "The probability of finding two sets of dentition with six teeth in the same position….is 1.4 x 10 to the 13th."
- "This mathematical evaluation of a general population sample *demonstrates the uniqueness of the dentition beyond any reasonable doubt…*"

Exhibit F

- Statistical Evidence for the Individuality of the Human Dentition. Rawson RD et al 1984.J Forensic Sci 1984;29(1):245-53
- Statistical Evidence for the Similarity of the Human Dentition. Bush MA, Bush PJ, Sheets, HD. J Forensic Sci 2011; 56(1):118-123.

Hypotheses

- Can matches be found in populations?
- Was Rawson’s methodology sound?

Methods

- Two separate datasets (lower jaws):
  Set 1, N = 172,
  Set 2, N = 344
- Measured as per Rawson: x, y and angle
- Resolution +/- 1mm, +/- 5 degrees
- 14,706 and 58,996 pairwise comparisons

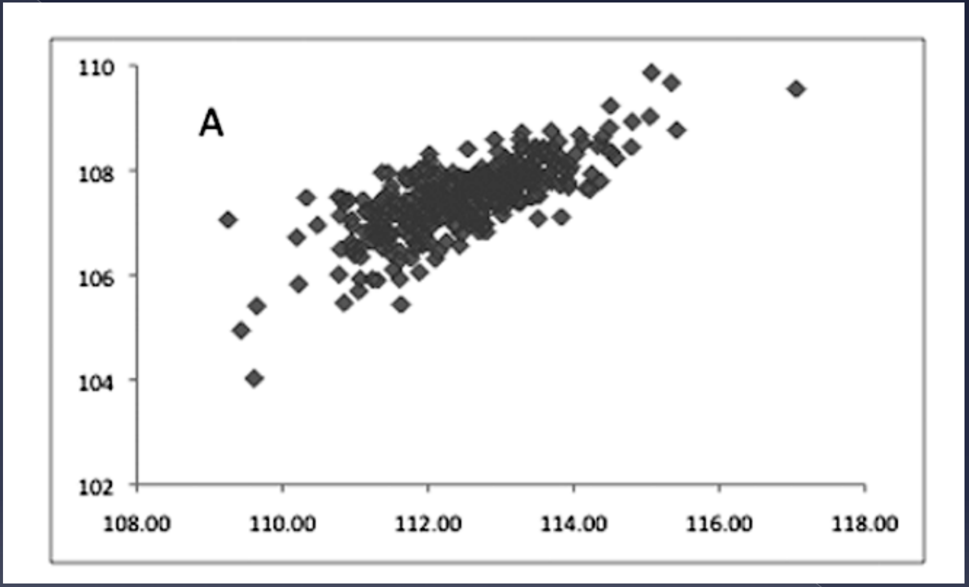
Results

- Found matches in the two datasets:
- 7 in N = 172, 4.0%

  16 in N = 344, 4.6%

Low but significant match rate

Correlation of tooth position:
X-position of #22 vs #23



If the x position of 22 is high, it is probable that 23 is also high:

Correlation 0.75

Conclusion I

- Tooth positions are correlated
- The position of one tooth is highly suggestive of it’s neighbor
- The product rule is not applicable

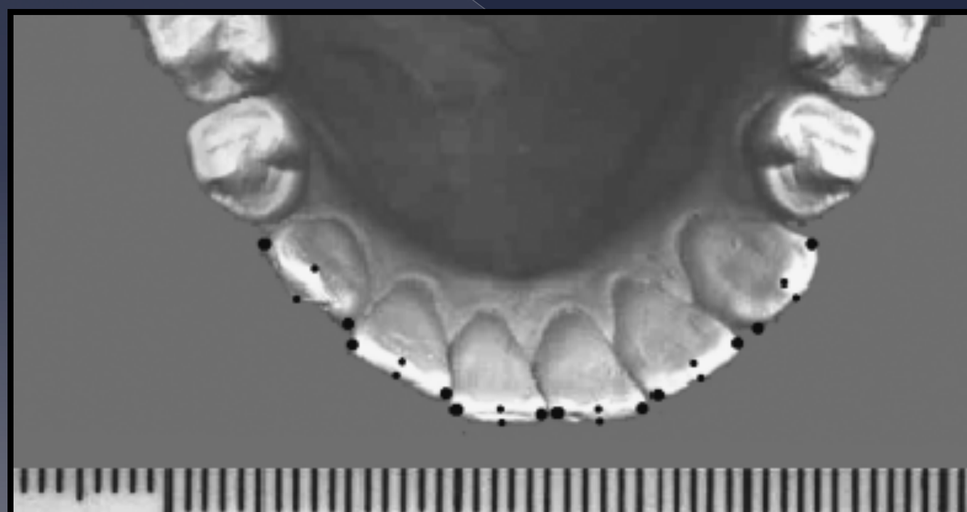
Conclusion II

- Tooth positions are not uniformly distributed
- They cluster around the mean
- Most people have similar dental shape

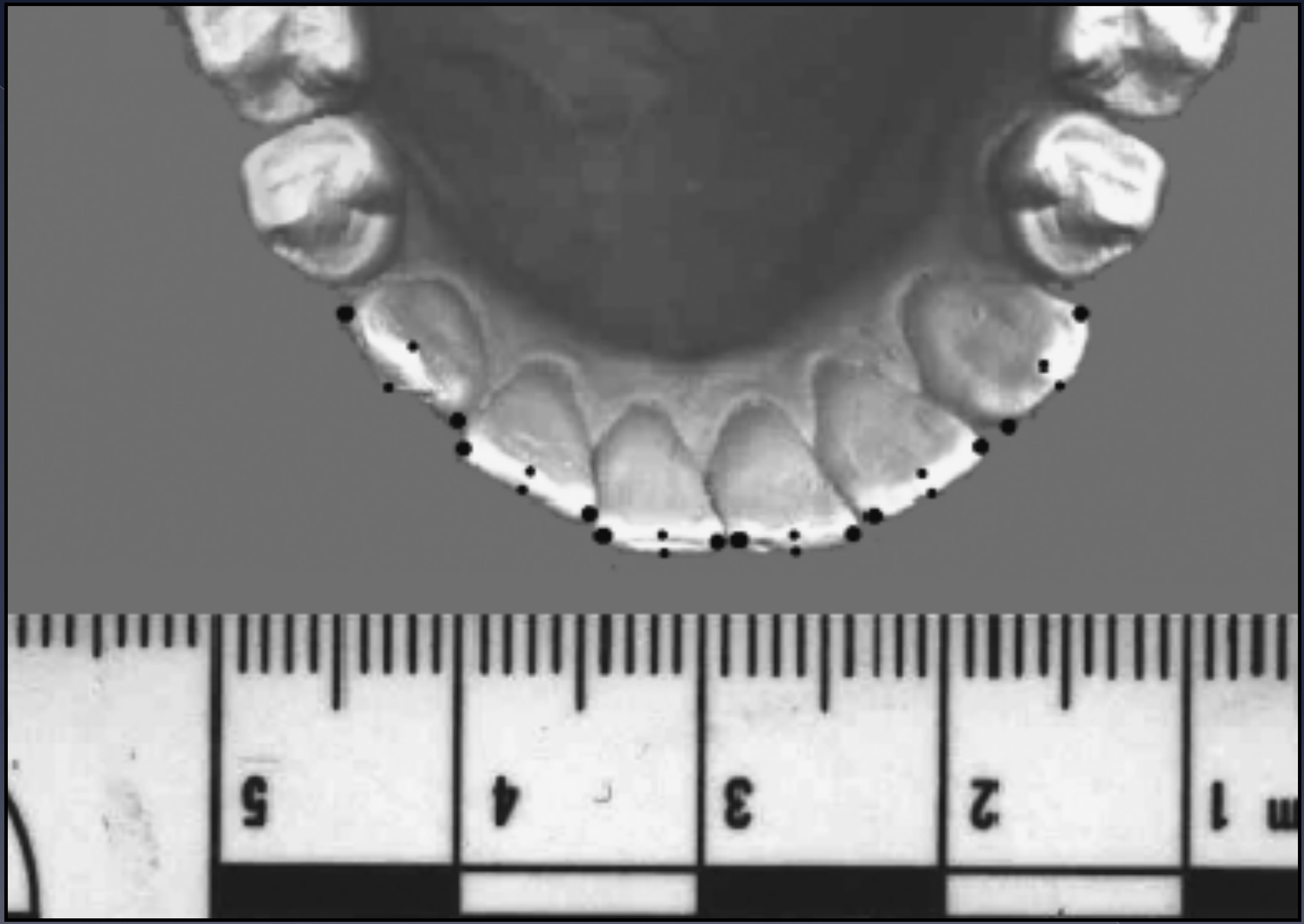
Jules A. Kieser,[1] Ph.D.; Valeria Bernal,[2] Ph.D.; John Neil Waddell,[1] M.Dip. Tech.; and Shilpa Raju,[1] BDS

The Uniqueness of the Human Anterior Dentition: A Geometric Morphometric Analysis

Kieser, 2007, used freeware to place *landmarks* describing the anterior teeth

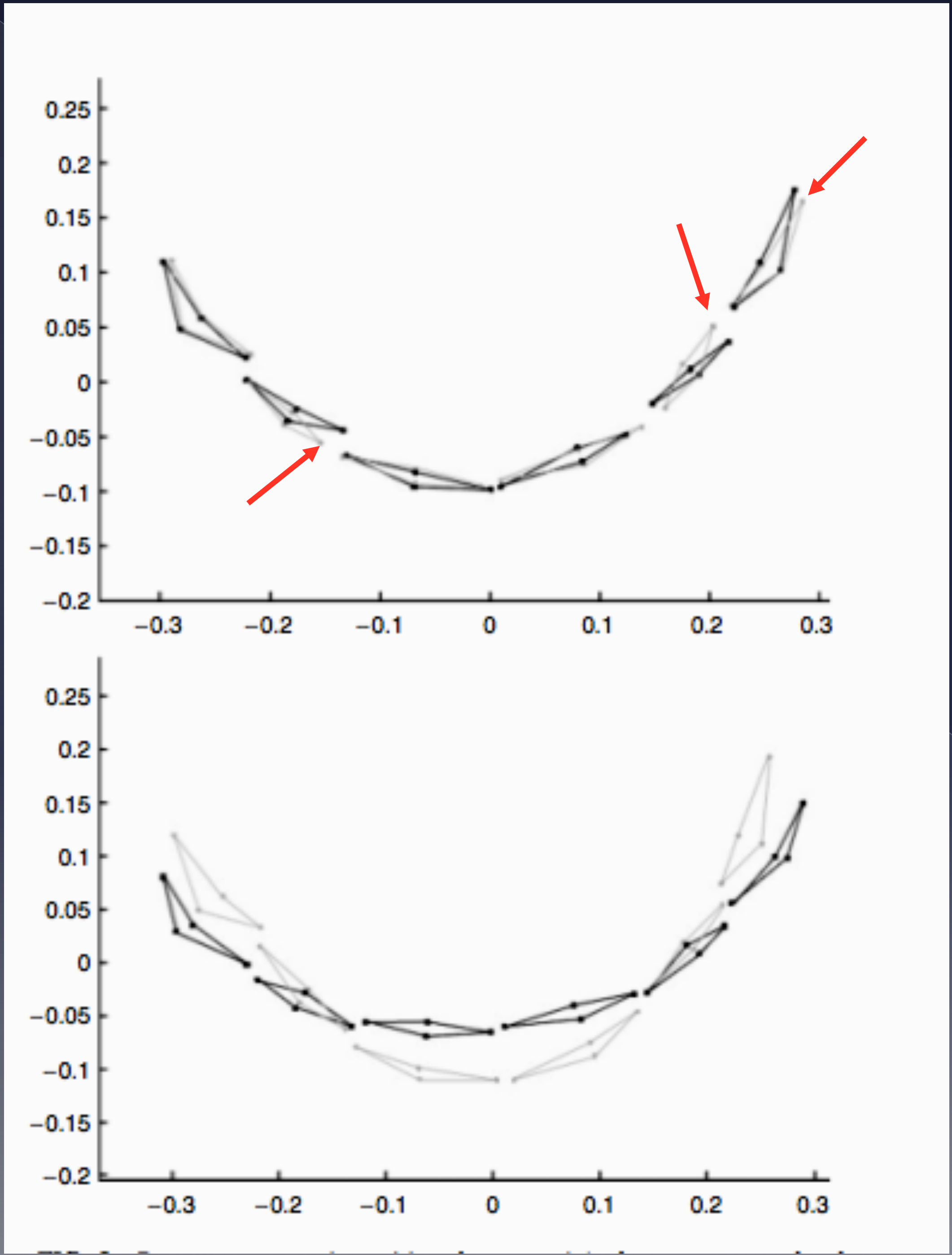


Kind permission,
JA Kieser



Orthodontically treated, 33 maxillas, 49 mandibles

Kind permission,
JA Kieser



Kieser, Maxillas, N=33.
Two most similar, two most different.

"our study supports the notion of the individuality of the…dentition"

Kind permission, JA Kieser

Kieser 2007

- Small Population
- Did not report measurement error
- Semi-landmarks were not useful in describing tooth arrangement

Kieser 2007

18. Sheets HD, Keonho K, Mitchell CE. A combined landmark and outline-based approach to ontogenetic shape change in the Ordovician Trilobite *Triarthrus becki*. In: Elewa A, editor. Applications of morphometrics in paleontology and biology. New York: Springer, 2004:67–81.
19. Rohlf FJ. Relative warps analysis and an example of its application to Mosquito wings. In: Marcus LF, Bello E, García-Valdecasas A, editors. Contributions to morphometrics. Madrid: Monografías del Museo Nacional de Ciencias Naturales, 1993:132–59.
20. Rohlf FJ, Bookstein FL. Computing the uniform component of shape variation. Syst Biol 2003;52:66–9.
21. Sheets HD. IMP-integrated morphometrics package. Buffalo, New York: Department of Physics, Canisius College, 2003.

Exhibit G

- Dental Shape Match Rates in Selected and Orthodontically Treated Populations in New York State: A 2 Dimensional Study. Sheets HD, Bush PJ, Brzozowski C, Nawrocki LA, Ho P, and Bush MA. (July 2011). Journal of Forensic Sciences.

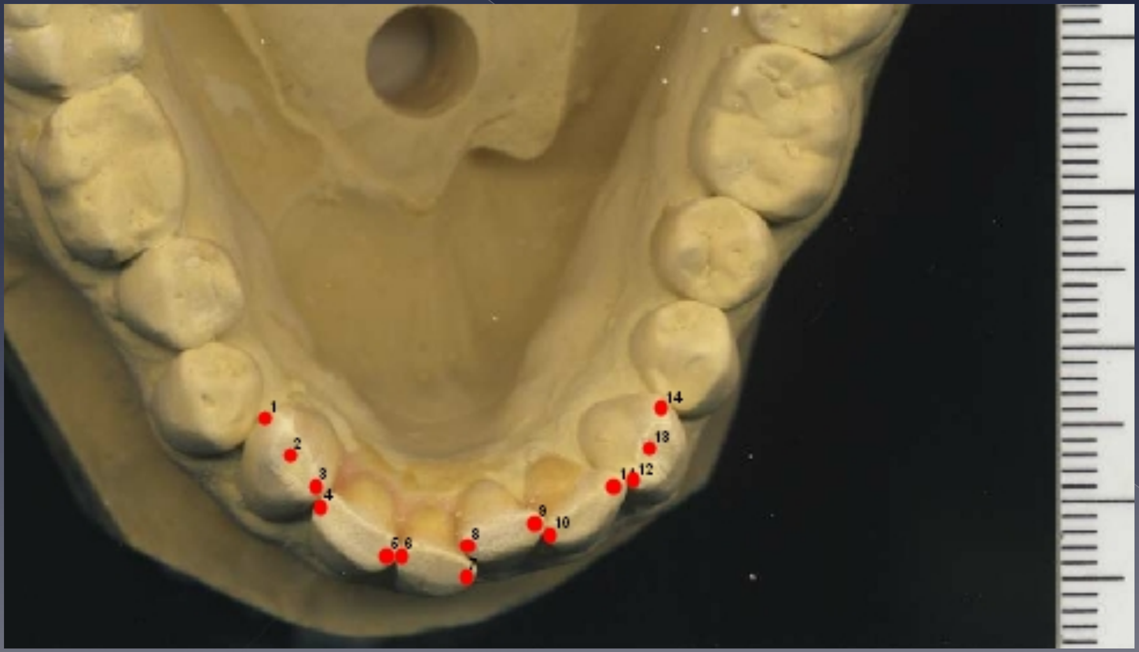
Exhibit G

- First author
- Sheets HD, Bush PJ, Brzozowski C, Nawrocki LA, Ho P, and Bush MA. (July 2011). Journal of Forensic Sciences.

Research team

Landmark placement

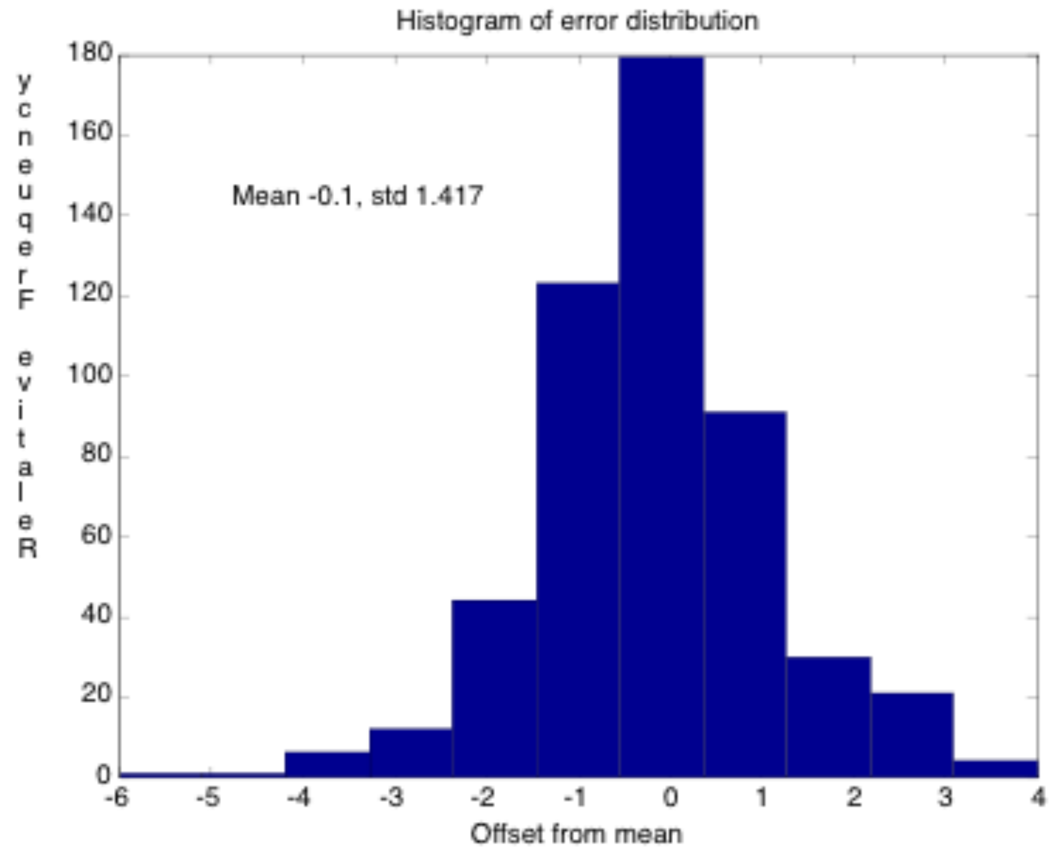
- 14 landmarks describe dental arrangement



Repeat Measures

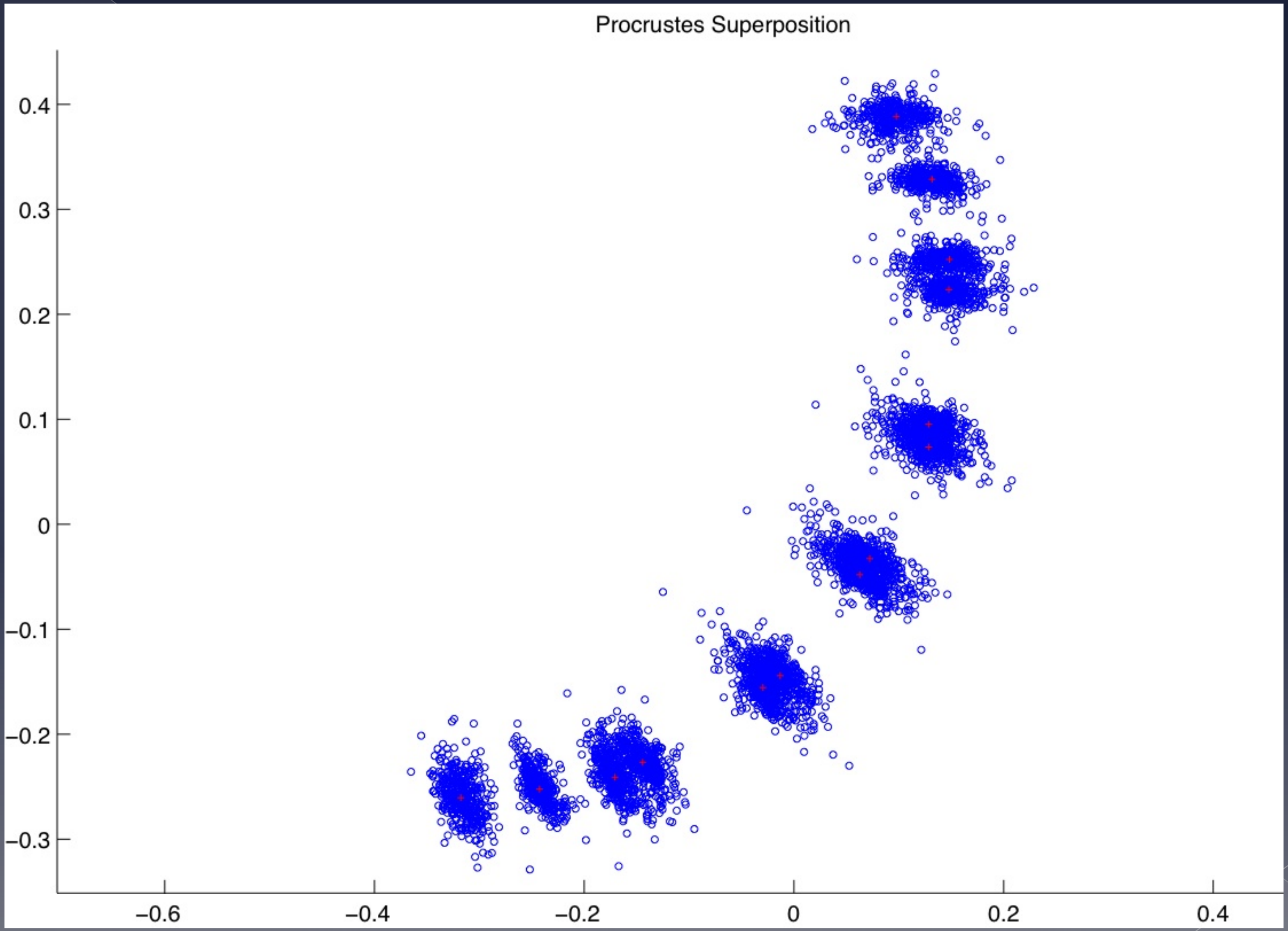
- Same specimen measured multiple times by same operator
- RMS scatter
- Determines measurement error
- Resolution of measurement

Std error (in pixels) : 1.417 (per LM)
Mean absolute value of error in pixels: 1.0 (per LM)
Var error (in pixels) : 2.0



Mean error of landmark placement
1.0 pixel, 85 microns

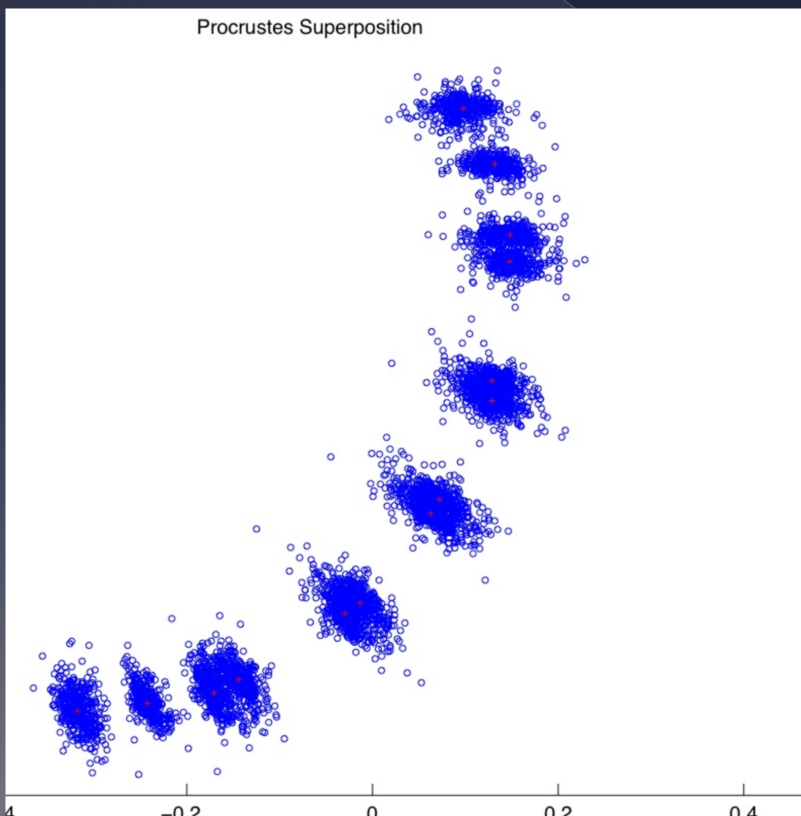
Dental shape match rates in large populations



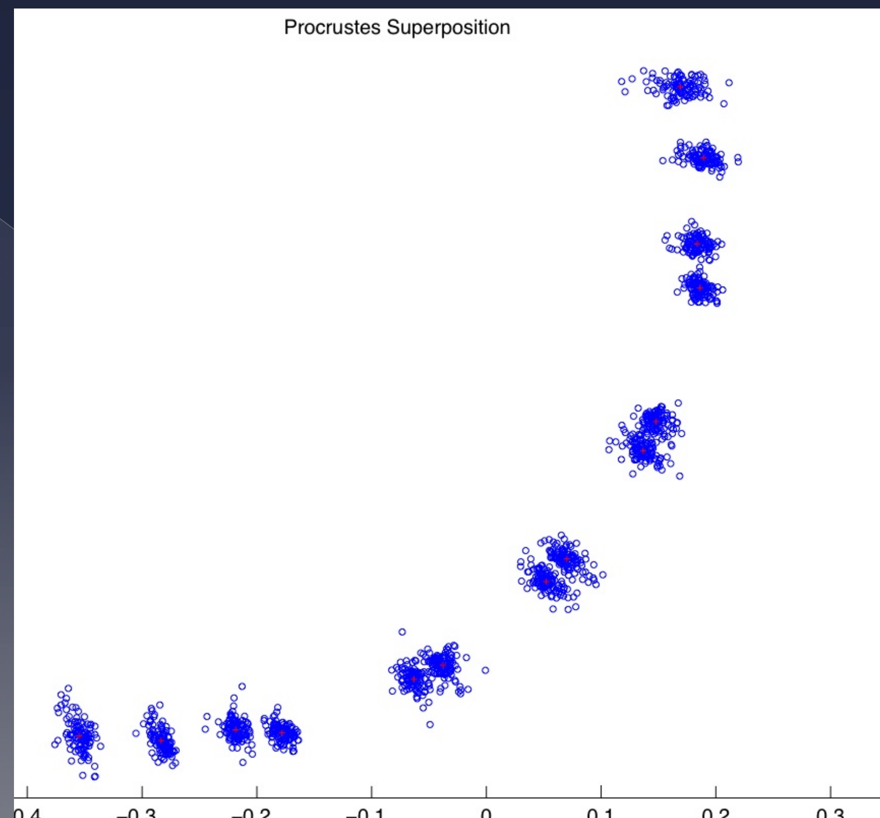
Procrustes superposition, N = 400

Ortho treated dentitions occupy tighter shape space as visualized by Procrustes Superposition

Non Ortho



Ortho



Procrustes distance

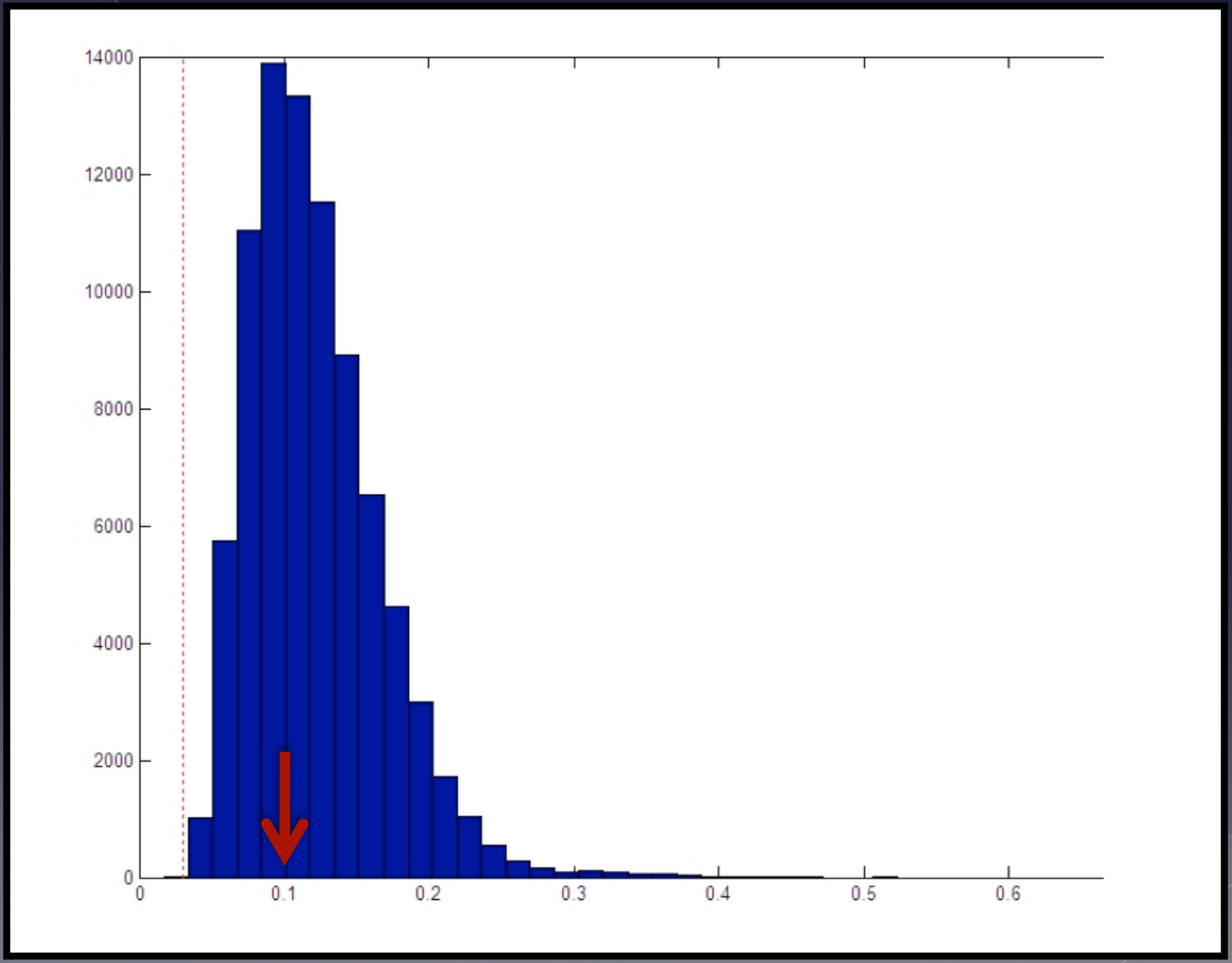
- Quantitative measure of shape similarity
- Similarity decreases as number increases in magnitude

We can search databases of collected specimens for *matches*

- A *match* is a pair of specimens who do not differ by repeated measurement error- they are within the experimental resolution.
- *Rawson et al*. Positions +/-1mm and angles within 5 degrees
- *Procrustes*- distances of 0.03 or less

Histogram: Procrustes distance

- General population

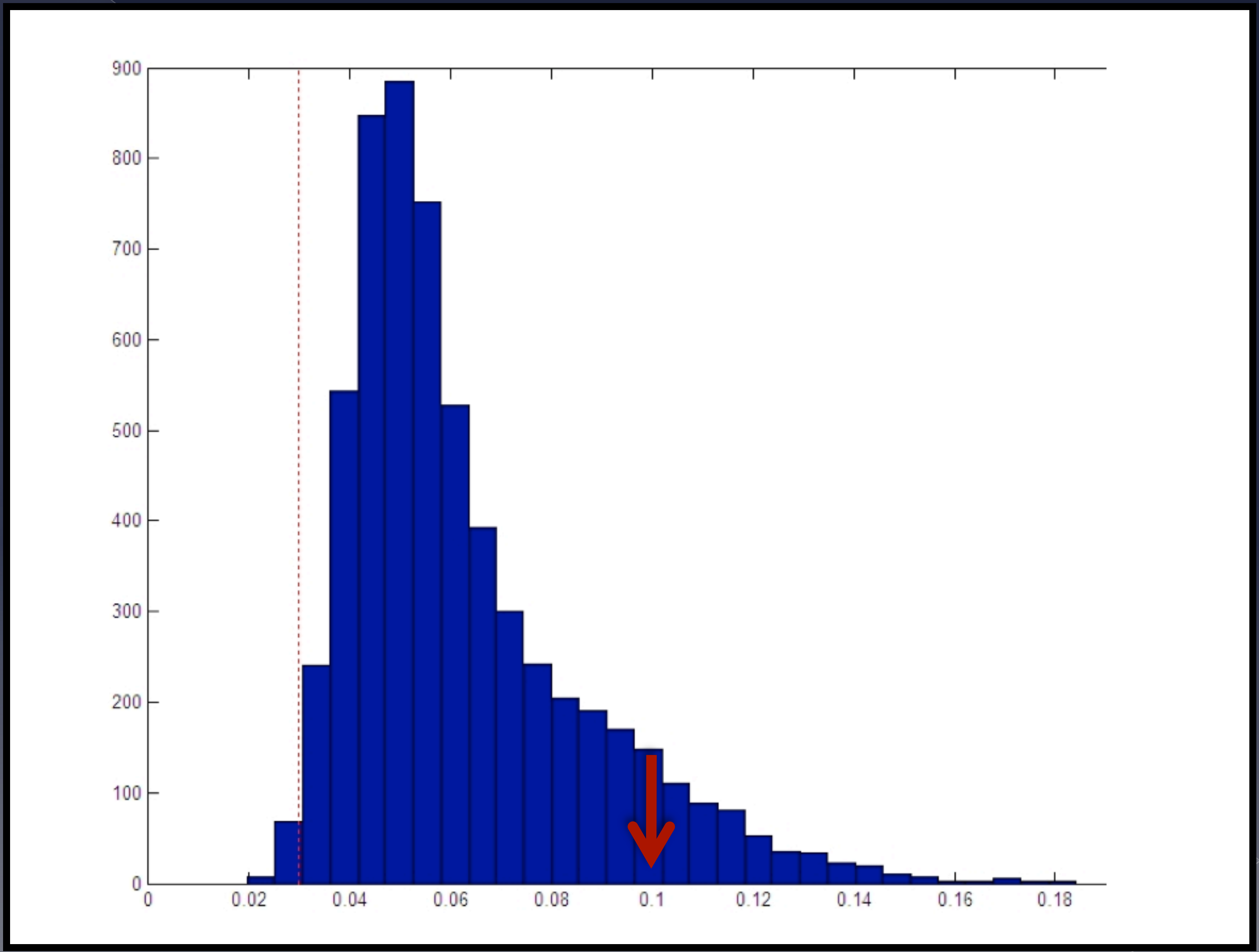


# of pairs

Similarity (Procrustes distance)

Histogram: Procrustes distance

- Ortho treated population



# of pairs

Similarity (Procrustes distance)

2011: Dental Shape Match Rates in Selected and Orthodontically Treated Populations in New York State: A 2 Dimensional Study. Sheets HD, Bush PJ, Brzozowski C, Nawrocki LA, Ho P, and Bush MA. (July 2011). Journal of Forensic Sciences.

- 2D GM method used, teeth represented by 14 mesial/distal landmarks
- General population n=410
- General match rate 1.46%
- Ortho population n=110
- Ortho match rate 42.7%

Research conclusion 1

- The front teeth do not have unique arrangements
- Matches exist
- As dataset grows in size, more matches will be found

Exhibit H

- Similarity and Match Rates of the Human Dentition In 3 Dimensions: Relevance to Bitemark Analysis. Bush MA, Bush PJ, Sheets HD. (Aug 2011) International Journal of Legal Medicine.

Hypotheses

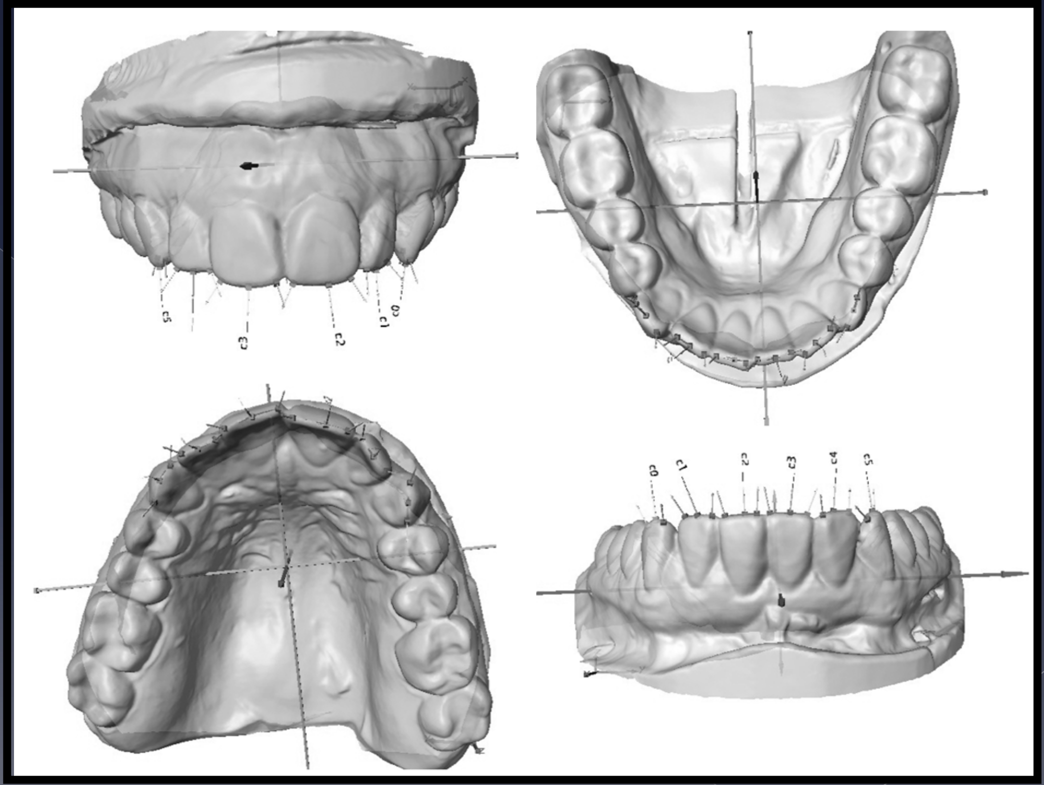
- Does match rate go down when including the 3rd dimension?
- Does the number of matches increase with database size?

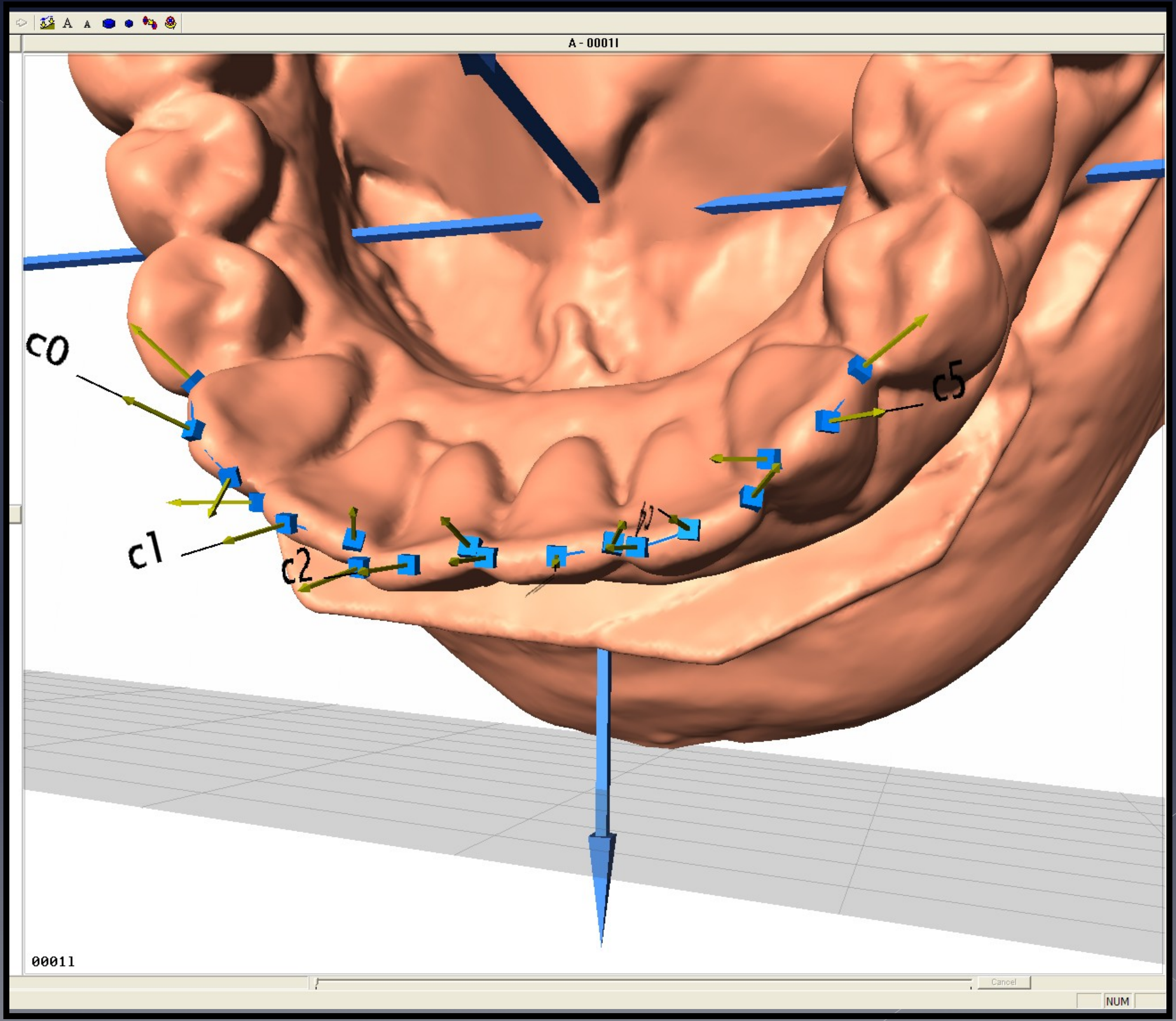
Methods and Materials

- Maxillary and Mandibular sets of 3D laser scanned models were collected
  - 497 Mandibular and 496 maxillary (matched sets)
  - Full complement of teeth canine to canine
- Resolution of the scanner is 100*um*

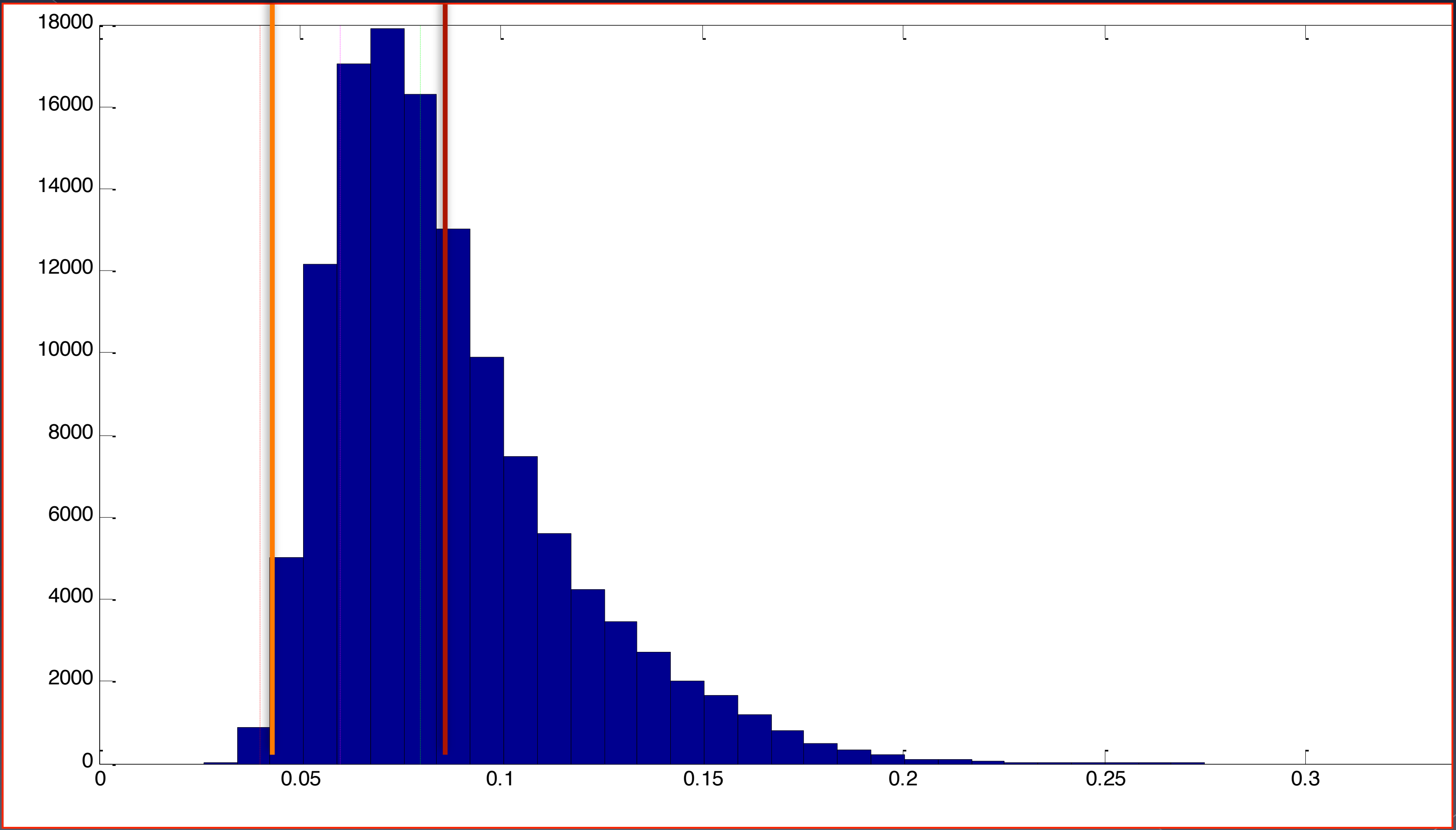
Methods:

- A wide range of information was recorded:
  - Mesial to distal width
  - Midpoints
  - Angulation
  - Incisal edge shape of each tooth
  - Mal-alignment patterns
  - Relative tooth heights and positions within the arch.




A - 0001l
c0
c1
c2
c5
00011
NUM

Results: maxillary



# of pairs

Similarity (Procrustes distance)

Out of 496 individuals, 197 had matches

122,760 pairwise comparisons (N(N-1)/2)

Results

- Match rate reduces in 3D

Results:Mandibular

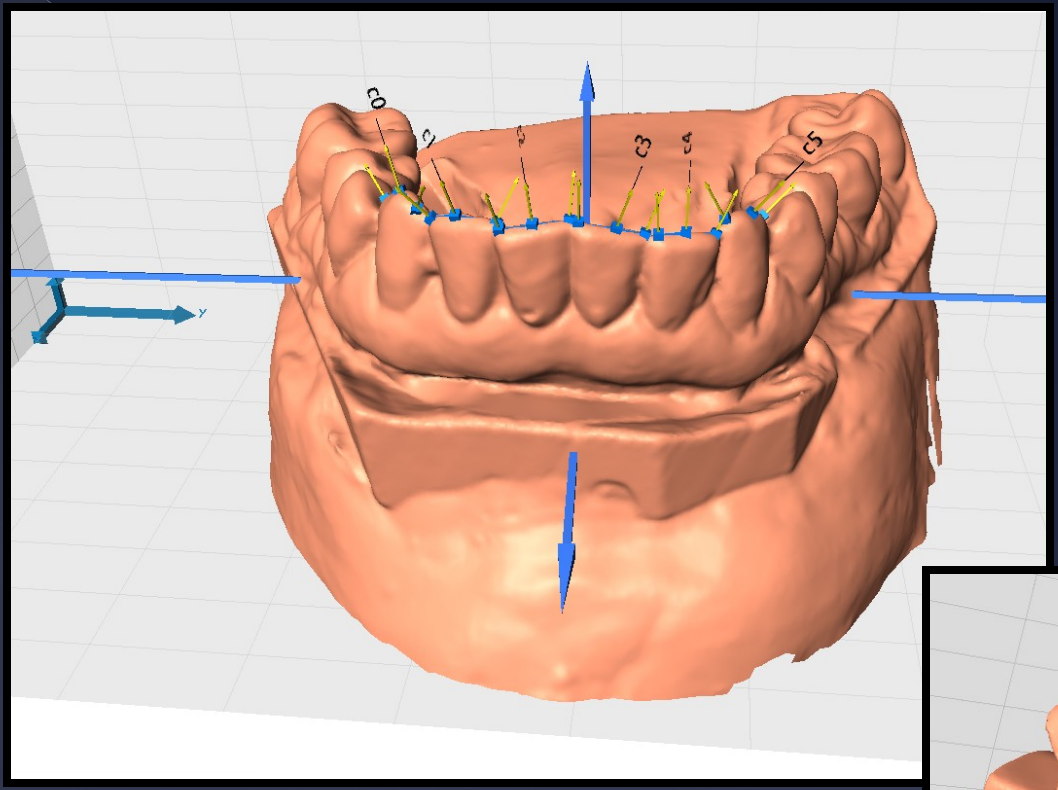
- 42 individuals: 1 match
- 5 individuals: 2 matches
- 3 individuals: 4 matches
- 1 individual: 6 matches

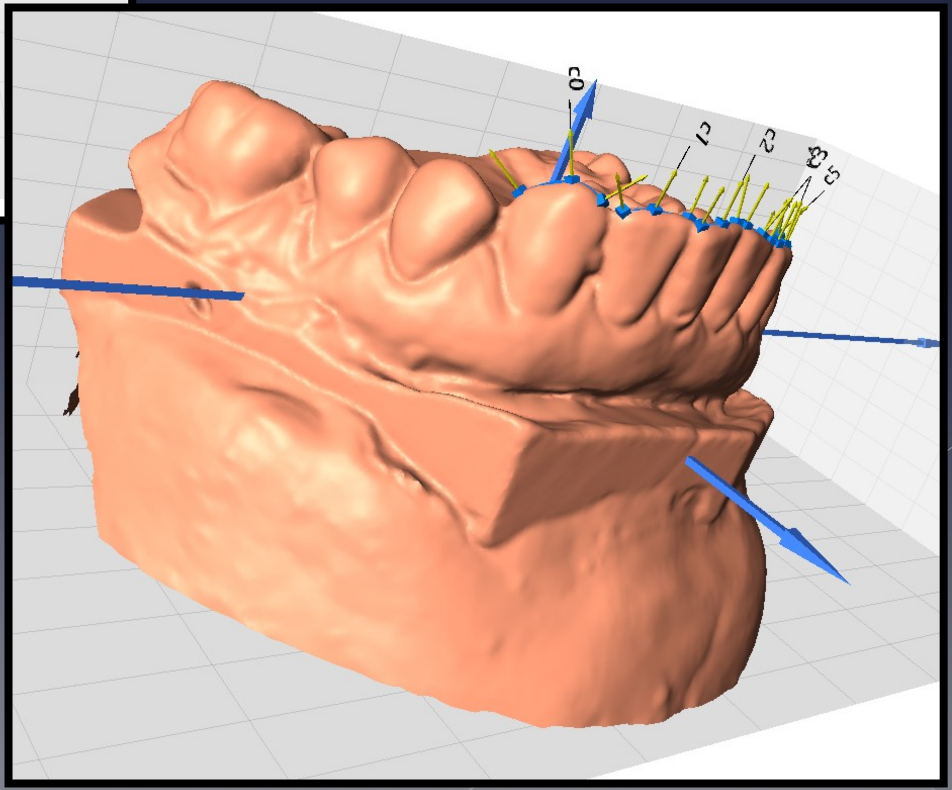
Results: Maxillary

- 117 individuals: 1 match
- 29 individuals: 2 matches
- 21 individuals: 3 matches
- 5 individuals: 4 matches
- 6 individuals: 5 matches
- 6 individuals: 6 matches
- 3 individuals: 7 matches
- 6 individuals: 8 matches
- 1 individual: 9, 11, 13, 16 matches

Exhibit ?

- Patterns of Variation and Match Rates of the Anterior Biting Dentition: Characteristics of a Database of 3D-Scanned Dentitions. Sheets HD, Bush PJ, Bush MA. (Jan 2013) J Forensic Sci, Vol. 58 No.1





1099 sets: Size and shape in 3D

Hypotheses

- What is the effect of including size?
- What is the match rate in a large population?
- What is effect of distortion on match rate

Results

- Including size reduces match rate
- Match rate did not geometrically increase with dataset size
- Probably due to specific population

Effect of Increased Distortion

			25%	50%	75%
	Matches	Individuals			
Maxilla	763	396			
Mandible	75	83			
Both	2	4			

Effect of Increased Distortion

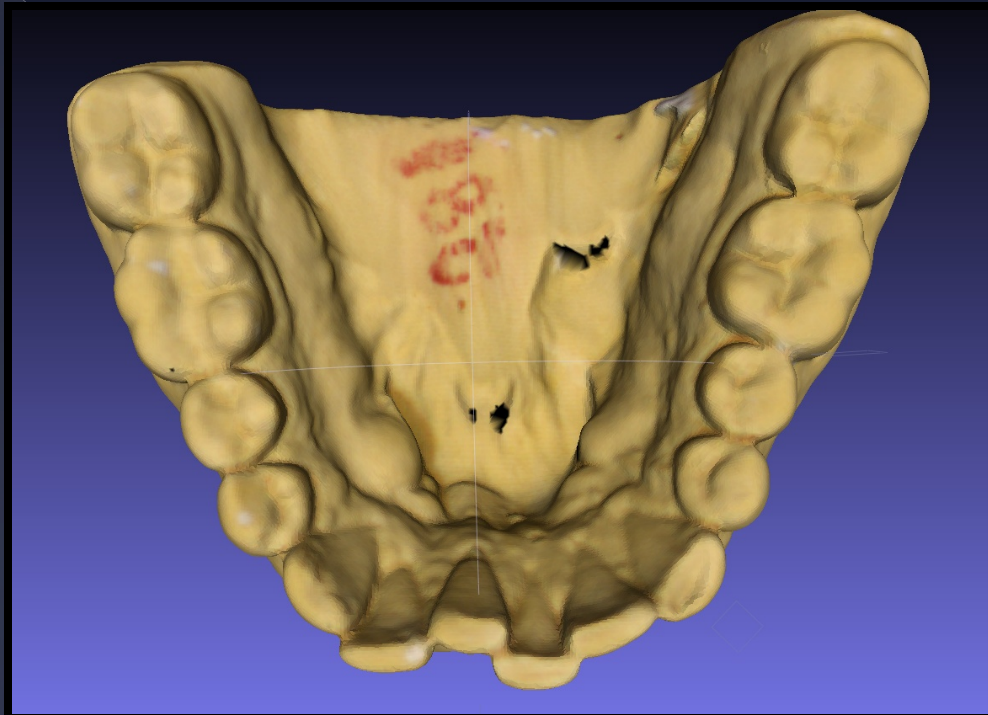
			25%		50%		75%	
	Matches	Individuals	Matches	Individuals				
Maxilla	763	396	9,660	826				
Mandible	75	83	1,658	451				
Both	2	4	166	144				

Effect of Increased Distortion

			25%		50%		75%	
	Matches	Individuals	Matches	Individuals	Matches	Individuals	[redacted]	
Maxilla	763	396	9,660	826	39,854	1001	[redacted]	
Mandible	75	83	1,658	451	9,510	759	[redacted]	
Both	2	4	166	144	2,056	502	[redacted]	

Effect of Increased Distortion

			25%		50%		75%	
	Matches	Individuals	Matches	Individuals	Matches	Individuals	Matches	Individuals
Maxilla	763	396	9,660	826	39,854	1001	93,091	1,059
Mandible	75	83	1,658	451	9,510	759	29,308	931
Both	2	4	166	144	2,056	502	20,217	773



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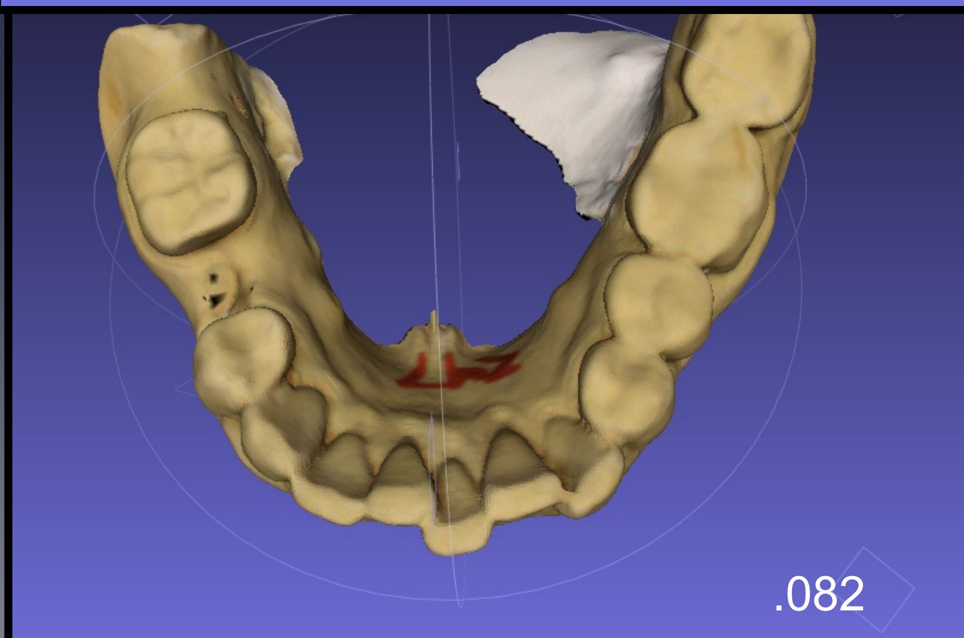
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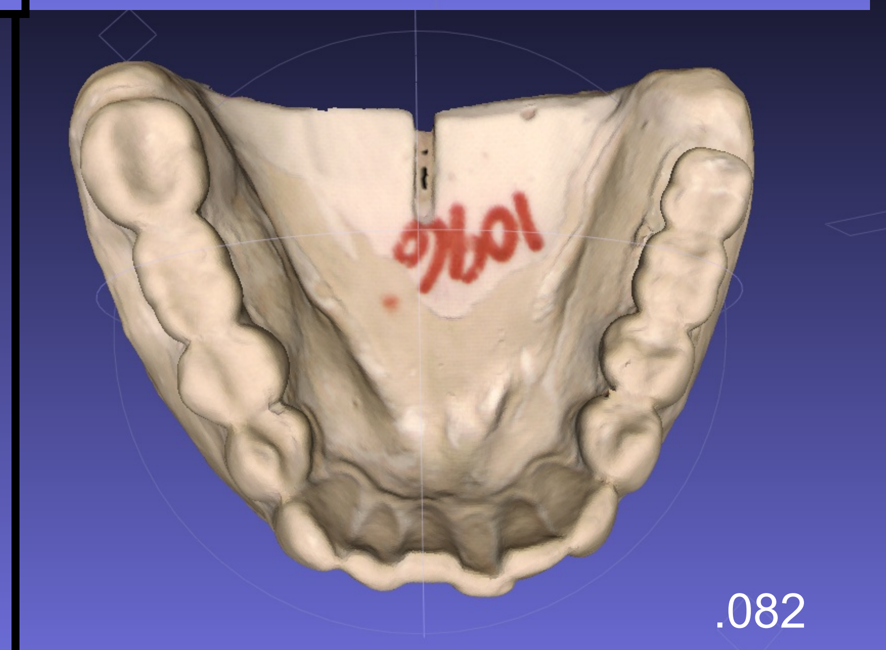
.082

Exhibit I

- A study of multiple bitemarks inflicted in human skin by a single dentition using geometric morphometric analysis. Mary A. Bush, Peter J. Bush, H. David Sheets For Sci Int 211 (2011) 1-8

Hypotheses

- Using GM methods compare 89 bitemarks from same dentition to population of 411 models
- Do other dentitions match bitemark better?
- Include size in analysis

Results

- None of the bitemarks matched the biting dentition
- Other dentitions matched bitemark better
- False negatives and false positives

Research conclusion

- No two bites from a single dentition are the same

Research conclusion

They are surprised when different, when the same teeth make bite marks and they look different, well, we've known that forever.

Q Well, even if a, one person, one biter makes multiple bite marks on a living human being, would you expect those bite marks to look the same?

A No.

Frye hearing

Dr David Senn, on Direct and re-Direct, 2012, People vs Clarence Dean NYC

Prade hearing

Dr. Franklin Wright, 2012, Ohio vs Prade

Q. Okay. Dr. Wright, let me ask you this: The 30 bitemarks this victim had, are you

OFFICIAL COURT REPORTER - C.A.T.

549

able to compare bitemark to bitemark?

A. No.

Q. Why not?

A. Because in the skin, and the movement of the skin, and the biting -- the way the biting dynamics occur in the skin and the pain, the whole environment in which the bitemarks are inflicted, no two bitemarks that I've ever seen from the same biter on the same victim look the same.

Q. Okay. Well, does that mean you can't compare someone's dentition to a bitemark then?

A. It does not preclude that, no.

Reliability?

- If dental transfer to skin is not repeatable, comparison must be unreliable

Conclusion from Research

- ~~The arrangement of the biting surfaces of front teeth is unique~~
- ~~Skin accurately records dental pattern~~
- The human dentition fits within boundaries dictated by biological form
- Similar dentitions exist
- Skin does not reliably record dental detail
- Distortion can be greater than variation in dental shape

Thank you!

EXHIBIT G

The views and opinions expressed in this document are mine and do not reflect the official policy or position of any agency or organization with which I am affiliated.

Dear Members of the Texas Forensic Science Commission,

I will begin where I will end: there are no studies within the body of research available which would support the hypothesis that when human teeth bite skin, the mark that those teeth have left has been faithfully recorded (by the skin) so that the bitemark does, in fact, reflect the size, shape, arrangement, and distribution of the class characteristics of the surfaces of the human dentition which made the mark.

Additionally, studies of the marks left in skin and the use of tracings of the biting edges of the anterior maxillary and mandibular teeth (presently, computer generated and known as hollow volume overlays) to associate or disassociate a biter to that bitemark have all led the authors of these studies to suggest that the practice is unsound, and that caution should be exercised. These studies date back to 1971, fully forty-five years ago.

The proponents of bitemark analysis, as has been taught and endorsed by the ABFO, have completely ignored the studies from the seventies and have relentlessly criticized the more recent studies, characterizing them as flawed, using as their proof nothing more than unsubstantiated assertions, or, unfortunately, by mounting personal attacks against the researchers.

Since the release of the NAS report in 2009, it seems that all we have heard from the ABFO has been:

1. the Innocence Project is picking on us,
2. we (odontologists) did not contribute to as high a percentage of wrongful convictions as they (IP) say we have (always an astounding argument because in the grand scheme of things, does that really matter? A single instance of contributing to a wrongful conviction should set one on their heels. To date, there are over 26 cases of wrongful convictions in which bitemarks and odontologists have played a significant role, representing over 258 collective years of the loss of liberty),
3. the NAS got it wrong, they misinterpreted what Dr. Senn said,
4. we *ARE* acting on the NAS recommendations- we are asking our members to get second opinions, and to perform “dental line-ups”,
5. the bulk of the wrongful convictions were due to “rogue” dentists (simply not true – Dr. West, the rogue in question, was involved in five of the twenty-six. Eleven other Diplomates of the ABFO (D-ABFO) either gave testimony in court or gave an opinion that contributed to conviction or arrest. Of course, Dr. West may have testified in many more cases which also resulted in convictions, and one might have hoped that the ABFO would be at the head of the phalanx advocating that such cases be identified and reviewed, but alas, they are not.)

6. odontologists simply need more training to become Diplomates and one needs to become a Diplomate, because D-ABFOs are most qualified to render opinions regarding bitemarks; the results of a study by **Avon, et. al., (Error Rates in Bite Mark Analysis in an In Vivo Animal Study, Forensic Science International, Volume 201, Issues 1–3, 10 September 2010, Pages 45–55)**, would suggest otherwise: neophytes and diplomates performed equally with regard to accuracy in bitemark analyses when using overlays. Compounding this, Dr. Freeman and Pretty's survey – presented in 2015 and with which you are familiar - shows a troubling disparity as to certainty by those who, in theory, should be most certain.

The leadership of the ABFO, rather than embracing research and perhaps embarking on either some collective soul searching or aggressive research, or both, have instead dropped the portcullis and barricaded the doors, taking a defensive stance and responding with vitriol.

A review of the literature offers no descriptions of skin as anything other than a capricious and unfaithful spouse in this partnership. In forty-five years our technological capabilities have advanced exponentially, but skin has not evolved a whit into a material more akin to aged cheese or wax - skin continues, research shows us, to behave like skin.

I know that Mr. Peter Bush went over some research with the Commission, but please indulge me and allow me to review some of the published literature with respect to the fidelity and reliability of skin as a recording medium:

DeVore, D T
Bitemarks for Identification? A Preliminary Report
Med. Sci. Law; 11(3), 1971: 144-145

Demonstrated the degree of distortion that can occur in a bitemark.
Concluded that in order to accurately evaluate a mark the exact position of the body when bitten must be known and replicated.
"Techniques where comparisons are made by measuring spaces, teeth widths, arch curvature etc. on models of the alleged assailant and comparing them by any superimposition technique to size and shape of photographs taken of bite marks on the victim have been shown by this study to be invalid."

Harvey, et. al.
Bite-marks - the clinical picture; physical features of skin and tongue. Standard and scanning electron microscopy.
Int. Journal of Legal Medicine, 1973,Vol. 8 . Page 3

Discussed stress/strain curve for skin and biomechanical properties affecting the same.
"Both the directional variations in skin properties and their alteration on movement have serious implications in bitemark matching."

Whittaker, D.K.
Some Laboratory Studies on the Accuracy of Bitemark Comparisons
Int. Dent. J., 1975 Vol. 25 (3);166-71

Compared bites in pig skin and in wax.
Found that pig skin was less reliable than wax.
Evaluated bites immediately after the bite was inflicted, at one hour then at 24 hours.
Immediate analysis yielded a 75% correct attribution, which also means a 25% incorrect attribution.
After one hour only 35% of the attributions were correct and after 24 hours that rate dropped to 16%.

"It may be that bitemarks in human flesh are more readily matched with a suspect's teeth than those in the skin of a pig, but it appears likely that variations in quality of bite, variations in tissue bitten, and subsequent bruising and oedema would render bitemark comparison an unsatisfactory means of identification in many cases."

Bush, M.A., Miller, R.G., Bush, P.J., and Dorion, R.B.J.
Biomechanical Factors in Human Dermal Bitemarks in a Cadaver Model
J. Forensic Sci., January 2009, Vol. 54, No. 1

Twenty three bites were made with a single set of models on two cadavers in a variety of sites and positions.
"Of the 23 bites made, none were measurably identical, and in some cases, dramatic distortion was noted."

Miller, R.G., Bush, P., Dorion, R.B.J., and Bush, M.
Uniqueness of the Dentition as Impressed in Human Skin: A Cadaver Model
J. Forensic Sci., July 2009, Vol. 54, No. 4

Bitemark interpretation assumes that the human dentition is unique and that its attributes can be accurately transferred to skin.
A cadaver model was used to investigate whether the correct biter could be determined from similarly aligned dentitions once the dentitions were impressed in human skin.
One hundred models were divided into ten groups of ten based on similarities of mal/alignment patterns.
One model from each group was randomly selected and bites were produced on the cadavers.
Measurements and overlays from all of models ("biters" and non -biters) were then compared in each of the groups.

"Results showed difficulty distinguishing the biter from individuals with similarly aligned dentitions and in some cases, an incorrect biter appeared better correlated to the bite."

Bush, M. A., Cooper, H.I., and Dorion, R.B.J.
Inquiry into the Scientific Basis for Bitemark Profiling and Arbitrary Distortion Compensation
J. Forensic Sci., July 2010, Vol. 55, No. 4

Sixty six bites were evaluated for fidelity and distortion.
None of the bites were positionally changed (thus there was no additional distortion due to that).
Arches with missing teeth left marks which had no spaces.
Full arches with crooked teeth left marks which were straight
Arches without crooked teeth left marks which indicated a tooth might be crooked/labially/lingually positioned.
Because of pre-tension in skin, which varies by anatomy, thickness, articulation etc. there is distortion of the bitemarks.
This was not uniform within the bite i.e. one part of a particular bite might be more distorted (and in a different manner) than another part of that same bite.

"With regard to bitemark profiling, 38% of the bites created patterns that could be misleading if profiled. Features were present/absent that were inconsistent with the biter's dentition. Conclusions indicate bitemark profiling and arbitrary distortion compensation may be inadvisable."

Lewis, C., Marroquin, L.A.
Effects of Skin Elasticity on Bite Mark Distortion
Forensic Science International, Dec 2015; 257:293-6.

"The results are consistent with similar studies and suggest that caution should be exercised in the analysis of bite mark evidence, given that the evidentiary uniqueness of human dentition is greatly diminished in the presence of high amounts of distortion. Bite mark patterns are found to be unpredictable because distortion is non-uniform across a particular dental arch. "

The ABFO has and continues to advocate that one, with enough training, can evaluate bitemarks left on skin, compare those marks to either a single dentition or multiple dentitions using metrics and overlays, and come to some sort of conclusion as to the origin of those marks (presently, the ABFO is advising that exclusion of a potential biter is something they endorse as opposed to inclusion).

For any comparison to be possible it is absolutely necessary that skin <u>*always*</u> be an accurate recorder of the teeth which bite it OR that we are able to fully recognize and identify the distortions of such marks **and** we have the algorithms and methods to correct for those distortions. We have no such tools.

The ABFO has not, to my knowledge, sponsored or initiated any studies of the fidelity of skin as a recording medium. If skin, as all the studies have shown, does not faithfully and consistently record those bitemarks as per the ABFO definition (i.e., the mark reflects the size, shape, arrangement, and distribution of the class characteristics of the surfaces of the human dentition) then the entire hypothesis must logically crumble. This would apply to the policy of exclusion versus inclusion as well (if we cannot identify which teeth made the mark, unless we are differentiating between an adult's dentition and a child's dentition, how on earth can we identify who didn't make the mark?).

Among the criticisms of the research from the SUNY Buffalo studies are the contentions that models mounted on vise grip pliers are an inadequate substitute for the human mandible, that bites made on cadaver skin would not create marks similar to those made on vital tissue, especially during an actual biting incident, that "real" bites would be worse than those made on the cadavers, that Peter Bush is not a dentist (a"pseudo-odontologist"), and that Mary Bush, while she is a dentist, does not in the course of her practice do bitemark analyses or has she ever testified in court.

Rather than dismissing the last two as patently absurd (which they are) let me address them. To argue that because Peter Bush is not a dentist and that Mary Bush does not perform bitemark analysis as part of her practice renders their research and opinions invalid (as has been the written opinion of a Past President of the ABFO, on his blog) is akin to arguing that the research of any cancer researcher who is not also a practicing oncologist is of no value and should be discounted.

With regard to the lack of courtroom testimony, that argument is simply diversionary in that it causes attention to be directed away from the very legitimate question being raised and which is basic to all of this, and that is "does skin faithfully and consistently record the features of the teeth which have caused a bite, so that said bitemark can be analyzed?"

The criticism aimed at the technique of mounting the dental casts on vise grip pliers is that the arc of motion of these pliers (Dr. Senn, in his presentation to the TFSC in November 2015 referred to these pliers as welder's pliers) is that of a simple hinge, without allowing for the forward translation of the human mandible. When asked by members of the Commission if there was something better Dr. Senn stated that the device being used at UT San Antonio (the device fabricated by the late Dr. Gerald Reynolds) would create better bites because Dr. Reynolds' device used a Hanau articulator (a dental lab device). In fact, and as was pointed out to Dr. Senn by Dr. Adam Freeman, the Hanau articulator, used by Dr. Reynolds, is what is known as a semi-adjustable articulator and the arc of motion of that particular device is that of a simple hinge, the same as the vise grip pliers. Dr. Senn is mistaken in his belief that the bites created at UT San Antonio are any different than those created by the researchers at SUNY Buffalo.

A second criticism is that the casts of the teeth were mounted in what is known as centric relation, not in a protrusive relationship, which Dr. Senn has declared is the proper position of the jaws when they bite. Another unsubstantiated assertion. Dr. Senn often voices this criticism, but has yet to offer any literature in support of it.

With regard to the assertion that cadaver studies cannot be carried over to vital tissue, in response to this particular criticism (cadaver skin, not vital tissue) I conducted a very simple project and presented it, in poster form, at the 63rd Annual Scientific Meeting of the AAFS, held in Chicago in 2011. Mind you, the research conducted in Buffalo is indeed, research. My project could be characterized as the equivalent of a middle school science experiment, and, frankly, I would have no issue with such a characterization. That having been said, we created bitemarks in vital skin and we did so by having one person actually bite another (so we can also eliminate the criticism of the vise grip mounted models). All photographic and overlay protocols as prescribed by the ABFO were adhered to.

Demas, J.P., DeLeonibus, J.M.
A Comparison of Bitemarks in Vital Tissue
Poster Presentation

American Academy of Forensic Sciences
63rd Annual Scientific Meeting
February 25, 2011
Chicago, IL

Five bites from a single biter were inflicted upon the right and left arms of a live subject.
These bites were made upon a willing, immobile subject and photographed, immediately, and in the same position in which each bite was inflicted.
"The hollow volume overlay of the biter exhibited full coincidence on not a single bite."

In fact, if the TFSC members were to compare the photographs of all of the bites created on cadavers, on vital skin from the UT San Antonio study, the Case Western Study, and both of my "kitchen table" projects (I have not yet referenced my second project) I think it would be quite evident that the bites are all remarkably similar.

Finally, the assertion that the cadaver studies are flawed because "real" bites would be worse leaves me flummoxed. While I would absolutely agree that "real" bites would be subject to movement and forces which would probably introduce more distortion to the resulting mark, I fail to understand how that would render any of the other research inapplicable and I daresay that during your November proceedings neither Dr. Senn nor Dr. Wright (after stating as a criticism of the SUNY Buffalo research that real bites would not be as clear as the cadaver bites) offered an explanation as to how exactly they arrived at their conclusion.

Another basic tenet underlying the whole premise that we can analyze a bitemark by overlay technique is that the anterior dentition is unique and the marks left by those teeth are also unique.

Mr. Peter Bush discussed the research regarding "uniqueness" already, so I will not belabor that point (as I am certainly doing with others).

An interesting case was presented at the AAFS Scientific Meeting in 2010, which dealt with the issue of uniqueness in a real world setting. Dr. Ord is the Chief Forensic Dentist for Clark County, Nevada.

Ord, David K.
Report on a Closed Population Bite Mark Case Involving Two Unrelated Individuals With Similar Dentitions
Oral Presentation
American Academy of Forensic Sciences
62nd Annual Scientific Meeting

Seattle, WA. February 2010

"It has been the basis of bite mark comparisons that no two unrelated individuals in a closed population would have dentitions that produce bite marks close enough in similarity as to prevent an outcome other than inconclusive to the case."

"This case disproves that assumption because two of the three persons of interest in the case had similarly positioned teeth and because of that both individuals fit a well defined bite mark."

In 2014 I presented the results of another project:

Aleksandravicius, D., Boguslaw, R., and Demas, J.P.
A Comparison of Hollow Volume Overlays to Bitemarks in Vital Tissue When a Postural Change is Effected
Oral Presentation
American Academy of Forensic Sciences
66th Annual Scientific Meeting
Seattle, WA. February 2014

"Bites" were created on vital skin using the mounted model technique. Two distinctly different sets of teeth were used. I assure you the marks created were not fleeting (another criticism of the cadaver bites) – the bruises remained on my arms for about a week. Our concern was: Could the overlay from Biter A "fit" a bite made by Biter B (or vice versa)?

We did, in fact, find such an instance. This was not unexpected, as it was predicted by the SUNY Buffalo studies.

In fact, in 2009, at the American Academy of Forensic Sciences 61st Scientific Meeting Mr. Peter Bush showed an almost perfect fit of an overlay of Eric Frimpong's teeth on a bite which was on a cadaver in Buffalo. Eric Frimpong had not, in fact, bitten the cadaver. Mr. Frimpong was, and still is, in prison in California, no physical evidence linking him to the crime of which he was accused, but convicted by bitemark evidence. The odontologist who analyzed that particular bitemark, a Past President of the ABFO, presented his findings at the American Society of Forensic Odontology meeting in 2009. He stated that he enlarged the photographs of the alleged bitemarks on the victim by 28% which enabled him to "fit" the overlay to the bite. His explanation as to why one would enlarge a 1:1 photo (and *only* the photo, not the overlay) by 28% is that skin shrinks, therefore, he had to enlarge the photo. No literature was offered in support of this statement and there was no scientific or mathematical rationale offered to justify the decision to enlarge it 28% as opposed to say 25% or 50%.

The ABFO rarely misses an opportunity to trot out the Doyle, Marx, and Bundy cases. In Doyle, the bitemark was in cheese, not skin. In Marx, the bite was in skin, but the bitemark was also three dimensional, not just contusions on the surface. Bundy is one of those cases where, perhaps, the skin actually did record the marks of the biter accurately – I do believe that sometimes this does, in fact, happen.

I have also seen, in the course of my role as a Forensic Dental Consultant to the Office of Chief Medical Examiner of the City of New York, bitemarks where, yes, the skin did seem to capture the characteristics of the teeth exceptionally well. Those cases were all child abuse cases and I have my own theory as to why we might sometimes see these very distinct marks.

However, even though we may from time to time see marks exhibiting such clarity, the bottom line is that skin is an awful recording medium. A Potter Stewart approach to bitemark analysis (I'll know a "good" bitemark when I see it) should hold no weight as science, and science by fiat (i.e., "because we said so") is not, in fact, science, at all.

Until there comes a time when studies have been performed which will map out and explain the type and degree of skin distortion (as influenced by the Langer lines) and mathematically correct that distortion, we should not be depriving people of their liberty based upon bitemark analysis.

Respectfully,

John Peter Demas, DDS
Fellow, American Academy of Forensic Sciences
Forensic Dental Consultant, NYC OCME

John Peter Demas, D.D.S.
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Brooklyn, N.Y. 11209
Phone: (718) 745-4225 Fax: (718) 745-1428

Education

September 1972- May 1976
Columbia University
Bachelor of Arts

September 1976- June 1979
New York University College of Dentistry
Doctor of Dental Surgery

Received the 1979 American Association of Oral and Maxillofacial Surgeons Award for outstanding achievements in the undergraduate study and clinical training of Oral Surgery

July 1, 1979- June 30, 1980
General Practice Residency
The Long Island College Hospital
Certificate

Hospital Affiliations

The Long Island College Hospital
Department of Dentistry
Attending October 1981 - March 2011

The Long Island College Hospital
Department of Dentistry
Co-Chief, Division of Operative Dentistry   July 1983 - June 1986

The Long Island College Hospital
Department of Dentistry
Chief, Division of Operative Dentistry   June 1986 – March 2011

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Hospital Affiliations (cont.)

Lutheran Medical Center
Division of Dentistry, LICH Campus
Consultant March 2011 – June 2012

SUNY Downstate Medical Center
Department of Surgery / College of Medicine
Division of Dentistry
Clinical Assistant Professor May 2011 - June 2012

New York Methodist Hospital
Department of Surgery
Division of Dental Medicine
Attending January 2015 - Present

Professional Memberships

American Dental Association
Dental Society of the State of New York
Second District Dental Society
Bay Ridge Dental Society
Sheepshead Dental Study Club
Hellenic Dental Society
Academy of General Dentistry
American Society of Forensic Odontology
New York Society of Forensic Dentistry
American Academy of Forensic Sciences, Fellow

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Publications/Presentations

Utilization of the OdontoSearch Comparison Program to Support Identification in a Modern Identification Case American Academy of Forensic Sciences, 62nd Annual Scientific Session, Seattle, WA., February 26, 2010

A Comparison of Bite Marks in Vital Tissue American Academy of Forensic Sciences, 63rd Annual Scientific Session, Chicago, Il., February 25, 2011

A Comparison of Hollow Volume Overlays to Bitemarks in Vital Tissue When a Postural Change is Effected American Academy of Forensic Sciences, 66th Annual Scientific Session, Seattle, WA., February 21, 2014

Forensic Education/Experience and Affiliations

Armed Forces Institute of Pathology
Forensic Dentistry/Mass Disaster Course
February 2002

Armed Forces Institute of Pathology
Forensic Anthropology Course
June 2006

Flight 587 Dental Identification Team
Office of the Chief Medical Examiner, City of New York
November 2001

World Trade Center Dental Identification Team
Office of the Chief Medical Examiner, City of New York
September 2001 - conclusion

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Forensic Education/Experience and Affiliations (cont.)

Tour Commander
World Trade Center Dental Identification Team
Office of the Chief Medical Examiner, City of New York
January 2002 - conclusion

Forensic Dental Consultant
Office of the Chief Medical Examiner, City of New York
January 2006 – present

Forensic Dentist
Medical Examiner's Special Operations Response Team (MESORT)
Office of the Chief Medical Examiner, City of New York
January 2006 – present

Visiting Lecturer
New York University College of Dentistry
Senior Elective, Forensic Dentistry
Dr. Nicholas Vernice, Course Director
2014 – present

Visiting Lecturer
Rutgers School of Dental Medicine (formerly UMDNJ)
Senior Elective, Forensic Dentistry
Dr. Harry Zohn, Course Director
2012 – present

A Response to a Critic of the Critics

Mark Page, Ph.D.

The author of the website *www.bitemark.org* posted an article regarding the admissibility of bitemark evidence in several cases in Texas, and spent some time discussing the supposedly 'asinine' nature of applying experimental scientific methodology to forensic science. The article makes the point that the scientific method should not apply to some disciplines, as they are not 'hard' sciences, like physics and chemistry. This commentary represents an example of why critics of forensic science find these disciplines particularly frustrating, in that they attempt to justify their forensic practice on the basis that they are somehow 'different' or 'immune' to good scientific practice. But there is no logical reason why forensic science and the scientific method should be mutually exclusive.

The author begins this part of his discussion by referring to the decision in *Coronado v Texas* [1], which held that not all 'science' should be considered equal in as far as its theories and practices. There is much to say about the *Coronado* ruling, most of which should be reserved for a different forum, however, suffice to say that the majority opinion in this case has created more problems for itself than it realises by attempting to draw a line between standards for 'hard' versus 'soft' sciences. Despite the fact it references *Daubert*[2] and *Kelly*,[3] both of which hold independently that in order for expert testimony to be considered reliable, and hence admissible: (1) the underlying scientific theory must be valid; (2) the technique applying the theory must be valid; and (3) the technique must have been properly applied on the occasion in

[1] *David Cesar Coronado v. The State of Texas*, No. 05-11-00605-CR, Texas App., 5th Dist.; Tex. App. LEXIS 9405 (2012)
[2] *Daubert v. Merrell Dow Pharmaceuticals Inc*., 509 US 579 (1993)
[3] *Kelly v. State,* 824 S.W.2d 568, 573 (Tex. Crim. App. 1992)

question, the court affirmed a stance taken in *Nenno*[4] that some expert evidence is exempt from this requirement. They then went on to say that this type of expert evidence, of which they offer no definition (other than to say that it would be of the type that is considered 'soft science' – whatever that term means), can affirm its reliability by proving that: (1) the field of expertise is a legitimate one; (2) the subject matter of the expert's testimony is within the scope of that field; and (3) the expert's testimony properly relies on or utilizes the principles involved in that field.

These three principles as held by the Texas Court of Appeals badly undermines the US Supreme Court's elucidation of the term 'reliable' in *Daubert*, which Texas itself adopted as precedent, beginning with *Robinson*[5] in 1995. Read carefully, the Court of Appeals application of these three factors in *Coronado* amount to nothing more than what has been termed 'counting expert noses'. They established that the field of forensic odontology was legitimate by referencing the existence of the American Board of Forensic Odontology, a body recognized by the American Academy of Forensic Sciences. By this reasoning, one could conclude that the science of astrology is also valid, as there is an Organization for Professional Astrology, yet most courts would have difficulty applying the very same reasoning in such a case. This practice harks back to the pre-*Daubert* days of *Frye*,[6] where experts could claim to be experts on the basis of 'pulling themselves up by their own bootstraps': in other words, they were essentially 'self-validating'. This was one of the primary reasons for the over-ruling of *Frye* at the federal level, to ensure that experts were subject to a form of accountability beyond that of their own professional affiliation. If you ask another astrologer whether their practice is legitimate, what does one imagine that they will say? Similarly, asking the American Board of Odontology whether it feels

[4] *Nenno v. State,* 970 S.W.2d 549, 561 (Tex. Crim. App. 1998)
[5] *E.I. du Pont de Nemours & Co. v. Robinson*, 923 S.W.2d 549 (Tex. 1995).
[6] See *Frye v United States* 293 F. 1013 (D.C.Cir. 1923)

that it is a legitimate forensic body seems ridiculous. In fact, so much so that the court in *Coronado*, like other before it, didn't even bother to ask, it just noted the existence of such an organization and therefore assumed that such a field was 'reliable' on this basis.

The court in *Coronado* heard about the existence of several professional organizations that recognize the practice of odontology, they heard about how bitemark analysis was performed, and agreed that the method used in the case before it was considered acceptable in as far as a recognized methodology. But it completely failed to consider whether this method actually yielded appropriate results that could be relied upon to any degree. So where was the analysis of the underlying basis for the discipline in *Coronado*? The answer appears to be: there wasn't any, because forensic odontology is a 'soft science'.

This distinction between 'hard' and 'soft' sciences is difficult to determine, and virtually all who purport that there is a difference then go on to say that the distinction is difficult to make, so much so that they avoid making it entirely, relying instead on the reasoning that it is 'obvious' that bitemark analysis is a 'soft science'. The author of the bitemark.org website maintains that 'soft sciences', at least forensic odontology and bitemark analysis in particular, are so called because science is observational, rather than experimental. But then the question arises – why is it one and not the other? Is it observational because there is no way to test its theories through experimentation, or because it just lacks experimental data? It seems that the category of 'observational' science is, in reality, just an excuse for a category of science that lack robust data to support their current practice. Astrology is also an 'observational' science in this respect: astrologers supposedly report on horoscopes by 'observing' positions of various celestial bodies, yet few would claim it would have a place in legal proceedings.

The notion that forensic odontology is observational, and therefore is different to the experimental sciences is largely true, but I would argue that this distinction is artificial and borne of excuses rather than amounting to true difference in scientific philosophy. How does one suppose that 'experimental' sciences became that way? Science almost always began through *observation* of a particular phenomenon. But note that the use of pure observation to verify scientific theories is basically pure *induction*: a methodology generally considered inappropriate, by itself, for the acquisition of 'scientific' knowledge. The true distinction between forensic science and hard science is that while much of forensic science started with observation, unlike physics or chemistry it failed to progress to the next stage: that of assessing whether the observations held for any given circumstance. For example, it was through observation that in the middle ages that the notion that eating eels was one of the causes of scurvy.[7] In reality, eating eel did not cause scurvy, although this belief was held for many years, until James Lind performed an *experiment* in which he attempted to treat sailors afflicted with scurvy with various cures, among one of which was citrus fruit. Through this experiment, considered widely to be the first clinical trial, it was suggested (although largely ignored for another hundred years) that a lack of some dietary factor was responsible for causing scurvy, rather than caused by eating a particular food. Since Lind's time, many clinical trials in both humans and animals have been conducted in order to verify the claim that scurvy is caused by a lack of vitamin C, to the point where the evidence is now virtually conclusive.

Take even the 'hardest' of 'hard' sciences: physics. It too began with observations that progressed through experimentation into standard theories that now hold almost uncontroversial weight. Newton first *observed* that a prism split white light into a beam of

---

[7] Crusaders noted that scurvy epidemics often arose during Lent. During this time, eel was traditionally eaten as a substitute for meat. See David Harvie's *Limeys, The True Story of One Man's War against Ignorance, the Establishment and the Deadly Scurvy*, Sutton Publishing, Phoenix Mill UK (2002).

varying colors we now refer to as the 'visible spectrum'. This suggested that white light was itself made up of a number of colors (all of them, in fact). How did he prove that this was not simply his unverified opinion? He conducted a series of systematic *experiments* that ended up proving he was right not only to his satisfaction, but to the rest of the learned world at the time.

The author at *bitemark.org* maintains that the appropriate view of forensic science is an *epidemiological* one: involving a retrospective analysis of results. The distinction between epidemiological and experimental science as applied to forensic disciplines is flawed here for various reasons. The most important reason this argument is flawed is because one cannot rely on historical instances in order to prove the reliability of forensic science because in each case, ground truth is never known with certainty. In 1991, Ray Krone was convicted on the basis of a bitemark, so in a retrospective analysis conducted in, say, 1996 we could chalk this up as proof that association between an individual and a bitemark is not only possible, but accurate. But eleven years later, in 2002, it became apparent that this conviction represented a grave error, Ray Krone was innocent. Forensic evidence cannot be validated as 'reliable' from judicial casework because the judicial outcome is usually dependent on that forensic evidence to start with: the question of forensic science's reliability becomes a self-fulfilling prophecy.

The author further claims that because forensic events are unique, their circumstances can never be repeated, and so any experiment that attempts to duplicate one scenario is likely never to be applicable to any other. He appears to then make the leap that 'experimentation' would therefore be near useless. This is a very narrow approach to how science works. No experiment is ever perfect (that is why good scientists always express the likelihood of error, or at least discuss the possible limitations of their evidence in papers submitted for publication), nor does it always completely account for a single observed phenomenon. Modern science evolves through the accumulation of evidence, that when taken as a collective whole, allows theories to be verified, or discounted. Just because one experiment fails to account for every possible scenario does not mean that it is worthless. The calcium carbonate molecules in a test tube in Hungary are not the same calcium carbonate molecules in the test tube in Sweden, yet enough research has been done to categorically conclude that when combined with hydrochloric acid, carbon dioxide gas will reliably be produced. Chemists didn't verify this test with every sample of calcium carbonate, in all its various physical forms known to man, in order to establish that such a consequence could reliably be predicted.

It is true that forensic events are very difficult to reproduce in the lab. But again, no experiment in science ever attempts to replicate the exact conditions under which the world operates – this is already recognized as being beyond the realms of achievability in most areas of science. Nonetheless, experiments in bitemark analysis do generally try to replicate the conditions as best they can, in the experiments alluded to by the author by using actual models of dentition, biting into actual human flesh. Despite the fact that these conditions are not ideally representative of the real world, if we consider that the purpose of the bitemark experiments criticized in this article was to disprove that there was sufficient variation in bitemarks to be able to distinguish one from another, the laboratory conditions in these experiments actually favor the *null* hypothesis: in other words, these (non-realistic) conditions would assist in proving that there *is* sufficient variation. The author points out the fact that there is no 'struggle' by the victim, or that there is no 'vital reaction' in this experimental bite, but the absence of these conditions should make the resulting mark even more distinct, and *easier* to be related to a given dentition, not harder. While these conditions are not as relevant as it could be to real-life forensic work, they actually increase the likelihood that these bitemarks could be reliably related to dentitions in this experiment. Such bias 'towards the null' is often deliberately designed into scientific experiments, in order to further increase their overall validity. Unfortunately, despite the presence of factors which favor the null hypothesis, the experiments *still* demonstrate that distinction between similar dentitions is difficult, if not impossible, even on the basis of these 'near perfect' bitemarks.

The author maintains that the particular research group's methods in these experiments have not been verified as reliable. In actual fact, the method that they use to describe and compare the resulting bitemark with a dentition (a technique known as geometric-morphometric analysis) is supported as a method of geometric comparison by a wealth of mathematical and other scientific literature. Perhaps his concern is more that the method has not reliably been applied to bitemark analysis. This is arguably legitimate, however, an important distinction to note here is that they are not performing bitemark analysis *per se*, they are using a well-established method of geometric comparison to compare shapes of bitemarks to dentitions. The ability to distinguish and relate shapes of this nature is one of the fundamental tenets of bitemark analysis, but does not account for the whole practice itself, and it is only this particular aspect of bitemark analysis that they are attempting to challenge. How this then affects the overall theory of bitemark analysis is a conclusion that one is then free to draw oneself from these results.

This critical response to some of the only true 'scientific' research ever conducted on bitemark analysis belies the type of thinking that has got forensic science into trouble in the first place: a failure to understand the importance of scientific methods in modern scientific reasoning, and a perfunctory dismissal of its rightful place in forensic science. The distinction of 'soft' versus 'hard' sciences amount to nothing more than excuses for a lack of proper research data, and while judges may be happy with this distinction for the sake of advancing trials in a timely fashion, it is not one that the forensic science profession should be happy with if they are to truly consider themselves scientists.

EXHIBIT H

I am honored and humbled by the trust the diplomates and imparted upon me as your president for the next year. There are many of you who have served in this position and I can only hope to live up to your legacy. There are so many to thank for mentoring me through my forensic career, you all know who you are as I have thanked each of you personally over the years. I remember my first Diplomate's dinner sitting next to Dr. Weems swelling with pride, astonished that those in the room knew who I was, addressing me by my name. I leaned over to Dr. Weems and said "I feel like I am in a room full of giants and I don't belong" He put his arm on my shoulder and reassured me that I had earned my seat at the table.

These are interesting times for the ABFO. We do great work! We walk away from our normal lives during times of national tragedy to identify the victims of manmade and natural disasters. We travel to faraway places, often in austere environments to give names to the nameless. We go to morgues and see things that no person should see and identify those who are unidentifiable. We do this with great pride, we do it with the utmost respect for those whom we are viewing, we often give the deceased more respect in death then they had in life. We mentor those who demonstrate an interest in the field, we want others to succeed and become board certified. We do these things with little to no remuneration. Personally, I am honored and humbled at the mere request to participate in the identification process.

We as an organization have gone through some disconcerting times in the past years, both in relation to bitemark analysis/comparison as well as the way we interact with each other. Our work is too important to have interpersonal conflict impact the ABFO's functionality. We need to always remember to be collegial in dealing with fellow diplomates as well as the scientific community at large. We all hopefully have the same common goal, to be dispassionate scientific analysts. Lively, honest discourse is important to our organization, but we must achieve it in the absence of rancor and vitriol. Contempt of collegiality will make the ABFO weaker and dysfunctional, it will prevent us from progressing, and we must always be attempting to progress our discipline.

Our work in bitemarks have done much good, however there is significant wreckage in our past. This wreckage is just as unacceptable as those who commit the horrible crimes we often see. It terrifies me to think of being imprisoned knowing that I was innocent of what I was accused of. I think we need to take responsibility for these miscarriages of justice our discipline has been a part of. To those who have been wrongfully convicted, while of little consolation for the years of your life lost, I am sorry. While apologies are important what is most important is action! None of us want an innocent person imprisoned due to bitemark analysis, and I can only assume that those working to exonerate the innocent never wants a guilty person freed. I would encourage all to review our individual cases. Where opinions went too far, we have an absolute duty to correct and we need to take this responsibility seriously. To those who are fearful of such refection, I remind you of what Thomas Jefferson once said, *"Question with boldness even the existence of a God; because, if there be one, he must more approve of the homage of reason, than that of blind-folded fear."*

The recent decision of the Texas Forensic Sciences Commission (TFSC) has brought this to the forefront. They are not our enemy. In fact I think that their decision will be the catalyst our organization needed to get our forensic house in order. I cannot overstate the importance of getting our house in order. The commission in a letter to Dr. Berman and me gave us a framework for a path forward. They stated;

> The Commission seeks to work collaboratively with the leadership of the American Board of Forensic Odontology ("ABFO") as it moves forward on these recommendations. As a threshold matter, Commissioners believe the following items should be established to ensure the integrity and reliability of the forensic analysis:
>
> 1. *Criteria for identifying when a pattern injury constitutes a human bitemark.* This criteria should be expressed clearly and accompanied by empirical testing to demonstrate sufficient inter and intra-examiner reliability and validity when the criteria are applied.
>
> 2. *Criteria for identifying when a human bitemark was made by an adult versus a child.* This criteria should be expressed clearly and accompanied by empirical testing to demonstrate sufficient inter and intra-examiner reliability and validity when the criteria are applied.
>
> 3. Rigorous and appropriately validated proficiency testing using the above criteria.
>
> 4. A collaborative plan for case review including a multidisciplinary team of forensic odontologists and attorneys. (Drs. Senn and Wright have graciously offered to work on this project.)
>
> After addressing these basic items, the Commission believes follow-up research should focus on the criteria that form the basis for the "exclude" and "cannot exclude" categories contemplated by both of the "draft" decision trees currently in circulation through the OSAC and ABFO processes. ABFO guidelines should also follow the example of other forensic disciplines by including peer/technical review of cases as well as the development of a model report that provides information to the trier of fact regarding the limitations of the forensic analysis.

The Court needs us. Victims of bitemarks need us, often being children and those who don't have a voice. To protect this important evidence, we need to correct for the past deficiencies of bitemark analysis. We all individually should support research in the field. I encourage many of the talented individual diplomates to consider doing research. I also encourage you all to participate in research projects when asked to do so. You must treat these projects in a realistic fashion as the results are crucial to the future of our discipline. We also need to inform the legal system of the strengths and weaknesses of bitemark analysis, but I am convinced that we are up to the task.

The TFSC has identified a pathway forward for us, we now need to do the heavy lifting. This has begun by us recognizing that individualization of a suspect based on a bitemark injury alone is not supported by our guidelines. While we have adopted new bitemark guidelines and terminology and I am proud of these changes, I think we need to do more. I will work to implement the following guideline changes, but encourage all of you to immediately adopt the following in your practices;

- To restrict ourselves to only bitemarks of the highest evidentiary value.
- To be blinded of suspect(s) when doing comparisons.
- The same investigator should not document patterned injuries and take suspected biter information.
- We need blinded second opinions- not just technical reviews.
- We need to be vigilant about bias and do everything in our power to mitigate it.
- We need bitemark proficiency testing.
- We need to change the requirement that a potential ABFO certification candidate be the primary investigator in a bitemark case in order to satisfy the requirements to become certified.

We need to also enact bylaws changes that allow us to implement change in a more efficient way, while also allowing us all to participate in such change. With current technology we can have diplomate meetings and votes electronically. While we were formed in 1976 we no longer live in that era, and our bylaws need to evolve to allow us to be a more nimble organization.

I am proud to serve as your president. I will make sure that all voices within the ABFO are heard. I will make sure that information is free flowing to all of you. As always I am available to talk or exchange ideas so, never hesitate to reach out to me.

Adam J. Freeman, DDS, D-ABFO
President
American Board of Forensic Odontology

EXHIBIT I

TEXAS FORENSIC
SCIENCE COMMISSION
Justice Through Science
1700 North Congress Ave., Suite 445
Austin, Texas 78701

TEXAS FORENSIC SCIENCE COMMISSION
COMPLAINT FORM

Please complete this form and return to:

Texas Forensic Science Commission
1700 North Congress Avenue, Suite 445
Austin, Texas 78701
Email: info@fsc.texas.gov
[P] 1.888.296.4232
[F] 1.888.305.2432

The Texas Forensic Science Commission ("FSC") investigates complaints alleging professional negligence or misconduct that would substantially affect the integrity of the results of a forensic analysis conducted by an accredited crime laboratory. The Commission also has jurisdiction to investigate non-accredited forensic disciplines and non-accredited entities under more limited circumstances, such as to make observations regarding best practices or for educational purposes. (For a comprehensive review of the Commission's jurisdiction, please refer to Tex. Code Crim. Proc. 38.01 as amended by Tex. S.B. 1238, 83rd Leg., R.S. (2013)).

Please be aware that the FSC investigates allegations involving "forensic analysis." This term includes any medical, chemical, toxicological, ballistic, or other expert examination or test performed on physical evidence, including DNA evidence, for the purpose of determining the connection of the evidence to a criminal action.

However, the term "forensic analysis" does not include the portion of an autopsy conducted by a medical examiner or other forensic pathologist who is a licensed physician. **Please be advised that if you submit a complaint regarding the results of an autopsy, it is highly likely your complaint will be dismissed.** (Note: the forensic testing done in connection with an autopsy, such as toxicology, is included within the Commission's jurisdiction even though the autopsy itself is not.)

The FSC will examine the details of your complaint to determine what level of investigation to perform, if any. All complaints are taken seriously. Because of the complex nature and number of complaints received by the FSC, we cannot give you any specific date by which that review may be completed.

If the criteria for an investigation are met, the FSC will send a letter to the laboratory/facility and/or individual(s) named in the complaint indicating that the FSC has received the complaint. The FSC will then request a response from the entity and/or individual who is the subject of the complaint. We may also need to obtain additional information from you.

If the criteria for an investigation are not met or the FSC declines to investigate further, you will receive a letter from the FSC.

The Commission's statute allows it to withhold from disclosure information submitted regarding a complaint until the final investigative report is issued. **However, after a report is issued, all information and complaints are subject to public disclosure under the Texas Public Information Act (Texas Government Code Chapter 552).**

You may submit a complaint without disclosing your identity. However, the FSC cannot guarantee your anonymity. Also, please note that filing a complaint without disclosing your identity may impede the investigation process, especially if our ability to contact you is limited.

Your cooperation, patience and understanding are appreciated.

1. PERSON COMPLETING THIS FORM

Name: M. Chris Fabricant
Address: Innocence Project, Inc. - 40 Worth St., Suite 701
City: New York
State: NY Zip Code: 10013
Home Phone:
Work Phone: 212.364.5997
Email Address *(if any)*: cfabricant@innocenceproject.org

Your relationship with the defendant:

- Self ☐
- Family Member ☐
- Parent ☐
- Friend Attorney ☒
- None ☐
- Other *(please specify)*:

If you are not the defendant, please provide us with the following information regarding the defendant:

Name: Steven Mark Chaney
Address *(if known)*: 810 FM 2821; Huntsville, TX 77349
Home Phone:
Work Phone:

2. SUBJECT OF COMPLAINT

List the full name, address of the laboratory, facility or individual that is the subject of this disclosure:

Individual/Laboratory:
Address:
City:
State: Zip Code:
Date of Examination, Analysis, or Report:
Type of forensic analysis: Forensic Odontology/Bitemark Analysis
Laboratory Case Number *(if known)*:

Is the forensic analysis associated with any law enforcement investigation, prosecution or criminal litigation?
Yes ☒ No ☐

* If you answered "Yes" above, provide the following information *(if possible)*:

* Name of Defendant: Steven Mark Chaney
* Case Number/Cause Number: F87-95754-MK
(if unknown, leave blank)
* Nature of Case: Murder
(e.g burglary, murder, etc.)
* The county where case was investigated, prosecuted or filed: Dallas County
* The Court: Criminal District Court No. 4, Dallas County
* The Outcome of Case:

Convicted after jury trial, sentenced to life imprisonment.

* Names of attorneys in case on both sides *(if known)*:

ADA Neal Pask and Mark Nancarrow; Defense Counsel John Tatum

3. WITNESSES

Provide the following about any person with factual knowledge or expertise regarding the facts of the disclosure. Attach separate sheet(s), if necessary.

First Witness *(if any)*:
Name:
Address:
Daytime Phone:
Evening Phone:
Fax:
Email Address:

Second Witness *(if any)*:
Name:
Address:
Daytime Phone:
Evening Phone:
Fax:
Email Address:

Third Witness *(if any)*:
Name:
Address:
Daytime Phone:
Evening Phone:
Fax:
Email Address:

4. DESCRIPTION OF COMPLAINT

Please write a brief statement of the event(s), acts or omissions that are the subject of the disclosure.

Please see the attached letter.

5. EXHIBITS AND ATTACHMENT(S)

Whenever possible, disclosures should be accompanied by readable copies **(NO ORIGINALS)** of any laboratory reports, relevant witness testimony, affidavits of experts about the forensic analysis, or other documents related to your disclosure. Please list and attach any documents that might assist the Commission in evaluating the complaint. Documents provided will **NOT** be returned. List of attachments:

Please see the attached exhibit list..

6. YOUR SIGNATURE AND VERIFICATION

By signing below, I certify that the statements made by me in this disclosure are true. I also certify that any documents or exhibits attached are true and correct copies, to the best of my knowledge.

Signature: [signature]

Date Signed: 7/22/15

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July 22, 2015

Texas Forensic Science Commission
1700 North Congress Avenue, Suite 445
Austin, Texas 78701

Dear Commissioners:

Please accept this complaint, filed on behalf of our client, Steven Mark Chaney, and on behalf of the Innocence Project, Inc. We ask that the Texas Forensic Science Commission ("the Commission") exercise its statutory mandate to investigate and report on "the integrity and reliability" of bite mark evidence as used in criminal proceedings. Tex. Crim. Proc. Code Ann. § art. 38.01(4)(b-1)(1).[1]

The Innocence Project is a national litigation and public policy organization dedicated to exonerating wrongfully convicted persons through DNA testing and improving the criminal justice system to prevent future miscarriages of justice. To date, 330 people in the United States, including 18 who served time on death row, have been exonerated by DNA testing. One lesson to be drawn from these exonerations is that the misapplication of forensic sciences is one of the leading causes of wrongful conviction, contributing to the original wrongful conviction in approximately half of the DNA exoneration cases. Some forensic techniques are more problematic than others, however, and of those disciplines currently in use, it is bite mark comparison evidence that poses the most acute threat to the reliability and fairness of Texas's criminal justice system. Indeed, despite the relative rarity of its application, no less than 24 people have been wrongfully convicted or indicted on the basis of bite mark evidence,[2] including *at least*

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[1] Forensic odontology is not specifically enumerated as an accredited field of forensic science. *See* 37 Tex. Admin. Code § 28.145. However, it may be treated as a form of impression evidence, *see Milam v. State*, No. AP-76,379, 2012 WL 1868458, at *12-*13 (Tex. Crim. App. May 23, 2012) (unpublished opinion), which may thus be conducted out of an accredited laboratory, giving the Commission additional jurisdiction. *See* Tex. Crim. Proc. Code Ann. § art. 38.01(4)(a)(3).

[2] *See* Ex. B (Amanda Lee Myers, *Men Wrongly Convicted or Arrested on Bite Evidence*, ASSOCIATED PRESS, June 16, 2013, available at http://news.yahoo.com/men-wrongly-convicted-arrested-bite-evidence-150610286.html); Ex. C (Amanda Lee Myers, *Bites Derided as Unreliable in Court*, ASSOCIATED PRESS, June 16, 2013, available at http://news.yahoo.com/ap-impact-bites-derided-unreliable-court-150004412.html); *see also* Ex. D (List of Bite Mark Exonerations).

two in Texas to date.[3] That this technique is responsible for so many miscarriages of justice is not surprising. As this complaint outlines, no validated and reliable science remotely supports bite mark evidence, and what science there is affirmatively disproves even the most basic assumptions which underlie it. Bite marks, moreover, "often are associated with highly sensationalized and prejudicial cases, and there can be a great deal of pressure on the examining expert to match a bite mark to a suspect," *see* Ex. A at 175 (NATIONAL ACADEMY OF SCIENCES, Committee on Identifying the Needs of the Forensic Sciences Community, STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES: A PATH FORWARD (2009) ("NAS Report")). This, along with the fact that bite mark analysis is entirely subjective, greatly increases the risk of wrongful conviction in bite mark cases.

Given the complete lack of science supporting bite mark analysis, and the grave risk of wrongful conviction use of the technique poses, bite marks represent an ideal and critical opportunity for this Commission to bring to bear its statutory mandate to "advance the integrity and reliability of forensic science" in Texas. *See* Tex. Crim. Proc. Code Ann. § art. 38.01(4)(a-1). We thus ask that this Commission undertake a thorough investigation of bite mark evidence. Our request is that this investigation include retrospective and prospective components. Retrospectively, we ask that this Commission audit those cases in which bite mark comparison testimony was offered. Prospectively, we ask this Commission declare a moratorium on the continued use of bite mark comparison evidence in criminal prosecutions until such time as the technique has been scientifically validated and proven reliable. Doing so will not only advance this body's statutory mission, but also help ensure that no more innocent Texans are incarcerated as a result of this dangerously unreliable "science."

Bite Mark Analysis Has Never Been Validated or Proven Reliable

The use of bite mark comparison evidence in criminal trials rests on a series of unproven assumptions. First, bite mark comparison evidence assumes that the biting surfaces of teeth (i.e., the dentition) are unique. Second, it assumes that human skin is capable of accurately recording the dentition's unique features. Third, it assumes that forensic dentists can reliably associate a dentition with a bite mark. Finally, bite mark comparison assumes that, given all the foregoing, forensic dentists can provide a scientifically valid estimate as to the probative value of the association. But, as this letter will demonstrate, no science supports these assumptions, and thus no science supports the conclusion that a perpetrator can be identified from a bite mark in human skin.

The Dentition Has Never Been Scientifically Demonstrated to be Unique

The first assumption of bite mark comparison evidence is that the human dentition (i.e., the biting surfaces of teeth) is unique. But this proposition has never been demonstrated by science to be valid or reliable. In 2009, the National Academy of Sciences ("NAS")—an organization made up of the nation's most accomplished

[3] For more on the exonerations of Calvin Washington and Joe Sidney Williams, and the probable wrongful convictions of Steven Mark Chaney and others in Texas, *see infra.*

scientists "charged [by an Act of Congress] with providing independent, objective advice to the nation on matters related to science and technology"[4]—undertook the first examination by an independent scientific body of bite mark evidence. After nearly four years of work, including thorough literature reviews and extensive testimony from a vast array of scientists, law enforcement officials, medical examiners, crime laboratory officials, investigators, attorneys, and leaders of professional and standard-setting organizations, the NAS issued its groundbreaking and authoritative report. While the report criticized the scientific foundation for many forensic disciplines, the NAS reserved its most pointed and devastating critique for bite mark evidence, concluding that the technique lacks scientific validity and has never been proven reliable.

In particular, the NAS rejected the first assumption of bite mark analysis as baseless, finding that "[t]he uniqueness of the human dentition has not been scientifically established." Ex. A at 175-76 (NAS Report). Recent scientific research published largely after the NAS Report suggests that not only has this uniqueness *not* been scientifically established, but that it *cannot* be. This research indicates that the limited features of the biting surfaces of teeth, which are likely to involve only one narrow surface of less than eight teeth within a bite mark (as opposed to 32 teeth with five sides for a typical adult), may not actually be unique.[5] Indeed, these studies have found there are "matches" between dentitions within certain populations.[6] *See* Ex. E at ¶¶ 8, 14-15 (Affidavit of Dr. Mary and Peter Bush ("Bush Affidavit")) ("Our results indicate that the biting surfaces of human anterior (front) teeth (i.e., the dentition) is not unique within measurement error. This is particularly true within a bitemark, in which only those anterior teeth may be involved.").

Even if the Dentition Were Unique, Human Skin Is Not Capable Of Accurately Recording Those Unique Features

Even if there were scientific support for the proposition that the dentition is unique, there is no support for the proposition that human skin is capable of accurately recording those unique features. The NAS Report found that this assumption, too, was unsupported, concluding that "[t]he ability of the dentition, if unique, to transfer a unique pattern to human skin and the ability of the skin to maintain that uniqueness has not been scientifically established . . . ." Ex. A at 175-76 (NAS Report).

Moreover, as with the supposed uniqueness of the dentition, a new body of science—much of which emerged after publication of the NAS Report—suggests that this ability will never be established. This peer-reviewed research indicates that due to its

[4] *See* National Academy of Sciences, available at http://www.nasonline.org/about-nas/mission/.
[5] Ex. F (Bush MA, Bush PJ, Sheets, HD. Statistical Evidence for the Similarity of the Human Dentition. J Forensic Sci 2011, 56(1):118-123 (observing significant correlations and non-uniform distributions of tooth positions as well as matches between dentitions)); Ex. G (Sheets HD, Bush PJ, Brzozowski C, Nawrocki LA, Ho P, and Bush MA. Dental Shape Match Rates in Selected and Orthodontically Treated Populations in New York State: A Two Dimensional Study. J Forensic Sci 2011, 56(3): 621-626 (finding random dental shape matches)); Ex. H (Bush MA, Bush PJ, Sheets HD. Similarity and Match Rates of the Human Dentition In 3 Dimensions: Relevance to Bitemark Analysis. Int J Leg Med 2011, 125(6): 779-784 (same)).
[6] *See supra fn.* 5.

anisotropic, viscoelastic, and non-linear properties, human skin cannot accurately record whatever uniqueness may be present in the human dentition.[7] *See* Ex. E at ¶ 8 (Bush Affidavit). This work demonstrates that skin's natural tension lines and tissue movement distort bite marks, often dramatically.[8] Bite marks from the same dentition may appear substantially different depending on the angle and movement of the body and whether the mark was made parallel or perpendicular to tension or Langer lines.[9] Other studies indicate that skin is so unreliable as a medium that similarly aligned dentitions may create indistinguishable marks. Even more concerning, this research also revealed that dentitions may appear to best match marks *they did not create*.[10]

Thus, current research strongly suggests that "even if the human dentition were unique . . . human skin is not capable of faithfully recording that uniqueness with sufficient fidelity to permit bitemark comparison." Ex. E at ¶ 23 (Bush Affidavit); *see also* Ex. A at 174 (NAS Report) ("[B]ite marks on the skin will change over time and can be distorted by the elasticity of the skin, the unevenness of the surface bite, and swelling and healing. These features may severely limit the validity of forensic odontology.").

Forensic Dentists Cannot Reliably Associate A Dentition With A Bite Mark

The third false assumption of bite mark analysis is that forensic dentists can reliably associate a dentition with a bite mark. But the NAS found that "[t]here is no science on the reproducibility of the different methods of analysis that lead to conclusions about the probability of a match. This includes reproducibility between experts and with the same expert over time." Ex. A at 174 (NAS Report). Indeed, "a standard for the type, quality, and number of individual characteristics required to indicate that a bite mark has reached a threshold of evidentiary value has not been established." *Id.* at 176. This is an especially acute problem in bite mark comparison because the manner in which skin heals or decomposes over time is not predictable, and therefore there is no methodology to account for the distortion of the injury caused by these processes. As a result, experts attempting to associate a particular dentition with a bite mark made on human skin can, at best, make educated guesses.

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[7] Ex. I (Bush MA, Bush PJ, Sheets HD. A Study of Multiple Bitemarks Inflicted in Human Skin by a Single Dentition Using Geometric Morphometric Analysis. Forensic Science International 211 (2011) 1-8); Ex. J (Bush MA, Thorsrud K, Miller RG, Dorion RBJ, Bush PJ. The Response of Skin to Applied Stress: Investigation of Bitemark Distortion in a Cadaver Model. J Forensic Sci 2010;55(1):71-76); Ex. K (Bush MA, Cooper HI, Dorion RBJ. Inquiry into the Scientific Basis For Bitemark Profiling and Arbitrary Distortion Compensation. J Forensic Sci 2010; 55(4):976-983); Ex. L (Miller RG, Bush PJ, Dorion RBJ, Bush MA. Uniqueness of the Dentition as Impressed in Human Skin: A Cadaver Model. J Forensic Sci 2009; 54(4):909-14) ("Miller, Uniqueness").

[8] Ex. M (Bush MA, Miller RG, Bush PJ, Dorion, RB. Biomechanical Factors in Human Dermal Bitemarks in a Cadaver Model. J Forensic Sci 2009 54(1): 167-176)).

[9] *Id.*

[10] *E.g.,* Ex. L (Miller, Uniqueness). For a real life example of how well an innocent person's dentition can appear to match a bite mark, *see* Ex. N at p. 46 (Amici Curiae Brief of Michael J. Saks, Thomas Albright, Thomas L. Bohan, Barbara E. Bierer and 34 Other Scientists, Statisticians and Law-And-Science Scholars and Practitioners In Support Of the Petition for Writ of Habeas Corpus by William Joseph Richards ("Scientists' Brief")) and *infra* on the wrongful conviction of Ray Krone.

Moreover, while the American Board of Forensic Odontology ("ABFO"), forensic odontology's only board certifying body, has issued "guidelines" for a range of conclusions concerning an association between a bite mark and a suspect, its members are not required to adopt the suggested terminology. Nor are they provided with any guidance on delineating between the various conclusions. More importantly, these guidelines were not arrived at scientifically but instead with nothing more than a show of hands of the members present at a meeting. *See* Ex. A at 174 (NAS Report) ("The [ABFO] guidelines, however, do not indicate the criteria necessary for using each method to determine whether the bite mark can be related to a person's dentition and with what degree of probability."). As the NAS found, "[e]ven when using the [ABFO] guidelines, different experts provide widely differing results . . . ." *Id.*

Ultimately, the NAS concluded that forensic odontologists lack "the capacity to consistently, and with a high degree of certainty, demonstrate a connection between evidence and a specific individual or source." *Id.* at 7; *see also id.* at 175 ("[T]he scientific basis is *insufficient to conclude that bite mark comparisons can result in a conclusive match*." (emphasis added)).

Even If Bite Marks Could Be "Matched," There Is No Evidence Of The Probative Value Of That Association

Even if there were science to support the notion that an association could reliably be made between a dentition and a bite mark, bite mark analysis still fails in its final assumption—that a scientifically valid estimate of the probative value of that association can be made. But as the NAS concluded, there is no way to determine the probability of a match because "there is no established science indicating what percentage of the population or subgroup of the population could also have produced [a] bite." *Id.* at 174; *see also* Ex. E at ¶ 28 (Bush Affidavit) ("[S]tatistical evidence for the likelihood of a random match is, as yet, unsupportable.").

This Commission recently took action regarding precisely the same type of scientifically invalid testimony in cases involving microscopic hair comparison. After the FBI acknowledged that its hair examiners had been making improper individualization claims and otherwise exaggerating the probative value of an association between a known and a suspected hair for decades, it, along with the National Association of Criminal Defense Lawyers and the Innocence Project, undertook an unprecedented review of thousands of cases to search for testimony that went beyond the bounds of science.[11]

The FBI also trained hundreds of state and local examiners to give similarly flawed testimony, and so the Commission has undertaken a case audit to "determine whether the issues identified by the FBI are also present in the testimony provided by state, county

[11] *See, e.g.,* Ex. A at 160 (NAS Report); Spencer Hsu, *U.S. Reviewing 27 Death Penalty Convictions for FBI Forensic Testimony Errors*, WASHINGTON POST, July 17, 2013, available at http://www.washingtonpost.com/local/crime/us-reviewing-27-death-penalty-convictions-for-fbi-forensic-testimony-errors/2013/07/17/6c75a0a4-bd9b-11e2-89c9-3be8095fe767_story.html.

and municipal laboratories."[12] This case audit will consider whether 1) "the report or testimony contain[ed] a statement of identification"; 2) "the report or testimony assign[ed] probability or statistical weight"; 3) "the report or testimony contain[ed] any other potentially misleading statements or inferences."[13] As the Commission has concluded, a hair

> examiner cannot provide a scientifically valid estimate of the rareness or frequency of [an] association. The examiner's testimony should reflect the fact that hair comparison cannot be used to make a positive identification of an individual. In other words, hair comparison can indicate, at the broad class level, that a contributor of a known sample could be included in a pool of people as a possible source of the hair evidence. However, the examiner should not give an opinion as to the probability or the likelihood of a positive association.[14]

These same limitations apply to bite mark evidence. *See* Ex. A at 176 (NAS Report). ("Bite mark testimony has been criticized basically on the same grounds as testimony by questioned document examiners and microscopic hair examiners."). Indeed, bite mark evidence is even more circumscribed, as the distorting properties of skin discussed above mean that bite mark comparison experts cannot even validly make an association between a mark and a dentition.

<u>Bite Marks Are Prone to Serious Error</u>

Given its lack of scientific basis, it is no surprise that bite mark comparison evidence is prone to serious error. Indeed, "error rates by forensic dentists are perhaps the highest of any forensic identification specialty still being practiced." Ex. N at 5 (Scientists' Brief). Devastating new research highlighting these profound error rates, conducted in part by the Vice President of the ABFO's own Executive Committee, has recently become public. This study, entitled *Construct Validity Bitemark Assessments Using the ABFO Bitemark Decision Tree* ("Construct Validity Study"), demonstrates that even the ABFO's most experienced forensic odontologists cannot agree on whether an injury is a bite mark *at all*, to say nothing of whether it was caused by a particular individual.

As part of the Construct Validity Study, photographs of 100 patterned injuries were shown to 103 ABFO board-certified Diplomates. They were asked to decide three questions: first, whether there was sufficient evidence to render an opinion on whether the patterned injury was a human bite mark; second, whether consistent with the ABFO decision tree, the injury was, indeed, a human bite mark, not a human bite mark, or

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[12] Texas Forensic Science Commission, *Statement Regarding Texas Hair Microscopy Review Texas Forensic Science Commission*, available at http://www.fsc.texas.gov/sites/default/files/Statement%20re%20Texas%20HM%20Review%20Final%20Draft%5B1%5D.pdf.

[13] *Id.*

[14] *Id.*

suggestive of a human bite mark (the three options the ABFO's guidelines currently provide); and third, whether, if a human bite mark, it had distinct, identifiable arches and individual tooth marks.[15] Thirty-nine Diplomates—accounting for nearly 40% of practicing ABFO Diplomates— finished all 100 questions, resulting in nearly 4,000 decisions. Drs. Pretty and Freeman did not examine the results for ground truth—i.e., whether the diplomates accurately determined what type of injury they were looking at—but rather, on an even more basic level, whether the diplomates agreed with one another. The results were shockingly poor. Determinations were wildly inconsistent across forensic odontologists on the vast majority of marks. As *The Washington Post* reported, on the question of whether the injury provided sufficient information from which to make a determination as to origin—"the most basic question a bite mark specialist should answer before performing an analysis"—

> the 39 analysts came to unanimous agreement on just 4 of the 100 case studies. In only 20 of the 100 was there agreement of 90 percent or more on this question. By the time the analysts finished question two — whether the photographed mark is indeed a human bite — there remained only 16 of 100 cases in which 90 percent or more of the analysts were still in agreement. And there were only 38 cases in which at least 75 percent were still in agreement. . . By the time the analysts finished question three, they were significantly fractionalized on nearly all the cases. Of the initial 100, there remained just 8 case studies in which at least 90 percent of the analysts were still in agreement.[16]

These failures are deeply disturbing. As a group of distinguished scientists reviewing the study's results concluded, "if dental examiners cannot agree on whether or not there is enough information in an injury to determine whether it is a bitemark, and cannot agree on whether or not a wound is a bitemark, then there is nothing more they can be relied upon to say." Ex. N (Scientists' Brief).

Given the lack of a scientific basis for bite mark comparison evidence, the Construct Validity Study's results are hardly surprising. Nor are they anomalous: a study published in the May 2013 Journal of Forensic Sciences largely presaged its findings.[17] As that study noted, "[w]hile most odontologists would suggest they can determine with a reasonable degree of certainty what is and what is not a bitemark, there is little evidence to support this claim."[18] Looking to close this gap, researchers asked fifteen Australian forensic odontologists—who comprised the majority of those practicing forensic odontology in Australia—to examine six images of potential bite marks, five of which

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[15] Ex. O (Radley Balko, *A Bite Mark Matching Advocacy Group Just Conducted A Study That Discredits Bite Mark Evidence*, WASHINGTON POST, April 8, 2015, available at http://www.washingtonpost.com/news/the-watch/wp/2015/04/08/a-bite-mark-matching-advocacy-group-just-conducted-a-study-that-discredits-bite-mark-evidence/).

[16] *Id.*

[17] Ex. P (Mark Page, et al., Expert Interpretation of Bitemark Injuries—A Contemporary Study , 58(3) J. Forensic Sci. 664, 664 (May 2013)).

[18] Id.

were of marks confirmed by living victims to have been caused by teeth.[19] The odontologists were then asked in narrative form whether the injuries were, in fact, bite marks. As with the Construct Validity Study, "conclusions between practitioners [were] highly variable."[20] Thus, "the qualitative data plainly verifie[d] the fact that there is a wide range of opinion expressed over even the most basic assumption in bitemark analysis: that of the origin of the mark itself."[21] The study further concluded that this "[i]nconsistency indicates a fundamental flaw in the methodology of bitemark analysis and should lead to concerns regarding the reliability of any conclusions reached about matching such a bitemark to a dentition."[22]

The inability of bite mark analysts to properly identify human bite marks as such in the first instance are only compounded when they are asked to make conclusions regarding the perpetrator. Study after study has demonstrated a "disturbingly high false-positive error rate" in bite mark comparisons.[23] For example:

- a 1975 study found that bite mark examiners made "incorrect identification[s] of . . . bites" on pig skin 24% of the time even when the bites were made "under ideal laboratory conditions" and 91% of the time when the bites were photographed 24 hours after being made;

- a 1999 American Board of Forensic Odontology Bitemark Workshop in which "ABFO diplomats attempted to match four bite marks to seven dental models" resulted in 63.5% false positives;

- a 2001 study of "bites made in pig skin" resulted in between 11.9 and 22.0% "false positive identifications . . . for various groups of forensic odontologists."[24]

These studies demonstrate that bite mark evidence simply cannot do what its practitioners purport.

Bite Marks Have Led to Many Miscarriages of Justice

Steven Mark Chaney

Simply put, there is no science that confirms biting surfaces of teeth are unique, that these unique features can be accurately recorded in human flesh, or that practitioners can objectively and systematically measure this uniqueness—which is to say there is no

[19] *Id.* at 665.
[20] *Id.* at 671.
[21] *Id.* at 668.
[22] *Id.* at 670.
[23] Ex. Q (C. Michael Bowers, Problem-Based Analysis of Bitemark Misidentifications: The Role of DNA, 159S Forensic Sci. Int'l S104, S107 (2006)).
[24] *Id.* at S106.

science whatsoever which "confirm[s] the fundamental basis for the science of bite mark comparison." Ex. A at 175 (NAS Report). What science there is, moreover, affirmatively disproves it. *See* Ex. E at ¶ 30 (Bush Affidavit) ("The fundamental tenets of bitemark analysis are not supported by science. Our research, confirmed by the NAS report, suggests, moreover, that they cannot be."). The practice of bite mark comparison is also prone to high rates of serious error. Yet our client, Steven Mark Chaney, and others like him, languish in prisons and jails in Texas and elsewhere, often on the basis of little more than subjective speculation masquerading as science.

On December 14, 1987, Mr. Chaney was convicted of the murder of John Sweek and sentenced to life in prison. The primary driver of his conviction was the testimony of two forensic odontologists that Mr. Chaney's teeth matched an alleged bite mark on the body of one of the victims and that there was only a one-in-a-million chance that Mr. Chaney wasn't the source of the mark. The prosecution told the jury that it was on this evidence alone that they should convict:

> Most of all, we have the bite mark. I wouldn't ask you to convict just based on the testimony of the tennis shoe, of the statements [Chaney] made to Investigator Westphalen, or the statements [Chaney] made to . . . [the informant]. But, by golly, I'm going to ask you to convict on that dental testimony. . . . And [Dr. Hales] said to you that only one in a million people could have possibly made that bite mark. What more do you need?[25]

The prosecutor's exhortations had their intended effect; as one juror testified in a post-verdict colloquy, "Do you want me to tell what made my decision? [...] The bitemark."[26]

Without the link provided by forensic odontology, the case against Mr. Chaney could not have been sustained. He was arrested in June of 1987, after the bodies of a drug dealer and his wife were found murdered in the apartment they shared in East Dallas.[27] John Sweek and his wife Sally had had their throats slit, and both suffered many additional stab wounds.[28] The Sweeks had been dealing cocaine from their apartment for at least two years prior to their deaths, and their family members immediately informed the police that the couple's drug suppliers had threatened to kill John in the past for non-payment.[29] The family believed these suppliers included a man named Juan Gonzalez, who they understood to be a member of the "Mexican Mafia" active in Dallas's drug trade. Gonzalez had apparently been looking for John just before the murders, and the family accordingly suspected his involvement.[30]

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[25] Tr. II 801-02.
[26] Tr. II Vol. 9, p. 6.
[27] *Chaney v. State,* 775 S.W.2d 722, 723 (Tex. Ct. App. 1989).
[28] *Id.*
[29] *E.g.,* First Trial Tr. ("Tr. I") 158-61, 167; Detective Westphalen Investigative Notes, Dallas Police Department File ("W. Notes") 150.
[30] *E.g.,* W. Notes 185.

While this information originally led police to suspect Gonzalez, Mr. Chaney, a regular client and friend of the Sweeks, was ultimately arrested after a friend and fellow customer of the Sweeks informed police that he believed that Mr. Chaney had a motive for the murders because he owed the Sweeks approximately $500 for drugs.[31] Though Mr. Chaney had nine alibi witnesses who broadly confirmed his whereabouts the day of the murders (and no criminal history apart from two misdemeanor marijuana convictions), the state proceeded to trial against him.[32]

As the prosecutor told the jury in closing, by far the most compelling evidence of Mr. Chaney's guilt was the testimony of two forensic odontologists, Drs. Jim Hales and Homer Campbell, both of whom also played key roles in the wrongful Texas convictions of Calvin Washington and Joe Sidney Williams. Drs. Hales and Campbell each testified that the alleged bite mark on John's forearm matched Chaney's dentition. *See* Ex. R (Hales Testimony) at 359, 368, 373, 375, 384, 389; Ex. S at 480, 482 (Campbell Testimony). Dr. Campbell testified that Chaney made the alleged bite mark to a reasonable dental certainty. *See* Ex. S at 462, 482–83 (Campbell Testimony). Dr. Hales also testified that there was a "[o]ne to a million" chance that someone other than Mr. Chaney could have left the bite mark. *See* Ex. R at 433 (Hales Testimony).

Today, we know that the bite mark evidence offered against Mr. Chaney was not worthy of belief and should never have been proffered to a jury. Indeed the testimony proffered by Drs. Hales and Campbell is exactly the type that the NAS has recognized as unreliable and baseless and that substantial scientific evidence has disproved. As an initial matter, the testimony purporting to "match" Mr. Chaney to the marks, or otherwise to identify him as the biter, is unsupportable as a matter of science. *See* Ex. A at 175 (NAS Report) ("[T]he scientific basis is *insufficient to conclude that bite mark comparisons can result in a conclusive match.*" (emphasis added)); Ex. N at 25 (Scientists' Brief) (noting that "the uniqueness assumption [regarding the dentition] has increasingly come to be recognized as unproved and unsound . . . ."); Ex. E at ¶ 29 (Bush Affidavit) (conclusions "that bitemark comparison evidence permitted an odontologist to determine that a particular dentition created a particular mark left in human skin (i.e., individualization) . . . are not supported by science. Indeed, we know from our research that the distorting effects of skin can result in random matches of non-biting dentitions to bitemarks").

Dr. Hales's assertion that there was a "[o]ne to a million" chance that someone other than Mr. Chaney made the mark further exemplifies the foundationless conclusions characteristic of bite mark testimony. *See* Ex. A at 174 (NAS Report) ("[T]here is no established science indicating what percentage of the population or subgroup of the population could also have produced the bite."); Ex. N at 22 (Scientists' Brief) ("Unfortunately, forensic dentists have very little information of the kind needed to make an informed assessment [as to the likelihood of a random match]. . . . Actual probabilities are not known because no population studies have been carried out to determine what

[31] *E.g.,* Second Trial Transcript ("Tr. II") 200-207; Tr. I 146-47; *Chaney* at 775 S.W.2d at 724.
[32] *E.g.,* Tr. II 530-41, 636-644, 644-58, 659-670, 711-723, 670-711, 740-46; 724-727; 727-730; *Chaney* at 775 S.W.2d at 724-25.

features to consider, much less the actual degree of variation in teeth shapes, sizes, positions, etc., that exist in the population." (internal quotation marks omitted)); Ex. E at ¶ 29 (Bush Affidavit) ("Dr. Hales's assertion that there was 'one to a million' chance that anyone other than Mr. Chaney created the mark has now been entirely discredited by our work and by the work of the NAS; there is simply no scientific support to offer that, or any other figure, regarding the likelihood of a random match."). This proffer of statistical evidence without sufficient foundation, is, moreover, exactly the same as the flawed hair microscopy testimony on which this Commission recently took action.

Mr. Chaney is currently in the process of challenging his conviction pursuant to Texas's new discredited science statute, Article 11.073. Whether or not Mr. Chaney ultimately obtains relief from the courts, it is clear that the continued incarceration of a person like Mr. Chaney on what we now know to be utterly unreliable testimony, without basis in science, is an injustice that this Commission can and should ensure that Texas avoids repeating.

Bite Mark Evidence Has Led to Many Wrongful Convictions

Bite mark evidence has also been directly responsible for the wrongful conviction or indictment of at least two dozen people. (A complete list of these known wrongful convictions is attached as Ex. D). Ray Krone's case is the paradigmatic example such a wrongful conviction. Mr. Krone was wrongfully convicted and sentenced to death after a bartender at a bar he frequented was kidnapped and murdered.[33] Police had a Styrofoam impression made of Mr. Krone's apparently distinctive teeth for comparison to injuries found on the victim's body; he thereafter became known in the media as the "Snaggle Tooth Killer" due to his crooked teeth.[34] Mr. Krone was convicted in two trials, both times largely on the testimony of Dr. Raymond Rawson, a board-certified ABFO Diplomate, that a bite mark found on the victim matched Mr. Krone's teeth. Mr. Krone served ten years in prison, some of this time on death row before being exonerated by DNA testing. This testing excluded Mr. Krone but inculpated another man, who had lived near the victim and who was then serving a sentence for an unrelated sexual assault.[35] A picture of the bite mark found on the victim along with Mr. Krone's dentition (appearing on page 46 of Ex. N (Scientists' Brief)) is a powerful demonstration of how well-matched an innocent person's dentition may appear to be to a mark in fact made by another person.

Robert Lee Stinson, too, served more than two decades in prison for the rape and murder of an elderly woman he did not commit. Mr. Stinson became a suspect after police officers, who had been informed by a forensic odontologist that the perpetrator

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[33] Innocence Project, *Know the Cases: Ray Krone*, http://www.innocenceproject.org/Content/Ray_Krone.php.
[34] Ex. D (List of Bite Mark Exonerations).
[35] Innocence Project, *Know the Cases: Ray Krone*, http://www.innocenceproject.org/Content/Ray_Krone.php.

was missing a tooth, told him a joke, causing him to laugh and expose his teeth.[36] Mr. Stinson's ultimate conviction rested largely on the testimony of a forensic dentist that bite marks found on the victim "had to have been made by teeth identical" to Mr. Stinson's. The dentist testified that there was "no margin for error" in his conclusion.[37] DNA later demonstrated that, despite the odontologists' certainty, Mr. Stinson was innocent.[38] Mr. Krone and Mr. Stinson's stories represent only a few of the injustices borne from the use of this so-called science.[39]

In addition to the decades stolen from innocent people, bite mark evidence has also been responsible for at least one needless death, after a real perpetrator was left free to rape and kill.[40] Levon Brooks was wrongfully convicted of the rape and murder of a three-year old girl after bite mark comparison not only wrongly included him, but also excluded the actual perpetrator, Justin Albert Johnson. After Johnson evaded punishment for this terrible crime, he raped and murdered another three-year old child.[41] After this second child was killed, bite mark evidence was used *again* to inculpate another innocent man, Kennedy Brewer. Mr. Brewer was convicted of capital murder and sexual battery and sentenced to death, based in part on testimony that the supposed bite marks found on the victim were "indeed and without a doubt" made by him.[42] DNA evidence ultimately proved Mr. Brewer's innocence and Johnson's guilt.[43]

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[36] Innocence Project, *Know the Cases: Robert Lee Stinson*, http://www.innocenceproject.org/Content/Robert_Lee_Stinson.php (another dentist also testified that the bite mark evidence was "high quality" and "overwhelming").
[37] *Id.*
[38] *Id.*
[39] In addition to Ex. D, the Innocence Project's list of known bite mark wrongful convictions and indictments, more about other wrongful convictions can be found in Ex. T, the Washington Post's exhaustive four-part series on bite mark evidence. *See, e.g.*, Radley Balko, *How The Flawed 'Science' Of Bite Mark Analysis Has Sent Innocent People To Prison*, Washington Post, Feb. 13, 2015, *available at* http://www.washingtonpost.com/news/the-watch/wp/2015/02/13/how-the-flawed-science-of-bite-mark-analysis-has-sent-innocent-people-to-jail/. ("[T]he scientific community has declared that bite mark matching isn't reliable and has no scientific foundation for its underlying premises, and that until and unless further testing indicates otherwise, it shouldn't be used in the courtroom.").
[40] Innocence Project, *Know the Cases: Levon Brooks*, http://www.innocenceproject.org/Content/Levon_Brooks.php ("[I]t could be no one but Levon Brooks that bit this girl's arm."); Shaila Dewan, *New Suspect Is Arrested in 2 Mississippi Killings*, N.Y. TIMES, Feb. 8, 2008, http://www.nytimes.com/2008/02/08/us/08dna.html?_r=0 ("Mr. Johnson had been excluded in both cases by bite-mark comparisons.").
[41] *See* Innocence Project, *Know the Cases: Kennedy Brewer*, http://www.innocenceproject.org/Content/Kennedy_Brewer.php.
[42] *Id.*
[43] *Id.* In a similar story, Dane Collins was wrongfully charged with the rape and murder of his stepdaughter based largely on bite mark evidence. Though the state ultimately did not proceed against Mr. Collins, "the DA gave several public interviews stating that while there was not enough evidence to try the case, he believed Collins was guilty of the crime." Ex. D (List of Bite Mark Exonerations). Fifteen years later, DNA from a databank was found to match DNA left at the crime scene; the real perpetrator was already serving a sentence of life imprisonment for the kidnapping and rape of another woman. *See* Jeremy Pawloski, *Plea in '89 Slaying Eases Parents' Pain*, Albuquerque Journal, August 14, 2005, available at http://abqjournal.com/news/state/380765nm08-14-05.htm.

Wrongful Convictions in Texas: Calvin Washington and Joe Sidney Williams

Texas has not escaped the scourge of wrongful bite mark convictions. Calvin Washington and his codefendant, Joe Sidney Williams, were exonerated after spending years in prison for a murder they did not commit. On March 1, 1986, the body of Juanita White[44] was discovered beaten, raped, and murdered in her home. A bite mark was found on her body.[45] The prosecution produced evidence that Mr. White and Mr. Williams were in possession of Ms. White's car the day after the murder and had sold some of her belongings the night she was killed.[46] Originally, forensic odontologist Jim Hales told police that Mr. Washington made the mark, but by the time of trial, another forensic odontologist, Homer Campbell, had concluded that Mr. Williams was the source of the mark.[47] Campbell testified at both trials that Mr. Washington's teeth were consistent with the mark found on Ms. White's body, thus linking both men to the crime.[48]

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[44] Ms. White was also the mother of David Wayne Spence, another person possibly wrongfully convicted and executed in Texas on the basis of bite mark evidence. *See* Michael Hall, *The Murders at the Lake*, Texas Monthly, April 2014, http://www.texasmonthly.com/story/investigating-the-lake-waco-murders?fullpage=1 (Hall, *Murders*). Mr. Spence, along with three co-defendants, was convicted in 1985 of the murders of three teenagers in Waco, Texas. *Id.* The prosecution's theory was that Muneer Deeb, the 23 year-old operator of a convenience store, had hired Mr. Spence and brothers Tony and Gilbert Melendez to kill an employee on whom, like all his employees, he had taken out a life insurance policy. The state theorized that Mr. Spence killed another woman by mistake, along with two other teenagers who had witnessed the crime. *See* National Registry of Exonerations, *Muneer Deeb,* https://www.law.umich.edu/special/exoneration/Pages/casedetail.aspx?caseid=3168 (Deeb Registry). The state's major evidence of guilt was the testimony of Dr. Homer Campbell that "Spence was 'the only individual' to a 'reasonable medical and dental certainty' who could have bitten the women." Hall, *Murders supra.*

Mr. Deeb and Mr. Spence were both convicted at trial in 1985, with Mr. Spence sentenced to death; the Melendez brothers pleaded guilty. In 1992, Texas Criminal Court of Appeals overturned Mr. Deeb's conviction on the basis of improperly admitted informant testimony; he was then acquitted on retrial. *See* Deeb Registry *supra.* Despite substantial doubts about his guilt, Mr. Spence was executed in 1997. *See* Bob Herbert, *The Wrong Man*, N.Y. TIMES, July 25, 1997, available at ("Mr. Spence was almost certainly innocent. This is not a hypothesis conveniently floated by death-penalty opponents. Those who believe that David Spence did not commit the crime for which he died include the lieutenant, now retired, who supervised the police investigation of the murders; the detective who actually conducted the investigation, and a conservative Texas businessman who, almost against his will, looked into the case and became convinced that Mr. Spence was being railroaded."). Both Gilbert Melendez and Mr. Deeb have since passed away from natural causes. Tony Meldenez, who remains incarcerated, has recently sought and obtained DNA testing on, among other items, shoelaces used to tie up the victims; results of these tests have yet to be made public. *See* Cindy V. Culp, *Evidence From Lake Waco Murders Case To Be Sent To Arkansas Lab,* WacoTrib.com, April 4, 2013, available at http://www.wacotrib.com/news/courts_and_trials/evidence-from-lake-waco-murders-case-to-be-sent-to/article_fd971525-8adf-5375-b683-d0ab1b7717bf.html.

[45] Innocence Project, *Know the Cases: Calvin Washington*, http://www.innocenceproject.org/cases-false-imprisonment/calvin-washington.

[46] *Id.*

[47] Hall, *Murders*, *supra note* 44.

[48] *Id.*

In 1992, the Texas Court of Criminal appeals set aside Mr. Williams's conviction, determining that alleged statements by Mr. Washington were improperly admitted at Mr. Williams's trial. The charges against Mr. Williams were ultimately dismissed, and he was released in 1993.[49] Mr. Washington, who remained imprisoned, continued to seek DNA testing. In 2001, he obtained tests which proved that blood on a shirt found at his home was not the victim's, as the prosecution had claimed at trial. Later DNA tests excluded both Mr. Washington and Mr. Williams from semen found inside the victim; DNA in the semen was matched to an original suspect in the crime, who committed a similar crime shortly after Ms. White was killed.[50]

The Need for This Commission's Intervention

Bite mark evidence is unscientific and unreliable, and thus grossly unfit for use in criminal proceedings. *See* Ex. E at ¶ 30 (Bush Affidavit) ("Unless and until these premises [regarding the uniqueness of the dentition and the ability of human skin to record that uniqueness] can be scientifically demonstrated, bitemark comparison evidence should not be admitted in criminal proceedings."); Ex. N at 45 (Scientists' Brief) ("[T]he foundations of bitemark identification are unsound."). It thus presents a perfect opportunity for this Commission to exercise its statutory mandate to evaluate and report on the discipline's "integrity and reliability." Tex. Crim. Proc. Code Ann. § art. 38.01(4)(b-1)(1). A thorough review of the state of bite mark science and an audit of the cases premised upon it would ameliorate some of the damage this technique has already done to the Texas criminal justice system; a moratorium on its use would prevent it from doing any further harm. *See* Tex. Crim. Proc. Code Ann. § art. 38.01(4)(b-1)(3) ("the investigation may include the preparation of a written report that contains: . . . other recommendations that are relevant, as determined by the commission"); Tex. Crim. Proc. Code Ann. § art. 38.01(4)(a)(3).

Not only is such a report and audit well within this Commission's statutory authority, but action by an independent body like this one may well be necessary to ensure that bite marks are no longer used to convict innocent people in Texas. A series of articles published earlier this year by *The Washington Post* (appended as Ex. T) revealed the ABFO's longstanding pattern and practice of suppressing dissent and punishing scrutiny. The articles reveal that most recently, the ABFO sought to silence one of its most prominent critics, Dr. C. Michael Bowers, by filing a retaliatory ethics complaint against him in front of the American Academy of Forensic Sciences ("AAFS"). *See* Ex. T at 27-38. In addition to this "transparent attempt to purge someone who has been a problem for [the ABFO]," *id.* at 29 (internal quotation marks omitted), *The Washington Post* stories also reflect efforts by the ABFO to silence Dr. Mary and Peter Bush, who have conducted the most substantial (and indeed, largely the only) scientific research into the fundamental assumptions underlying bite mark analysis. *Id.* at 27-38. *The Washington Post* reveals that the Bushes' basic research was welcomed and supported by the ABFO until they "began to come back with results that called the entire discipline

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[49] National Registry of Exonerations, *Joe Sidney Williams*, available at https://www.law.umich.edu/special/exoneration/Pages/casedetail.aspx?caseid=3748.
[50] *Id.*

into question. . . ." *Id.* at 38-46. Once the Bushes' results made plain that there is no scientific basis for bite mark comparisons, the forensic dentistry community undertook "a nasty campaign to undermine [their] credibility." *Id.* at 40. These campaigns by bite mark adherents to silence their critics and suppress science showing the invalidity of their claims are all the more reason for this Commission, as an independent body not subject to capture or intimidation, to intervene.

On behalf of Mr. Chaney and others like him, we ask that this Commission take action and reverse the damage bite mark comparison and its disciples have done to the integrity of criminal justice in Texas. By conducting an investigation and audit, and in calling for a moratorium, this Commission can not only take a stand for reliability and integrity in forensic science in Texas, but also ensure that wrongful convictions like those of Calvin Washington and Joe Sidney Williams remain things of the past.

Very Truly Yours,

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List of Exhibits

Ex. A: National Academy of Sciences, Committee on Identifying the Needs of the Forensic Sciences Community, Strengthening Forensic Science in the United States: a Path Forward (2009).

Ex. B: Amanda Lee Myers, *Men Wrongly Convicted or Arrested on Bite Evidence*, Associated Press, June 16, 2013, available at http://news.yahoo.com/men-wrongly-convicted-arrested-bite-evidence-150610286.html.

Ex. C: Amanda Lee Myers, *Bites Derided as Unreliable in Court*, Associated Press, June 16, 2013, available at http://news.yahoo.com/ap-impact-bites-derided-unreliable-court-150004412.html.

Ex. D: List of Bite Mark Exonerations.

Ex. E: Affidavit of Dr. Mary and Peter Bush.

Ex. F: Bush MA, Bush PJ, Sheets, HD. Statistical Evidence for the Similarity of the Human Dentition. J Forensic Sci 2011, 56(1):118-123.

Ex. G: Sheets HD, Bush PJ, Brzozowski C, Nawrocki LA, Ho P, and Bush MA. Dental Shape Match Rates in Selected and Orthodontically Treated Populations in New York State: A Two Dimensional Study. J Forensic Sci 2011, 56(3):621-626.

Ex. H: Bush MA, Bush PJ, Sheets HD. Similarity and Match Rates of the Human Dentition In 3 Dimensions: Relevance to Bitemark Analysis. Int J Leg Med 2011, 125(6):779-784.

Ex. I: Bush MA, Bush PJ, Sheets HD. A Study of Multiple Bitemarks Inflicted in Human Skin by a Single Dentition Using Geometric Morphometric Analysis. Forensic Science International 211 (2011) 1-8.

Ex. J: Bush MA, Thorsrud K, Miller RG, Dorion RBJ, Bush PJ. The Response of Skin to Applied Stress: Investigation of Bitemark Distortion in a Cadaver Model. J Forensic Sci 2010;55(1):71-76.

Ex. K: Bush MA, Cooper HI, Dorion RBJ. Inquiry into the Scientific Basis For Bitemark Profiling and Arbitrary Distortion Compensation. J Forensic Sci 2010; 55(4):976-983.

Ex. L: Miller RG, Bush PJ, Dorion RBJ, Bush MA. Uniqueness of the Dentition as Impressed in Human Skin: A Cadaver Model. J Forensic Sci 2009; 54(4):909-14.

Ex. M: Bush MA, Miller RG, Bush PJ, Dorion, RB. Biomechanical Factors in Human Dermal Bitemarks in a Cadaver Model. J Forensic Sci 2009 54(1):167-176.

Ex. N: Amici Curiae Brief of Michael J. Saks, Thomas Albright, Thomas L. Bohan, Barbara E. Bierer and 34 Other Scientists, Statisticians and Law-And-Science Scholars and Practitioners In Support Of the Petition for Writ of Habeas Corpus by William Joseph Richards.

Ex. O: Radley Balko, *A Bite Mark Matching Advocacy Group Just Conducted A Study That Discredits Bite Mark Evidence*, Washington Post, April 8, 2015, available at http://www.washingtonpost.com/news/the-watch/wp/2015/04/08/a-bite-mark-matching-advocacy-group-just-conducted-a-study-that-discredits-bite-mark-evidence/.

Ex. P: Mark Page, et al., Expert Interpretation of Bitemark Injuries—A Contemporary Study , 58(3) J. Forensic Sci. 664, 664 (May 2013).

Ex. Q: C. Michael Bowers, Problem-Based Analysis of Bitemark Misidentifications: The Role of DNA, 159S Forensic Sci. Int'l S104, S107 (2006).

Ex. R: Dr. Hales Testimony.

Ex. S: Dr. Campbell Testimony.

Ex. T: Radley Balko, *How The Flawed 'Science' Of Bite Mark Analysis Has Sent Innocent People To Prison*, Washington Post, Feb. 13, 2015, *available at* http://www.washingtonpost.com/news/the-watch/wp/2015/02/13/how-the-flawed-science-of-bite-mark-analysis-has-sent-innocent-people-to-jail/.

Exhibit

A

STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES

A PATH FORWARD

Committee on Identifying the Needs of the Forensic Science Community

Committee on Science, Technology, and Law
Policy and Global Affairs

Committee on Applied and Theoretical Statistics
Division on Engineering and Physical Sciences

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By contrast, much more research is needed on the natural variability of burn patterns and damage characteristics and how they are affected by the presence of various accelerants. Despite the paucity of research, some arson investigators continue to make determinations about whether or not a particular fire was set. However, according to testimony presented to the committee,[118] many of the rules of thumb that are typically assumed to indicate that an accelerant was used (e.g., "alligatoring" of wood, specific char patterns) have been shown not to be true.[119] Experiments should be designed to put arson investigations on a more solid scientific footing.

FORENSIC ODONTOLOGY

Forensic odontology, the application of the science of dentistry to the field of law, includes several distinct areas of focus: the identification of unknown remains, bite mark comparison, the interpretation of oral injury, and dental malpractice. Bite mark comparison is often used in criminal prosecutions and is the most controversial of the four areas just mentioned. Although the identification of human remains by their dental characteristics is well established in the forensic science disciplines, there is continuing dispute over the value and scientific validity of comparing and identifying bite marks.[120]

Many forensic odontologists providing criminal testimony concerning bite marks belong to the American Board of Forensic Odontology (ABFO), which was organized in 1976 and is recognized by the American Academy of Forensic Sciences as a forensic specialty. The ABFO offers board certification to its members.[121]

Sample Data and Collection

Bite marks are seen most often in cases of homicide, sexual assault, and child abuse. The ABFO has approved guidelines for the collection of evidence from bite mark victims and suspected biters.[122] The techniques for obtaining bite mark evidence from human skin—for example, various forms of photography, dental casts, clear overlays, computer enhancement, electron microscopy, and swabbing for serology or DNA—generally are

[118] J. Lentini. Scientific Fire Analysis, LLC. Presentation to the committee. April 23, 2007. Available at www7.nationalacademies.org/stl/April%20Forensic%20Lentini.pdf.

[119] NFPA 921 Guide for Explosion and Fire Investigations, 2008 Edition. Quincy, MA: National Fire Protection Association.

[120] E.g., J.A. Kieser. 2005. Weighing bitemark evidence: A postmodern perspective. *Journal of Forensic Science, Medicine, and Pathology* 1(2):75-80.

[121] American Board of Forensic Odontology at www.abfo.org.

[122] Ibid.

well established and relatively noncontroversial. Unfortunately, bite marks on the skin will change over time and can be distorted by the elasticity of the skin, the unevenness of the surface bite, and swelling and healing. These features may severely limit the validity of forensic odontology. Also, some practical difficulties, such as distortions in photographs and changes over time in the dentition of suspects, may limit the accuracy of the results.[123]

Analyses

The guidelines of the ABFO for the analysis of bite marks list a large number of methods for analysis, including transillumination of tissue, computer enhancement and/or digitalization of the bite mark or teeth, stereomicroscopy, scanning electron microscopy, video superimposition, and histology.[124] The guidelines, however, do not indicate the criteria necessary for using each method to determine whether the bite mark can be related to a person's dentition and with what degree of probability. There is no science on the reproducibility of the different methods of analysis that lead to conclusions about the probability of a match. This includes reproducibility between experts and with the same expert over time. Even when using the guidelines, different experts provide widely differing results and a high percentage of false positive matches of bite marks using controlled comparison studies.[125]

No thorough study has been conducted of large populations to establish the uniqueness of bite marks; theoretical studies promoting the uniqueness theory include more teeth than are seen in most bite marks submitted for comparison. There is no central repository of bite marks and patterns. Most comparisons are made between the bite mark and dental casts of an individual or individuals of interest. Rarely are comparisons made between the bite mark and a number of models from other individuals in addition to those of the individual in question. If a bite mark is compared to a dental cast using the guidelines of the ABFO, and the suspect providing the dental cast cannot be eliminated as a person who could have made the bite, there is no established science indicating what percentage of the population or subgroup of the population could also have produced the bite. This follows from the basic problems inherent in bite mark analysis and interpretation.

As with other "experience-based" forensic methods, forensic odontology suffers from the potential for large bias among bite mark experts in evaluating a specific bite mark in cases in which police agencies provide the suspects for comparison and a limited number of models from which

[123] Rothwell, op. cit.
[124] American Board of Forensic Odontology, op. cit.
[125] Bowers, op. cit.

to choose from in comparing the evidence. Bite marks often are associated with highly sensationalized and prejudicial cases, and there can be a great deal of pressure on the examining expert to match a bite mark to a suspect. Blind comparisons and the use of a second expert are not widely used.

Scientific Interpretation and Reporting of Results

The ABFO has issued guidelines for reporting bite mark comparisons, including the use of terminology for conclusion levels, but there is no incentive or requirement that these guidelines be used in the criminal justice system. Testimony of experts generally is based on their experience and their particular method of analysis of the bite mark. Some convictions based mainly on testimony by experts indicating the identification of an individual based on a bite mark have been overturned as a result of the provision of compelling evidence to the contrary (usually DNA evidence).[126]

More research is needed to confirm the fundamental basis for the science of bite mark comparison. Although forensic odontologists understand the anatomy of teeth and the mechanics of biting and can retrieve sufficient information from bite marks on skin to assist in criminal investigations and provide testimony at criminal trials, the scientific basis is insufficient to conclude that bite mark comparisons can result in a conclusive match. In fact, one of the standards of the ABFO for bite mark terminology is that, "Terms assuring unconditional identification of a perpetrator, or without doubt, are not sanctioned as a final conclusion."[127]

Some of the basic problems inherent in bite mark analysis and interpretation are as follows:

(1) The uniqueness of the human dentition has not been scientifically established.[128]
(2) The ability of the dentition, if unique, to transfer a unique pattern to human skin and the ability of the skin to maintain that uniqueness has not been scientifically established.[129]
    i. The ability to analyze and interpret the scope or extent of distortion of bite mark patterns on human skin has not been demonstrated.
    ii. The effect of distortion on different comparison techniques is not fully understood and therefore has not been quantified.

[126] Bowers, op. cit.
[127] American Board of Forensic Odontology, op. cit.
[128] Senn, op. cit.
[129] Ibid.

(3) A standard for the type, quality, and number of individual characteristics required to indicate that a bite mark has reached a threshold of evidentiary value has not been established.

Summary Assessment

Despite the inherent weaknesses involved in bite mark comparison, it is reasonable to assume that the process can sometimes reliably exclude suspects. Although the methods of collection of bite mark evidence are relatively noncontroversial, there is considerable dispute about the value and reliability of the collected data for interpretation. Some of the key areas of dispute include the accuracy of human skin as a reliable registration material for bite marks, the uniqueness of human dentition, the techniques used for analysis, and the role of examiner bias.[130] The ABFO has developed guidelines for the analysis of bite marks in an effort to standardize analysis,[131] but there is still no general agreement among practicing forensic odontologists about national or international standards for comparison.

Although the majority of forensic odontologists are satisfied that bite marks can demonstrate sufficient detail for positive identification,[132] no scientific studies support this assessment, and no large population studies have been conducted. In numerous instances, experts diverge widely in their evaluations of the same bite mark evidence,[133] which has led to questioning of the value and scientific objectivity of such evidence.

Bite mark testimony has been criticized basically on the same grounds as testimony by questioned document examiners and microscopic hair examiners. The committee received no evidence of an existing scientific basis for identifying an individual to the exclusion of all others. That same finding was reported in a 2001 review, which "revealed a lack of valid evidence to support many of the assumptions made by forensic dentists during bite mark comparisons."[134] Some research is warranted in order to identify the circumstances within which the methods of forensic odontology can provide probative value.

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[130] Ibid.

[131] American Board of Forensic Odontology, op. cit.

[132] I.A. Pretty. 2003. A Web-based survey of odontologists' opinions concerning bite mark analyses. *Journal of Forensic Sciences* 48(5):1-4.

[133] C.M. Bowers. 2006. Problem-based analysis of bite mark misidentifications: The role of DNA. *Forensic Science International* 159 Supplement 1:s104-s109.

[134] I.A. Pretty and D. Sweet. 2001. The scientific basis for human bitemark analyses—A critical review. *Science and Justice* 41(2):85-92. Quotation taken from the abstract.

Exhibit

B

Men wrongly convicted or arrested on bite evidence

By **AMANDA LEE MYERS**
June 16, 2013 11:06 AM

At least 24 men convicted or arrested based largely on murky bite-mark evidence have been exonerated by DNA testing, had charges dropped or otherwise been proved not guilty. Many spent more than a decade in prison, and one man was behind bars for more than 23 years before he was exonerated. One man is still in prison as an appeal works through the courts. The Associated Press compiled this list of some of the more notable cases using court records, news reports and information from the Innocence Project.

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LEVON BROOKS AND KENNEDY BREWER

Brooks, of Brooksville, Miss., was convicted in 1992 of raping and killing his ex-girlfriend's 3-year-old daughter and sentenced to life in prison after Dr. Michael West testified marks on the girl were human bites that matched Brooks.

In a separate but similar case, Brewer, also of Brooksville, was convicted in 1995 of raping and killing his girlfriend's 3-year-old daughter and sentenced to death after West testified marks on her body matched Brewer's teeth.

Later, DNA testing in both cases matched a man named Justin Albert Johnson, who confessed. Johnson, who had been an initial suspect in the Brooks case and had a history of raping women and girls, was convicted and sentenced to life in prison, while the bite marks on both girls later were determined to be more likely made by crawfish and insects in water where their bodies were dumped.

FILE-In this Wednesday, April 10, 2002 file photo Ray Krone, center, smiles at his mother Carolyn, r …

Although Brewer's conviction was vacated while he awaited execution in 2001, he was held in prison until 2008 because the prosecutor said he was going to retry him. Brooks also wasn't released until 2008.

West, of Hattiesburg, defended his testimony by saying that he never told jurors that Brooks and Brewer were the killers, only that they bit the children, and that he's not responsible for juries who found them guilty. He told the AP that DNA has made bite-mark analysis almost obsolete and that he no longer practices it.

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DANE CLARK COLLINS

Collins, of Santa Fe, N.M., was arrested in 1989 and imprisoned for five months in the rape and killing of his 22-year-old stepdaughter Tracy Barker, even though a condition prevented Collins from producing sperm, which was found on Barker's body.

FILE-In this Friday, Feb. 15, 2008 file photo shows Levon Brooks, left, huging a friend, moments aft …

A forensic dentist had concluded that a mark on Barker's neck was a bite mark and matched Collins, and prosecutors vowed to seek the death penalty.

Collins was declared innocent after his attorneys revealed his medical condition and argued that the mark on Barker's neck was left when she was strangled and was not a bite mark.

Fifteen years later, the sperm found on Barker was entered into a national database not available at the time of the crime and matched Chris McClendon, a former Santa Fe ski instructor who had been convicted in a separate 1999 case of kidnapping and raping a 24-year-old Santa Fe waitress. McClendon pleaded no contest in Barker's killing to avoid the death penalty and is serving multiple life sentences.

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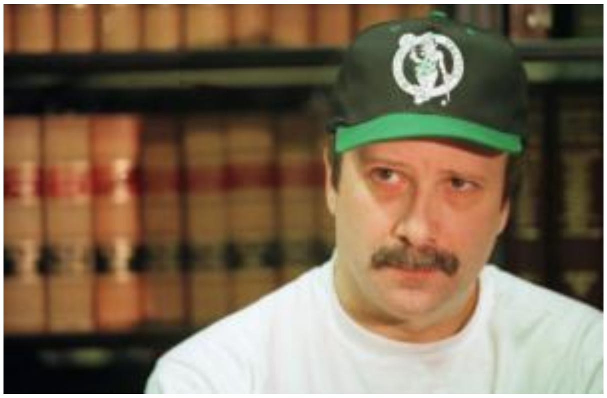

FILE- A Jan. 1999 file photo shows Edmund Burke, of Walpole, Mass., a former suspect in the killing …

WILLIE JACKSON

Jackson, of Natchez, Miss., was convicted in 1989 of rape in Marrero, La., 180 miles from where he lived, after the victim identified him in a lineup and a forensic dentist testified that bite marks matched Jackson's teeth, even though Jackson's brother, Milton Jackson, confessed to the rape just days after the crime and Jackson lived far away. Police focused on Willie Jackson because one of his bank statements was found at the crime scene.

DNA testing later showed Jackson was innocent, and he was exonerated in 2006.

A different forensic dentist later found the earlier bite-mark analysis was incorrect, and further DNA testing pointed to Milton Jackson, who was serving a life sentence for an unrelated rape.

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FILE- In this Jan. 30, 2009, file photo Robert Lee Stinson, second right, hugs a family friend as hi …

RAY KRONE

Krone, of Phoenix, was convicted in 1992 and again in 1996 after winning a new trial in the death of a Phoenix bartender who was found naked and stabbed in the men's restroom of her workplace. He spent a decade in prison, three of them on death row. Dr. Ray Rawson, a forensic dentist who is still on the American Board of Forensic Odontology, testified at both trials that bite marks on the bartender's breast and neck could have come only from Krone.

The jury at Krone's second trial found him guilty despite three top forensic dentists who testified for the defense that Krone couldn't have made the bite mark.

In 2002, DNA testing matched a different man and proved Krone's innocence, and Krone was released. Rawson did not return calls or emails seeking comment.

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FILE-A Monday, March 5, 2007 file photo shows Roy Brown, center, walking out of court a free man wit …

JEFF MOLDOWAN AND ROBERT CRISTINI

Moldowan and Cristini, of Warren, Mich., were convicted in 1991 in the kidnapping, brutal rape and attempted murder of Moldowan's ex-girlfriend in Warren, even though Moldowan and Cristini had alibis. A jury found them guilty after forensic dentists certified by the American Board of Forensic Odontology, Drs. Allan Warnick and Pamela Hammel, testified that bite marks on the woman had to have come from Moldowan and Cristini.

The victim identified Moldowan as one of her attackers, but his defense attorney argued that the rape was committed by drug dealers seeking revenge for lost payment of cocaine, and that she falsely accused Moldowan to cover up connections to drug dealers.

Cristini was sentenced to 44 to 60 years in prison, and Moldowan was sentenced to four terms of 60 to 90 years. The bite-mark testimony was later discredited, leading to retrials in 2003 and 2004, at which both Moldowan and Cristini were acquitted.

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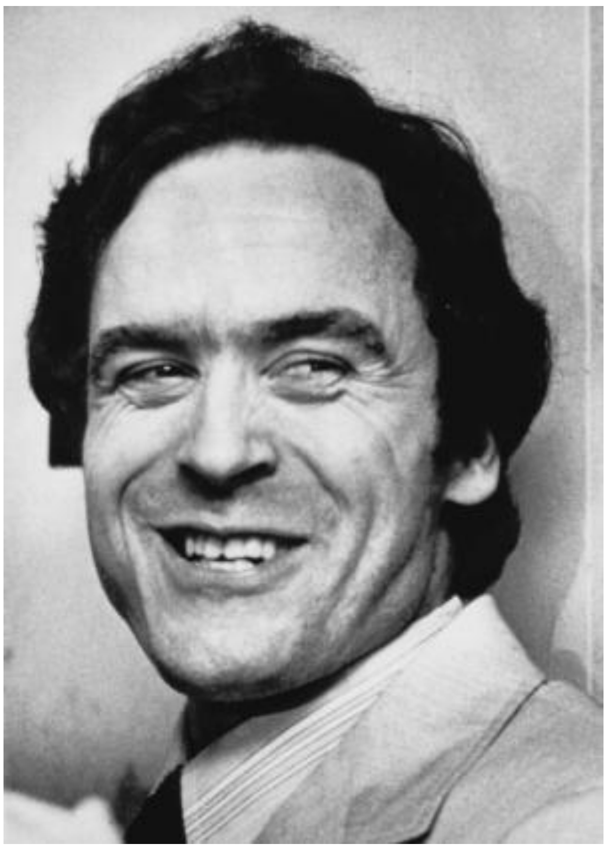

FILE - In an Oct. 3, 1978 file photo Theodore Bundy smiles at photographers in Tallahassee, Fla., A …

WILLIAM RICHARDS

Richards, of San Bernardino, Calif., was convicted in 1997 of murder in his wife's 1993 death after two trials resulted in hung juries. Drs. Norman Sperber and Gregory Golden, two top forensic dentists certified by the American Board of Forensic Odontology, testified during the trial, with Sperber testifying for the prosecution that a suspected bite mark on Pam Richards' body was consistent with a rare abnormality in William Richards' teeth and that only about 2 percent of the population had such unique teeth. Golden testified for the defense that he thought the bite-mark evidence was inconclusive and should be disregarded.

During an evidentiary hearing in 2009, Sperber recanted his testimony and said he had been wrong. Both Sperber and Golden testified at the hearing that current bite-mark science excluded Richards from making the mark, and the California Innocence Project presented evidence that male DNA found on two rocks used to beat Pam Richards did not match William Richards.

The presiding judge reversed Richards' conviction, finding that "the evidence before me points unerringly to innocence." But prosecutors appealed the ruling, and the California Court of Appeals ordered Richards to remain imprisoned pending the outcome of the appeal. Richards' attorneys say he has cancer and could die in prison waiting for his case to be resolved.

Golden recently told the AP that at the time of the trial, he had reservations about Sperber's testimony, but that he commended him for later trying to right his wrong.

Golden said he knew at the time that a photo of the bite mark in the case was distorted and unreliable, and now he's not even sure it was made by a human.

Sperber's home number does not accept messages, and his email box was full.

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CALVIN WASHINGTON AND JOE SIDNEY WILLIAMS

Washington and Williams, of Waco, Texas, were arrested after being found with Juanita White's car the day after her death, convicted in 1987 and sentenced to life in prison in the woman's rape, robbery and murder. A forensic dentist certified by the American Board of Forensic Odontology, Dr. Homer Campbell, now dead, testified a suspected bite mark was consistent with Williams' teeth, though not to a reasonable degree of certainty.

Waco police Officer Jan Price gave a sworn statement in 1991 that she believed Washington and Williams were innocent and the victims of another officer's improper conduct. She also identified a more likely suspect, Benny Carroll, who had committed a similar crime in White's neighborhood. Semen taken from White's body later excluded Washington and Williams but matched Carroll, who had killed himself in 1990.

Williams was released from prison in 1993, and Washington was released in 2001.

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Myers reported from Cincinnati.

Exhibit

C

AP IMPACT: Bites derided as unreliable in court

By **AMANDA LEE MYERS**
June 16, 2013 11:06 AM

At least 24 men convicted or charged with murder or rape based on bite marks on the flesh of victims have been exonerated since 2000, many after spending more than a decade in prison. Now a judge's ruling later this month in New York could help end the practice for good.

A small, mostly ungoverned group of dentists carry out bite mark analysis and their findings are often key evidence in prosecutions, even though there is no scientific proof that teeth can be matched definitively to a bite into human skin.

DNA has outstripped the usefulness of bite mark analysis in many cases: The FBI doesn't use it and the American Dental Association does not recognize it.

"Bite mark evidence is the poster child of unreliable forensic science," said Chris Fabricant, director of strategic litigation at the New York-based Innocence Project, which helps wrongfully convicted inmates win freedom through DNA testing.

Supporters of the method, which involves comparing the teeth of possible suspects to bite mark patterns on victims, argue it has helped convict child murderers and other notorious criminals, including serial killer Ted Bundy. They say problems that have arisen are not about the method, but about the qualifications of those testifying, who can earn as much as $5,000 a case.

"The problem lies in the analyst or the bias," said Dr. Frank Wright, a forensic dentist in Cincinnati. "So if the analyst is ... not properly trained or introduces bias into their exam, sure, it's going to be polluted, just like any other scientific investigation. It doesn't mean bite mark evidence is bad."

This photo made Thursday, March 28, 2013, in Cincinnati, shows Dr. Frank Wright, a forensic dentist, …

The Associated Press reviewed decades of court records, archives, news reports and filings by the Innocence Project in order to compile the most comprehensive count to date of those exonerated after being convicted or charged based on bite mark evidence. Two dozen forensic scientists and other experts were interviewed, including some who had never before spoken to a reporter about their work.

The AP analysis found that at least two dozen men had been exonerated since 2000, mostly as a result of DNA testing. Many had spent years in prison, including on death row, and one man was behind bars for more than 23 years. The count included at least six men arrested on bite mark evidence who were freed as they awaited trial.

Two court cases this month are helping to bring the debate over the issue to a head. One involves a 63-year-old California man who is serving a life term for killing his wife, even though the forensic dentist who testified against him has reversed his opinion.

In the second, a New York City judge overseeing a murder case is expected to decide whether bite mark analysis can be admitted as evidence, a ruling critics say could kick it out of courtrooms for good.

Some notable cases of faulty bite mark analysis include:

FILE- This Thursday, March 28, 2013, file photo, shows an overlay of a bite mark placed on top of a …

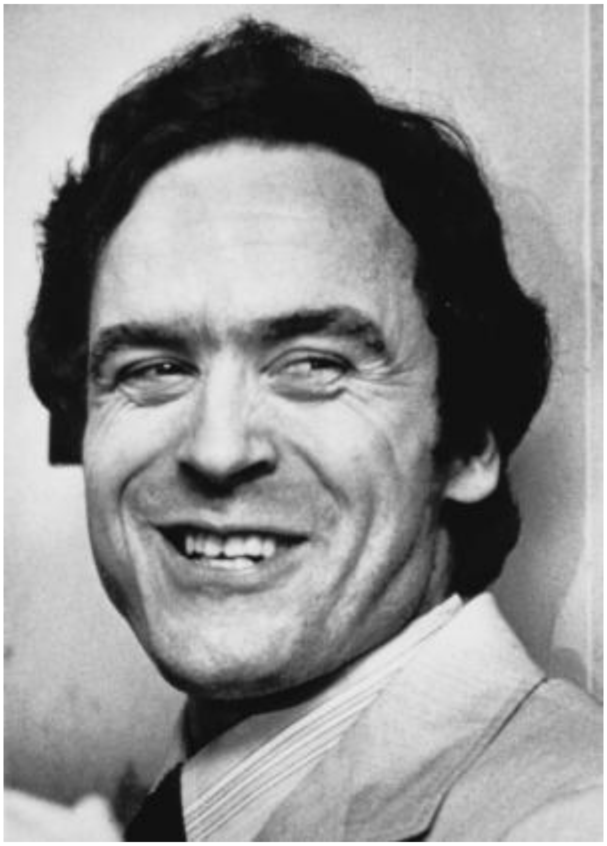
— Two men convicted of raping and killing two 3-year-old girls in separate Mississippi crimes in 1992 and 1995. Marks on their bodies were later determined to have come from crawfish and insects.

— A New Mexico man imprisoned in the 1989 rape and murder of his stepdaughter, who was found with a possible bite mark on her neck and sperm on her body. It was later determined that the stepfather had a medical condition that prevented him from producing sperm.

— Ray Krone, the so-called "Snaggletooth Killer," who was convicted in 1992 and again in 1996 after winning a new trial in the murder of a Phoenix bartender found naked and stabbed in the men's restroom of the bar where she worked. Krone spent 10 years in prison, three on death row.

Raymond Rawson, a Las Vegas forensic dentist, testified at both trials that bite marks on the bartender could only have come from Krone, evidence that proved critical in convicting him. At his second trial, three top forensic dentists testified for the defense that Krone couldn't have made the bite mark, but the jury didn't give their findings much weight and again found him guilty.

In 2002, DNA testing matched a different man, and Krone was released.



FILE - In an Oct. 3, 1978 file photo Theodore Bundy smiles at photographers in Tallahassee, Fla., A …

Rawson, like a handful of other forensic dentists implicated in faulty testimony connected to high-profile exonerations, remains on the American Board of Forensic Odontology, the only entity that certifies and oversees bite mark analysts. Now retired, he didn't return messages left at a number listed for him in Las Vegas.

Rawson has never publicly acknowledged making a mistake, nor has he apologized to Krone, who described sitting helplessly in court listening to the dentist identify him as the killer.

"You're dumbfounded," Krone said in a telephone interview from his home in Newport, Tenn. "There's one person that knows for sure and that was me. And he's so pompously, so arrogantly and so confidently stating that, beyond a shadow of doubt, he's positive it was my teeth. It was so ridiculous."

The history of bite mark analysis began in 1954 with a piece of cheese in small-town Texas. A dentist testified that a bite mark in the cheese, left behind in a grocery store that had been robbed, matched the teeth of a drunken man found with 13 stolen silver dollars. The man was convicted.

The first court case involving a bite mark on a person didn't come until two decades later, in 1974, also in Texas. Two dentists testified that a man's teeth matched a bite mark on a murder victim. Although the defense attorney fought the admissibility of the evidence, a court ruled that it should be allowed because it had been used in 1954.

This July 18, 1979, photo, shows forensic odontologist Dr. Richard Souviron pointing to a blown-up p …

Bite mark analysis hit the big time at Bundy's 1979 Florida trial.

On the night Bundy went on a killing spree that left two young women dead and three others seriously wounded, he savagely bit one of the murder victims, Lisa Levy. A Florida forensic dentist, Dr. Richard Souviron, testified at Bundy's murder trial that his unusual, mangled teeth were a match.

Bundy was found guilty and executed. The bite marks were considered the key piece of physical evidence against him.

That nationally televised case and dozens more in the 1980s and 1990s made bite mark evidence look like infallible, cutting-edge science, and courtrooms accepted it with little debate.

Then came DNA testing. Beginning in the early 2000s, new evidence set free men serving prison time or awaiting the death penalty largely because of bite mark testimony that later proved faulty.

FILE-A Monday, March 5, 2007 file photo shows Roy Brown, center, walking out of court a free man wit …

At the core of critics' arguments is that science hasn't shown it's possible to match a bite mark to a single person's teeth or even that human skin can accurately record a bite mark.

Fabricant, of the Innocence Project, said what's most troubling about bite mark evidence is how powerful it can be for jurors.

"It's very inflammatory," he said. "What could be more grotesque than biting someone amid a murder or a rape hard enough to leave an injury? It's highly prejudicial, and its probative value is completely unknown."

Fabricant and other defense attorneys are fighting to get bite mark analysis thrown out of courtrooms, most recently focusing their efforts on the New York City case.

It involves the death of 33-year-old Kristine Yitref, whose beaten and strangled body was found wrapped in garbage bags under a bed in a hotel near Times Square in 2007. A forensic dentist concluded a mark on her body matched the teeth of Clarence Brian Dean, a 41-year-old fugitive sex offender from Alabama, who is awaiting trial on a murder charge.

FILE-In this Friday, Feb. 15, 2008 file photo shows Levon Brooks, left, huging a friend, moments aft …

Dean told police he killed Yitref in self-defense, saying she and another man attacked him in a robbery attempt after he agreed to pay her for sex; no other man was found.

Dean's defense attorneys have challenged the prosecution's effort to admit the bite mark evidence, and a judge is expected to issue a ruling as early as mid-June — a pivotal step critics hope could eventually help lead to a ban on such evidence.

A dayslong hearing last year over the scientific validity of bite marks went to the heart of the debate.

"The issue is not that bite mark analysis is invalid, but that bite mark examiners are not properly vetted," Dr. David Senn, of San Antonio, testified at the hearing.

Another case gaining attention is that of William Joseph Richards, convicted in 1997 of killing his wife, Pam, in San Bernardino, Calif., and sentenced to life in prison.

FILE-In this Wednesday, April 10, 2002 file photo Ray Krone, center, smiles at his mother Carolyn, r …

Pam Richards had been strangled and beaten with rocks, her skull crushed by a cinder block, and her body left lying in the dirt in front of their home, naked from the waist down.

Dr. Norman Sperber, a well-respected forensic dentist, testified that a crescent-shaped wound on her body corresponded with an extremely rare abnormality in William Richards' teeth.

But at a 2009 hearing seeking Richards' freedom, Sperber recanted his testimony, saying that it was scientifically inaccurate, that he no longer was sure the wound was a bite mark, and that even if it was, Richards could not have made it.

Shortly after that, a judge tossed out Richards' conviction and declared him innocent. The prosecution appealed and the case went all the way to the California Supreme Court, which ruled in December that Richards had failed to prove his innocence, even though the bite mark evidence had been discredited. In a 4-3 decision, the court said forensic evidence, even if later recanted, can be deemed false only in very narrow circumstances and Richards did not meet that high bar.

Since April 27, Richards' attorneys have been on what they dubbed a two-month "innocence march" from San Diego to the state capital, Sacramento, to deliver a request for clemency to Gov. Jerry Brown and raise awareness about wrongful convictions. They are expected to arrive later this month.

FILE- In this Jan. 30, 2009, file photo Robert Lee Stinson, second right, hugs a family friend as hi …

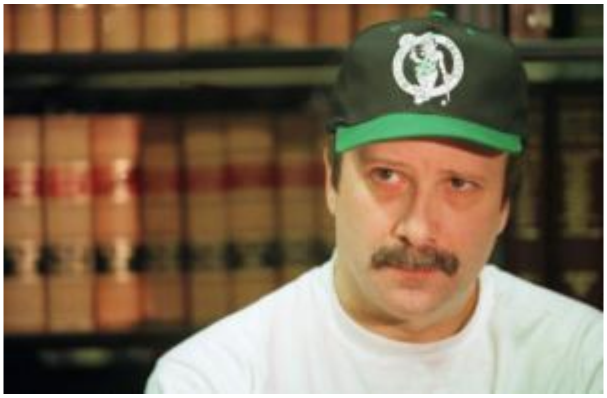
The American Board of Forensic Odontology recently got a request from Richards' attorneys, who are affiliated with the Innocence Project, for a written opinion on the shoddy bite mark evidence used against him. The board declined.

Only about 100 forensic dentists are certified by the odontology board, and just a fraction are actively analyzing and comparing bite marks. Certification requires no proficiency tests. The board requires a dentist to have been the lead investigator and to have testified in one current bite mark case and to analyze six past cases on file — a system criticized by defense attorneys because it requires testimony before certification.

Testifying can earn a forensic dentist $1,500 to $5,000 per case, though most testify in only a few a year. The consequences for being wrong are almost nonexistent. Many lawsuits against forensic dentists employed by counties and medical examiner's offices have been thrown out because as government officials, they're largely immune from liability.

Only one member of the American Board of Forensic Odontology has ever been suspended, none has ever been decertified, and some dentists still on the board have been involved in some of the most high-profile and egregious exonerations on record.

Even Dr. Michael West, whose testimony is considered pivotal in the wrongful convictions or imprisonment of at least four men, was not thrown off the board. West was suspended and ended up stepping down.



FILE- A Jan. 1999 file photo shows Edmund Burke, of Walpole, Mass., a former suspect in the killing …

Among his cases were the separate rapes and murders of the two 3-year-old girls in Mississippi, where West testified that two men later exonerated by DNA evidence were responsible for what he said were bite marks on their bodies. The marks later turned out to be from crawfish and insects, and a different man's DNA matched both cases.

West now says DNA has made bite mark analysis almost obsolete.

"People love to have a black-and-white, and it's not black and white," said West, of Hattiesburg, Miss., where he has a dental practice but no longer works on bite mark cases. "I thought it was extremely accurate, but other cases have proven it's not."

Levon Brooks, convicted of killing one of the girls, spent 16 years in prison. The other, Kennedy Brewer, was behind bars for 13 years, many of them on death row.

West defended his testimony, saying he never testified that Brooks and Brewer were the killers, only that they bit the children, and that he's not responsible for juries who found them guilty.

FILE-In this Friday, Feb. 15, 2008 file photo shows Kennedy Brewer, right, hugged by a friend, momen …

Other dentists involved in exonerations have been allowed to remain on the board as long as they don't handle more bite mark cases, said Wright, the Cincinnati forensic dentist.

"The ABFO has had some internal issues as far as not really policing our own," he said.

Wright and other forensic dentists have been working to develop guidelines to help avert problems of the past while retaining bite mark analysis in the courtroom.

Their efforts include a flow chart to help forensic dentists determine whether bite mark analysis is even appropriate for a given case. Wright also is working on developing a proficiency test that would be required for recertification every five years.

An internal debate over the future of the practice was laid bare at a conference in Washington in February, when scores of dentists — many specializing in bite mark analysis — attended days of lectures and panel discussions. The field's harshest critics also were there, leading to heated discussions about the method's limitations and strengths.

Dr. Gregory Golden, a forensic dentist and president of the odontology board, acknowledged that flawed testimony has led to the "ruination of several innocent people's lives" but said the field was entering a "new era" of accountability.

Souviron, who testified against Bundy in 1979 and is one of the founding fathers of bite mark analysis in the U.S., argued there's a "real need for bite marks in our criminal justice system."

In an interview with the AP, Souviron compared the testimony of well-trained bite mark analysts to medical examiners testifying about a suspected cause of death.

"If someone's got an unusual set of teeth, like the Bundy case, from the standpoint of throwing it out of court, that's ridiculous," he said. "Every science that I know of has bad individuals. Our science isn't bad. It's the individuals who are the problem."

Many forensic dentists have helped the Innocence Project win exonerations in bite mark cases gone wrong by re-examining evidence and testifying for the wrongfully convicted.

But a once-cooperative relationship has turned adversarial ever since the Innocence Project began trying to get bite mark evidence thrown entirely out of courtrooms, while at the same time using it to help win exonerations.

"They turn a blind eye to the good side of bite mark analysis," Golden told the AP.

One example is a case Wright worked on in 1998. He analyzed the bite marks of the only three people who were in an Ohio home when 17-day-old Legacy Fawcett was found dead in her crib. Of the three, two sets of teeth could not have made the bite marks, Wright testified; only the teeth of the mother's boyfriend could have. The boyfriend was found guilty of involuntary manslaughter and served eight years in prison.

Without the bite mark, Wright said, the wrong person might have been convicted or the man responsible could have gone free, or both.

"Bite mark evidence can be too important not to be useful," Wright said. "You can't just throw it away."

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Myers reported from Cincinnati. Associated Press News Researcher Barbara Sambriski in New York and AP writers Eric Tucker in Washington, D.C., and David B. Caruso in New York contributed to this report.

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Follow Amanda Lee Myers on Twitter at http://twitter.com/AmandaLeeAP

Exhibit

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INNOCENCE PROJECT

DESCRIPTION OF BITE MARK EXONERATIONS

1. **Robert Lee Stinson:** Robert Lee Stinson served over 23 years in a Wisconsin prison for the brutal rape and murder of 63-year-old victim Ione Cychosz. The only physical evidence against Stinson at his 1985 trial was the bite mark testimony of two board-certified ABFO Diplomates, Drs. Lowell Thomas Johnson and Raymond Rawson. Dr. Johnson concluded that the bite marks "had to have been made by teeth identical" to Stinson's, and claimed that there was "no margin for error" in his conclusion. Dr. Rawson, the chairman of the Bite Mark Standards Committee of the ABFO testified that the bite mark evidence was "high quality" and "overwhelming." Both experts testified "to a reasonable degree of scientific certainty," that the bite marks on the victim had been inflicted at or near the time of death, and that Stinson was the only person who could have inflicted the wounds. After examining Dr. Johnson's workup, Dr. Rawson stated that the methods Dr. Johnson used in gathering the evidence complied with the "standards of the American Board of Forensic Odontology."

   The Wisconsin Innocence Project accepted Stinson's case in 2005, and sought DNA testing of saliva and blood-stains on the victim's sweater, which ultimately excluded Stinson. On January 30, 2009, Stinson, then 44, was freed and his conviction was vacated.[1]

2. **Gerard Richardson:** On December 17, 2013, Gerard Richardson was exonerated after post-conviction DNA testing proved his innocence in a 1994 murder case. He spent nearly 20 years in prison for a crime he did not commit. At Richardson's 1995 trial, ABFO board-certified Diplomate Dr. Ira Titunik testified that a bite mark found on the victim's back " was made by Gerard Richardson . . . there was no question in my mind," and the prosecutor argued that the bite mark was indisputably made by Richardson: "Mr. Richardson, in effect, left a calling card. . . . It's as if he left a note that said, 'I was here,' and signed it because the mark on her back was made by no one else's teeth." There was no other physical evidence tying Richardson to the crime. He was sentenced to 30 years in prison without the possibility of parole. More than 19 years after Monica Reyes was murdered, new evidence demonstrated that Richardson was innocent. Post-conviction DNA testing of a swab collected from the bite mark revealed that the saliva left on the bite mark did not belong to Richardson.[2]

3. **Willie Jackson:** On May 26, 2006, Willie Jackson was exonerated after post-conviction DNA testing proved his innocence in a 1986 sexual assault case. He had spent 17 years in prison for a crime he did not commit. At Jackson's trial, Dr. Robert Barsley, past president of the American Board of Forensic Odontology (ABFO), told the jury that the

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[1] *The Innocence Project – Know the Cases: Browse Profiles: Robert Lee Stinson, http:// www.innocenceproject.org/ Content/Robert_Lee_Stinson.php*; *State v. Stinson,* 134 Wis. 2d 224, 228, 231, 397 N.W.2d 136, 137-38 (Ct. App. 1986).

[2] *The Innocence Project – Know the Cases: Browse Profiles: Gerard Richardson,* *http://www.innocenceproject.org/Content/Gerard_Richardson.php*; *http://www.innocenceproject.org/docs/Richardson_Final_Motion_to_Vacate_091713.pdf*.

bite marks on the victim matched Jackson, testifying: "My conclusion is that Mr. Jackson is the person who bit this lady." Ultimately, DNA evidence showed that it was Willie Jackson's brother, Milton Jackson, who attacked and raped the victim.[3]

4. **Roy Brown:** In January 2007, Roy Brown was exonerated of stabbing and strangling Sabina Kulakowski after spending 15 years in prison. He was convicted of her murder in January 1992 based on bite mark evidence which was the centerpiece of the prosecution's case against Brown. Kulakowski's body had been discovered with multiple bite marks on her back, arm and thigh, all of which board-certified ABFO Diplomate Dr. Edward Mofson[4] claimed matched Brown's teeth. Mofson testified to a "reasonable degree of dental certainty" that Brown's dentition was "entirely consistent" and "completely consistent" with all of the bite marks, noting that the bite marks depicted the absence of the same two teeth Brown was missing.

   15 years after the conviction, however, DNA testing performed on saliva stains left by the perpetrator excluded Brown and matched another suspect, Barry Bench. Nevertheless, citing the prosecution's bite mark evidence at the original trial, which the jury asked to review during deliberations, the judge in the case initially refused to release Brown. Ultimately, in January 2007, the district attorney acknowledged Brown's innocence and he was exonerated after spending 15 years in prison for a murder he did not commit.[5]

5. **Ray Krone:** On December 31, 1991, Ray Krone was arrested and charged with the murder, kidnapping, and sexual assault of a woman who worked at a bar he frequented. Police had a Styrofoam impression made of Krone's teeth for comparison to bite marks found on the victim's body and, thereafter, he became known in the media as the "Snaggle Tooth Killer" due to his crooked teeth. Dr. Raymond Rawson, a board-certified ABFO Diplomate, testified that the bite marks found on the victim's body matched Krone's teeth. Based on this, Krone was convicted of murder and kidnapping, and sentenced to death.

   In 1996, Krone won a new trial on appeal, but was convicted again based mainly on the state's supposed expert bite mark testimony. This time, however, the judge sentenced him to life in prison, citing doubts about whether or not Krone was the true killer. It was

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[3] *The Innocence Project – Know the Cases: Browse Profiles: Willie Jackson*, *http://www.innocenceproject.org/ Content/Willie_Jackson.php*; *Jackson v. Day*, No. Civ. A. 95-1224, 1996 WL 225021, at *1 (E.D. La. May 2, 1996), *rev'd*, 121 F.3d 705 (5th Cir. 1997); Barsley 1989 trial court testimony, *transcript available at http://www.law. virginia.edu/pdf/faculty/garrett/innocence/jackson.pdf*.

[4] All representations that the dentists at issue in this appendix were "board-certified ABFO Diplomates" are based on the *American Board of Forensic Odontology Diplomate Information*, *available at http://www.abfo.org/wp-content/ uploads/2012/08/ABFO-Diplomate-Information-revised-November-2012.pdf*.

[5] Fernando Santos, *In Quest for a Killer, an Inmate Finds Vindication*, N.Y. Times (Dec. 21, 2006), *http://www. nytimes.com/2006/12/21/nyregion/21brown.html?pagewanted=all&_r=0*; *The Innocence Project - Know the Cases: Browse Profiles: Roy Brown*, *http://www.innocenceproject.org/Content/Proven_Innocent_by_DNA_Roy_Brown_ Is_Fully_Exonerated.php*; Brandon L. Garrett, *Convicting the Innocent*: *Where Criminal Prosecutions Go Wrong* 108-09 (Harvard University Press 2011); Mofson 1992 trial court testimony, *transcript available at http://www.law. virginia.edu/pdf/faculty/garrett/innocence/brown1.pdf*; David Lohr, *Quest for Freedom: The True Story of Roy Brown*, *http://www.trutv.com/library/crime/criminal_mind/forensics/ff311_roy_brown/5.html*.

not until 2002, after Krone had served more than 10 years in prison, that DNA testing proved his innocence.[6]

6. **Calvin Washington & Joe Sidney Williams:** Calvin Washington was convicted of capital murder in 1987 after a woman was found beaten, raped, and murdered in Waco, Texas. It was alleged that Washington and Williams murdered and sexually assaulted the victim in the course of committing a burglary. Forensic dentist and former president of the American Academy of Forensic Sciences, Dr. Homer Campbell, testified that a bite mark found on the victim was "consistent with" Williams' dentition. While Campbell excluded Washington as the source of the bite mark, his bite mark testimony about Williams (which was given at Washington's trial) tied Washington to the crime.

   After serving more than 13 years of this sentence, Washington was finally exonerated in 2000 when DNA testing showed that blood on a shirt found in Washington's home did not come from the victim, as previously asserted; testing conducted a year later pointed to another man as the perpetrator.[7] Prior to Washington's exoneration, the Texas Court of Criminal Appeals had set aside Williams' conviction in 1992 and charges against him were dismissed on June 30, 1993.

7. **James O'Donnell:** James O'Donnell was convicted in 1998 of attempted sodomy and second-degree assault. Board-certified ABFO Diplomate Dr. Harvey Silverstein opined that a bite mark on the victim's hand was consistent with O'Donnell's dentition. Based on the eyewitness identification and the bite mark evidence, and despite testimony from his wife and son that he had been at home with them when the crime occurred, the jury convicted O'Donnell. He was sentenced to three-and-a-half to seven years in prison.

   In 2000, after DNA samples from a rape kit excluded O'Donnell as the source of the semen found on the victim, his conviction was formally vacated.[8]

8. **Levon Brooks:** Levon Brooks spent 16 years in prison for the rape and murder of a three-year-old girl that he did not commit. Forensic dentist Dr. Michael West claimed that the marks on the victim's body were human bite marks and he testified at Brooks' trial that, of 13 suspects whose bite marks he had compared to the ones on the victim's body, Brooks' teeth "matched" the marks on the victim. As he explained, "it could be no one but Levon Brooks that bit this girl's arm." Based on this, Brooks was convicted of capital murder and sentenced to life in prison.

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[6] *The Innocence Project – Know the Cases: Browse Profiles: Ray Krone, http://www.innocenceproject.org/Content/Ray_Krone.php*.

[7] *The Innocence Project – Know the Cases: Browse Profiles: Calvin Washington*, *http://www.innocenceproject.org/Content/Calvin_Washington.php*; Michael Hall, *The Exonerated*, Texas Monthly (Nov. 2008), *available at http://www.texasmonthly.com/story/exonerated*.

[8] *The Innocence Project – Know the Cases: Cases Where DNA Revealed That Bite Mark Analysis Led to Wrongful Arrests and Convictions*, *http://www.innocenceproject.org/Content/Cases_Where_DNA_Revealed_that_Bite_Mark_Analysis_Led_to_Wrongful_Arrests_and_Convictions.php*; Silverstein 1998 trial court testimony, *transcript available at http://www. law.virginia.edu/pdf/faculty/garrett/innocence/odonnell.pdf*.

In 2001, DNA testing and a subsequent confession revealed that Justin Albert Johnson committed the murder. Johnson had been one of the 12 other suspects whose dental impressions Dr. West had determined did not match the bite marks on the victim's body. Following Johnson's confession, Brooks was freed on February 15, 2008.[9]

9. **Kennedy Brewer:** In 1992, Kennedy Brewer was arrested in Mississippi and accused of killing his girlfriend's three-year-old daughter. The medical examiner who conducted the autopsy, Steven Hayne, testified that he had found several marks on the victim's body that he believed to be bite marks. Hayne called in Dr. West to analyze the marks and Dr. West concluded that 19 marks found on the victim's body were "indeed and without a doubt" inflicted by Brewer. Brewer was convicted of capital murder and sexual battery on March 24, 1995, and sentenced to death. His conviction was based almost entirely on the bite mark evidence.

   In 2001, DNA tests proved that Justin Albert Johnson, not Kennedy Brewer, committed the crime. Johnson was the same perpetrator responsible for murdering the child in the Levon Brooks case. As a result of the DNA testing, Brewer's conviction was overturned. He had served seven years on death row and one year in jail awaiting trial.[10]

10. **Bennie Starks:** Bennie Starks was convicted of raping and assaulting a 69-year-old woman in 1986, based in part on testimony by two forensic dentists, Drs. Russell Schneider and Carl Hagstrom. Both dentists testified that a bite mark on the victim's shoulder matched Starks' dentition. Starks spent 20 years in prison before an appeals court ordered a new trial, after DNA testing on semen recovered from the victim excluded Starks. On January 7, 2013, the district attorney dismissed all charges against Starks.[11]

11. **Michael Cristini & Jeffrey Moldowan:** In 1991, Michael Cristini and Jeffrey Moldowan were convicted of the rape, kidnapping, and attempted murder of Moldowan's ex-girlfriend, Maureen Fournier. At trial, two board-certified ABFO Diplomates, Drs. Allan Warnick and Pamela Hammel, testified that bite marks on the victim's body had to have come from both defendants, to the exclusion of all others. Both men were convicted. Cristini was sentenced to 44 to 60 years, and Moldowan to 60 to 90 years.

    After the conviction, an investigator hired by the Moldowan family found a witness who said he had seen four black men standing around a naked woman at the scene of the

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[9] *The Innocence Project – Know the Cases: Browse Profiles: Levon Brooks, http://www.innocenceproject.org/Content/Levon_Brooks.php*.

[10] *The Innocence Project – Know the Cases: Browse Profiles: Kennedy Brewer, http://www.innocenceproject.org/Content/Kennedy_Brewer.php*.

[11] *The Innocence Project – Innocence Blog*: *Bennie Starks Exonerated After 25 Year Struggle to Clear His Name, http://www.innocenceproject.org/Content/Bennie_Starks_Exonerated_After_25_Year_Struggle_to_Clear_His_Name.php*; Lisa Black, *Exonerated Man's Ordeal Ends: 'I Am Overwhelmed with Joy'*, Chicago Tribune (Jan. 7, 2013), *http://articles.chicagotribune.com/2013-01-07/news/chi-bennie-starks-lake-county-charges-dropped_1_bennie-starks-mike-nerheim-ordeal-ends*; Donna Domino, *Dentists Sue Over Bite Mark Testimony, http://www.drbicuspid.com/index.aspx?sec=nws&sub=rad&pag=dis&ItemID=309572*.

crime. The witness' story contradicted Fournier's, as Cristini and Moldowan are both white. Dr. Hammel then recanted her testimony, saying that she had been uncertain that either defendant had in fact been responsible for the bite marks. According to Dr. Hammel, she had agreed to testify only when Dr. Warnick had assured her that a third odontologist had also confirmed that the bite marks could be matched to Cristini and Moldowan to the exclusion of all others.

On October 20, 2003, the Macomb County Circuit Court granted Cristini a new trial, citing the new eyewitness evidence, Dr. Hammel's recantation, and stronger alibi evidence. Cristini was acquitted by a jury on April 8, 2004, after having served 13 years in prison. Later, Cristini filed wrongful conviction lawsuits against the city of Warren, Macomb County, and Dr. Warnick. The suit against Dr. Warnick was settled quickly for an undisclosed amount.

In 2002, the Michigan Supreme Court reversed Moldowan's conviction. On retrial, in February 2003, Moldowan was acquitted of all charges and released, having served nearly twelve years in prison. Moldowan's lawsuit was settled for $2.8 million in 2011.[12]

12. **Anthony Keko:** Anthony Keko was convicted in 1994 for the 1991 murder of his estranged wife Louise Keko. Dr. Michael West testified that a bite mark on the victim's shoulder matched Anthony Keko's dentition. Dr. West's testimony was the only direct evidence linking Keko to the crime, and prosecutors conceded that without the bite mark evidence there was no case. Keko was found guilty and sentenced to life in prison. In December 1994, however, the trial judge became aware of previously undisclosed disciplinary proceedings against Dr. West. The judge began to express doubts regarding West's forensic abilities and ultimately reversed Keko's conviction.[13]

13. **Harold Hill & Dan Young Jr.:** Harold Hill was 16 when he and his codefendant, Dan Young, Jr., were convicted of the rape and murder of 39-year-old Kathy Morgan in 1990. Both men would end up spending 15 years in prison for a crime they did not commit. At trial, board-certified ABFO Diplomate Dr. John Kenney linked a bruise and a bite mark on the victim's body to Hill and Young. Both were found guilty and sentenced to life in prison without parole. It wasn't until 2004 that DNA tests excluded both Hill and Young as the source of DNA evidence found on the victim. In 2005 prosecutors finally

[12] *People v. Moldowan*, 466 Mich. 862, 643 N.W.2d 570 (2002); *Moldowan v. City of Warren*, 578 F.3d 351 (6th Cir. 2009); Ed White, *Warren Settles Rape Case Lawsuit for $2.8 Million – Falsely Imprisoned Man Sued for Violation of His Civil Rights*, Detroit Legal News (Oct. 19, 2011). *http://www.legalnews.com/detroit/1109085*; Jameson Cook, *Michael Cristini Wants Bigger Settlement than Jeffrey Moldowan*, Macomb Daily (Dec. 25, 2012), *http://www.macombdaily.com/article/20121225/NEWS01/121229769/michael-cristini-wants-bigger-settlement-than-jeffrey-moldowan#full_story*; Michael S. Perry, *Exoneration Case Detail*: *Michael Cristini*, Nat'l Registry of Exonerations, *http://www.law.umich.edu/special/exoneration/Pages/casedetail.aspx?caseid=3133* (last visited Apr. 12, 2013); Hans Sherrer, *Prosecutor Indicted For Bribery After Two Men Exonerated of Kidnapping and Rape*, Justice: Denied, no. 27, 2005, at 10, *available at http://www.justicedenied.org/issue/issue_27/Moldowan_cristini_exonerated.html*.

[13] *A Dentist Takes The Stand*, The Daily Beast, Newsweek & The Daily Beast (Aug. 19, 2001, 8:00 P.M.), *http://www.thedailybeast.com/newsweek/2001/08/20/a-dentist-takes-the-stand.html*; Mark Hansen, *Out of the Blue*, ABA J., Feb. 1996, *available at http://www.abajournal.com/magazine/article/out_of_the_blue/print/*.

dismissed the charges against both men. Dr. Kenney later said that the prosecution pushed him to exaggerate his results.[14]

14. **Greg Wilhoit:** Greg Wilhoit's wife, Kathy, was murdered in Tulsa, Oklahoma in June 1985. Wilhoit was left to raise his two daughters—a 4-month-old and a 1-year-old. A year later, he was arrested and charged with the murder based on the opinions of two forensic odontologists that his dentition matched a bite mark on his wife's body. Wilhoit was found guilty and sentenced to death.

    During his appeal, other forensic odontologists examined the bite mark evidence and independently concluded that the bite mark could not be matched to Wilhoit. He was released on bail for two years and when a retrial was finally held in 1993 the judge issued a directed innocence verdict. In total, Wilhoit dealt with this tragedy for 8 years, fighting a case built entirely on bite mark analysis. Wilhoit's story was documented by John Grisham in "The Innocent Man."[15]

DESCRIPTIONS OF WRONGFUL ARRESTS <u>BASED ON BITE MARK EVIDENCE</u>

1. **Dale Morris, Jr.:** In 1997, Dale Morris, Jr. was arrested based on bite mark analysis matching his dentition to a mark found on a nine-year-old murder victim, Sharra Ferger. Morris was a neighbor to the little girl, who had been found, stabbed, sexually assaulted and bitten, in a field near her Florida home. Board-certified ABFO Diplomates Dr. Richard Souviron and Dr. Kenneth Martin agreed that the bite marks on the girl were a probable match to Morris. Morris spent four months in jail until DNA tests proved his innocence. Highlighting the importance of the bite mark evidence to the police's decision to arrest Morris, Detective John Corbin said that Morris "was probably one of our least likely suspects in the neighborhood, but through the forensics that we conducted in the investigation he was linked to the crime."[16]

2. **Edmund Burke**: In 1998, Edmund Burke was arrested for raping and murdering a 75-year-old woman. The victim had bite marks on her breasts and board-certified ABFO Diplomate Dr. Lowell Levine, the same expert involved in Douglas Prade's case (discussed above), "formed an initial opinion that Burke could not be excluded as the

[14] Ctr. on Wrongful Convictions, *Exoneration Case Detail: Harold Hill*, Nat'l Registry of Exonerations, *http://www.law.umich.edu/special/exoneration/Pages/casedetail.aspx?caseid=3296* (last visited Apr. 12, 2013).

[15] Journey of Hope, Greg Wilhoit, CA, *available at http://journeyofhope.org/who-we-are/exonerated-from-death-row/greg-wilhoit/*; Witness to Innocence, *Exonerees: Greg Wilhoit*, *available at http://www.witnesstoinnocence.org/exonerees/greg-wilhoit.html*.

[16] Ian James & Geoff Dougherty, *Suspect in Girl's Murder Freed after Four Months*, St. Petersburg Times, Feb. 28, 1998, at 1.A, *available at http://www.wearethehope.org/pdf/times_02_28_1998.pdf; Cases Where DNA Revealed That Bite Mark Analysis Led to Wrongful Arrests and Convictions*, Innocence Project, *supra* note 7; Flynn McRoberts & Steve Mills, *From the Start, a Faulty Science*, Chic. Trib. (Oct. 19, 2004), *http://www.chicagotribune.com/news/watchdog/chi-041019forensics,0,7597688.story*.

source of the bite marks," but asked to see enhanced photos before rendering a final opinion. After examining the enhanced photos, Dr. Levine concluded that Burke's teeth matched the bite mark on the victim's left breast to a "reasonable degree of scientific certainty." DNA testing on saliva taken from the bite mark site excluded Burke as the source of the DNA, however, and prosecutors dropped the case against him. The true killer was later identified when DNA from the bite mark was matched to a profile in the national DNA database. Dr. Levine remains one of the few full-time forensic odontologists in the nation, and is regarded as one of the field's top practitioners.[17]

3. **Anthony Otero:** In 1994, Anthony Otero was charged with larceny and the first-degree murder and rape of a 60-year-old woman, Virginia Airasolo, in Detroit, Michigan. A warrant for Otero's arrest was issued after ABFO Dimplomate Dr. Allan Warnick claimed to have matched the bite marks on the victim's body to Otero's dentition. At the preliminary hearing on December 13, 1994, Dr. Warnick testified that Otero was "the only person in the world" who could have caused the bite marks on Airasolo's body.

   In January 1995, DNA testing excluded Otero as the source of the DNA found on the victim and he was released in April, after spending 5 months in jail. Following Otero's release, a second forensic odontologist, ABFO Diplomate Dr. Richard Souviron, concluded that the marks on the victim were consistent with human bite marks, but were too indistinct to be used to identify a suspect. Ultimately, the charges against Otero were dismissed.[18]

4. **Johnny Bourn:** In 1992, Johnny Bourn was arrested for the rape and murder of an elderly Mississippi man after Dr. Michael West matched a bite mark on the victim to Bourn. Bourn was imprisoned for 18 months, despite hair and fingerprint evidence pointing to another suspect. Ultimately, Bourn was released when he was excluded as a suspect by DNA testing performed on fingernail scrapings from the victim, but not before he had spent about one and half years in jail awaiting trial.[19]

5. **Dane Collins:** In 1989, Dane Collins was arrested and charged with the rape and murder of his 22-year-old stepdaughter, based largely on bite mark comparison evidence. The Sante Fe, New Mexico District Attorney declared his intent to seek the death penalty. Despite evidence that Collins could not produce sperm and therefore could not have been the perpetrator, the DA gave several public interviews stating that while there was not enough evidence to try the case, he believed Collins was guilty of the crime. Fifteen years later, Chris McClendon was matched to DNA found on the victim. He pled "no contest" to the crime in exchange for describing how he had committed the rape and murder. (McClendon was already serving life in prison after he was convicted of

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[17] *Burke v. Town of Walpole*, 405 F.3d 66, 73 (1st Cir. 2005).

[18] *Cases Where DNA Revealed That Bite Mark Analysis Led to Wrongful Arrests and Convictions*, Innocence Project, *supra* note 7; *Otero v. Warnick*, 614 N.W.2d 177, 178-79 (Mich. Ct. App. 2000).

[19] Hansen, *supra* note 13; *Michael West Responds*, Part 167, The Agitator (March 1, 2009), *http://www.theagitator.com/page/167/*; Paul C. Giannelli & Kevin C. McMunigal, *Prosecutors, Ethics, and Expert Witnesses*, 76 Fordham L. Rev. 1493 (2007).

kidnapping and raping a 24-year-old woman.)[20]

6. **Ricky Amolsch:** Ricky Amolsch's girlfriend, Jane Marie Fray, was found dead on August 23, 1994. She had been stabbed 22 times and had an electrical cord wrapped around her neck. The arrest warrant for Amolsch was based on a finding by Dr. Allan Warnick that a bite mark that had been found on the victim's left ear was "highly consistent" with Amolsch's dentition. Charges were not dropped until 10 months later when the eyewitness who had identified Amolsch's van at the crime scene was himself arrested for raping another woman in the same trailer park. Amolsch was jailed for 10 months until his trial. During that time, he lost his home, savings and children.[21]

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[20] Jeremy Pawloski, *Suspect in '89 Slaying to Plead Guilty*, Albuquerque J. (Aug. 11, 2005), *http://www.abqjournal.com/north/379728north_news08-11-05.htm*.

[21] *Bite Mark Evidence*, Forensics Under Fire, Jim Fisher, The Official Website, *http://jimfisher.edinboro.edu/forensics/fire/mark.html* (last updated Jan. 16, 2008); Katherine Ramsland, *Bite Marks as Evidence to Convict – Whose Bite Mark is it, Anyway?*, Crime Library, TruTV.com, *http://www.trutv.com/library/crime/criminal_mind/forensics/bitemarks/5.html* (last visited Apr. 12, 2013).

Exhibit

E

IN THE CRIMINAL DISTRICT COURT NO. 4
DALLAS COUNTY, TEXAS

----------------------------------	x	
STEVEN MARK CHANEY,	:	
Petitioner,	:	
v.	:	Case No.: 05-87-01371-CR
THE STATE OF TEXAS,	:	
Respondent.	:	
----------------------------------	x	

AFFIDAVIT OF DR. MARY BUSH AND PETER BUSH

Dr. Mary Bush and Peter Bush, declare under penalty of perjury:

Professional Background of Affiants

1. I, Mary A. Bush, DDS, have been licensed to practice dentistry in New York State since 1999. I am Associate Professor in the School of Dental Medicine, State University of New York at Buffalo. I am also Adjunct Research Scientist of Chemistry, Forensic Chemistry Department, Buffalo State College. My academic research focus has been in Forensic Dentistry, and I have lectured and published extensively in the areas of dental victim identification and bitemark analysis. I have over 20 peer-reviewed journal publications and several book chapters relating to Forensic Dentistry. In 2011-2012 I was President of the American Society of Forensic Odontology. I am a Fellow of the Odontology Section in the American Academy of Forensic Sciences, and I serve on the Editorial Board of the Journal of Forensic Sciences. I am a member of the National

Institute of Justice General Forensics Research and Development Technical Working Group. I am also a member of American Dental Association, New York State Dental Association, 8th District Dental Association and elected Member of the Omicron Kappa Upsilon National Dental Honor Society. Recently, I was selected by the National Institute of Standards and Technology to serve as one of the 16 members of the Scientific Area Committee devoted to Odontology, which will attempt to develop scientifically valid standards and guidelines related to both sub-disciplines of forensic odontology, victim identification and bitemark analysis.

2. I, Peter J. Bush have been Director of the South Campus Instrument Center, State University of New York at Buffalo for the past 20 years, and Adjunct Professor of Art Conservation at Buffalo State College. I have co-authored over 70 peer-reviewed publications in diverse scientific fields including forensic dental victim identification and bitemark analysis research. I have lectured extensively at national venues on victim identification and bitemark analysis. I am a Fellow of the General Section of the American Academy of Forensic Sciences and Member of the American Society of Forensic Odontology.

Materials Reviewed

3. In December of 2014, we were forwarded various materials from the 1986 trial of Steven Mark Chaney for the murder of John Sweek by attorneys at the Innocence Project in New York, including the trial testimony of Drs. Jim Hales, Homer Campbell, and James Weiner.

4. In addition to the case-specific materials, we also reviewed Dr. Raymond Rawson's 1984 article in the Journal of Forensic Sciences, "Statistical Evidence for the Individuality of the Human Dentition" and the 2009 National Academy of Sciences (NAS) report, *Strengthening Forensic Science in the United States: A Path Forward.* We have also reviewed and consulted the 13 published, peer-reviewed papers addressing bitemark comparisons that one or both of us wrote in whole or in part.

5. We were not asked to, and did not, examine and/or analyze the injury located on the left forearm of John Sweek. Rather, we were asked to review, (1) the scientific basis of bitemark comparison evidence, and (2) the scientific basis for the testimonial conclusions of forensic experts Drs. Hales, Campbell and Weiner in light of contemporary scientific knowledge. We are qualified to comment on these matters because of our training, experience, and our scientific research into the foundational assumptions of bitemark comparison evidence.

The Scientific Basis For Bitemark Comparisons

6. Bitemark comparisons are based on two fundamental postulates: one, that the human dentition is unique; and two, that this uniqueness can be recorded in human skin with sufficient fidelity to enable the exclusion, inclusion, or identification of a perpetrator.

7. Neither of these premises, however, has ever been scientifically validated. In an attempt to determine whether such scientific proof would be possible, we conducted a number of studies, detailed in peer-reviewed publications, (publications list appended

as Exhibit A; publications appended as Exhibits B - I), on the supposed uniqueness of the human dentition, and on skin's ability as a medium to faithfully record such uniqueness.

8. Our research suggests that neither of the two fundamental bitemark assumptions is supported by science. Our results indicate that the biting surfaces of human anterior (front) teeth (i.e., the dentition) is not unique within measurement error. This is particularly true within a bitemark, in which only those anterior teeth may be involved. *See* National Academy of Sciences, *Strengthening Forensic Science in the United States: A Path Forward* ("NAS Report") at 174. Even assuming the uniqueness of the human dentition, our research suggests that human skin cannot record that uniqueness with sufficient fidelity to support a conclusion purporting to associate a particular dentition with a putative bitemark. Our research thus suggests that the two assumptions upon which all bitemark comparisons are based cannot withstand scientific scrutiny. Given these findings, the use of bitemark comparison evidence to identify the alleged "biter" in legal proceedings without significant further research is of grave concern.

9. That there is currently no scientific basis for bitemark comparison evidence has now been confirmed not only by our research but by the NAS Report, which, in addition to other findings detailed further in this affidavit, concluded that there is no scientific proof "confirm[ing] the fundamental basis for the science of bitemark comparison." *NAS Report* at 175.

<u>Our Research</u>

The Uniqueness of the Human Dentition Has Not Been Scientifically Established

10. The first major premise of bitemark comparison is that the human dentition is unique. Prior to publication of the NAS Report, the study most often cited to support this proposition, and apparently relied upon by Dr. Hales, is Dr. Raymond Rawson's 1984 article in the Journal of Forensic Sciences, "Statistical Evidence for the Individuality of the Human Dentition" ("Rawson Study").[1]

11. The Rawson Study examined tooth positions within dentitions and concluded that the very large number of possible positions meant that the human dentition is unique "beyond any reasonable doubt." The Rawson Study rested, however, on two fundamental, yet unproven, assumptions: first, that there was no correlation of tooth position (i.e., that the position of one tooth did not affect the position of any other); second, that there was a uniform or equal distribution over all possible tooth positions (i.e., that tooth locations did not gather into common patterns). Because the study assumed that all tooth positions were independent, it used the product rule to calculate the likelihood of a random match.

12. In our paper, *Statistical Evidence for the Similarity of the Human Dentition*, (Exhibit B)[2], we attempted to replicate the Rawson Study to determine whether his conclusions regarding the uniqueness of the human dentition were correct. Using Dr. Rawson's methods, we plotted landmark points on two sets of dentitions, resulting in *x*, *y*, and angle coordinates for each tooth. We then looked for matches one, two, three, four, five, and six teeth at a time.

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[1] Rawson RD, Ommen RK, Gordon K, Johnson J; Yfantis A. Statistical Evidence for the Individuality of the Human Dentition. J Forensic Sci Jan. 1984 29(1): 245-253.
[2] Bush MA, Bush PJ, Sheets, HD. Statistical Evidence for the Similarity of the Human Dentition. J Forensic Sci 2011, 56(1):118-123.

13. We ran two thousand simulation tests designed to verify our results and to determine whether the Rawson Study's results would remain accurate if its assumptions about the lack of correlation and non-uniformity of dental arrangement were ignored.

14. Contrary to the Rawson Study's assumptions, we observed significant correlations and non-uniform distributions of tooth positions in our data sets. Importantly, 7 and 16 matches of the six anterior lower teeth were found in the respective data sets.

15. These results indicate that the use of the product rule is inappropriate to calculate the likelihood of a random "match." More fundamentally, they indicate that claims of a unique match between a particular dentition and an alleged bitemark are unsupportable. This is particularly true in cases where the universe of potential suspects is unknown (i.e., "open population" or "undefined population" cases).

16. We continued to examine the scientific basis for the proclaimed uniqueness of the human dentition in further studies. It is important to note that for purposes of our research, the "dentition" refers to the biting surface of the front teeth, i.e., the instruments that actually create the bitemark. The dentition does *not* refer to the universe of identifying information that may be drawn from the entire mouth, which, in a typical adult, involves 32 teeth with five sides per tooth. This will provide much more information than captured in a typical bitemark, which may involve only 4-8 individual teeth marks and only one of the five available surfaces. Thus, our research undermines the assumption of uniqueness of the human dentition recorded in skin; it does not

purport to investigate or disprove that human teeth, in the aggregate, are indistinguishably similar.

17. In these studies, we tested the assumption of dental uniqueness by studying dental shape in large populations using geometric morphometric analysis and mathematical modeling methods common in other scientific disciplines. In each of these studies, we found dental shape matches occurred in the populations we studied. This suggests, consistent with our earlier work, that dentition is not unique.[3]

The Inability of Skin to Accurately Record the Human Dentition

18. In addition to our work on the supposed uniqueness of the human dentition, we have also conducted significant research on the second fundamental assumption of bitemark analysis—that human skin is able to accurately record unique features of the human dentition.

19. To examine this proposition, we undertook a series of cadaver studies which tested the nature of human skin as a recording medium for capturing dental uniqueness. It is well-established in the scientific literature that skin behaves in a nonlinear, visco-elastic, anisotropic manner.[4] Our research sought to establish a scientific understanding of how these biomechanical properties, and their potential distortive effects, might affect the ability of human skin to accurately record a human dentition. The use of cadavers allowed us to isolate the basic ability of skin to

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[3] Sheets HD, Bush PJ, Brzozowski C, Nawrocki LA, Ho P, Bush MA. Dental Shape Match Rates in Selected and Orthodontically Treated Populations in New York State: A Two Dimensional Study. J Forensic Sci 2011, 56(3): 621-626; Bush MA, Bush PJ, Sheets HD. Similarity and Match Rates of the Human Dentition In 3 Dimensions: Relevance to Bitemark Analysis. Int J Leg Med 2011, 125(6): 779-784.

[4] Viscoelasticity is the skin's ability to stretch and rebound. Nonlinearity is how skin responds to applied stress. Anisotropy is the directional variation in skin.

accurately record a dentition from the effects of other variables associated with bitemarks inflicted on living beings. These variables include the distortion caused by the "vital reaction" of the victim, such as bruising, swelling and/or shrinkage of tissue caused by the healing or decomposition processes of the body. A cadaver model eliminates such distortion, allowing our team to research skin as a substrate to capture the information relied upon by a forensic dentist to associate a bitemark with a particular dentition.

20. We began with a series of studies that used the same dentition impressed into cadavers to explore how skin might distort any marks. In one study we examined how anisotropy might create distortion by examining bitemarks made both parallel and perpendicular to skin's tension lines (also known as Langer lines). We also looked at the effect of tissue movement. We found the same dentition did not produce identical marks across these conditions. Indeed some marks made by the same dentition were dramatically distorted from others. Thus bitemarks created by the same dentition on the same individual appeared substantially different depending on the angle and movement of the body and whether the mark was made parallel or perpendicular to tension or Langer lines.[5]

21. In a further study, we examined whether the correct "biter" from a group of similarly aligned dentitions could be determined based on the impressions in cadaver skin. These results indicate that similarly aligned dentitions impressed in human skin can create marks so similar to one another that potential biters cannot be excluded,

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[5] Bush MA, Miller RG, Bush PJ, Dorion, RB. Biomechanical Factors in Human Dermal Bitemarks ina Cadaver Model. J Forensic Sci 2009 54(1): 167-176.

even in the absence of distortion typically associated with a bitemark. Some dentitions, moreover, appeared to better match certain marks than those of the actual biter — an outcome which could give rise to misidentification.[6]

22. Further research also demonstrated that variation of bite force produced unpredictable results with regard to skin damage.[7] Put differently, the same dentition will not only create different bitemarks depending on the position of the body, as discussed above, but will also create different marks depending on the amount of force associated with the creation of the bitemark.

23. This research suggests that even if the human dentition were unique (a proposition our other research indicates cannot be sustained), human skin is not capable of faithfully recording that uniqueness with sufficient fidelity to permit bitemark comparison.

24. In another research study, we conducted a geometric morphometric analysis[8] of a series of bitemarks made by a single dentition, which were then compared to several hundred other dentitions. These analyses resulted in matches from non-biting dentitions, a result which— in line with our prior research—suggests that skin is subject

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[6] Miller RG, Bush PJ, Dorion, RB, Bush, MA. Uniqueness of the Dentition as Impressed in Human Skin: A Cadaver Model. J Forensic Sci 2009 54(4): 909-914.

[7] Bush MA, Thorsrud K, Miller RG, Dorion RBJ, Bush PJ. The Response of Skin to Applied Stress: Investigation of Bitemark Distortion in a Cadaver Model. J Forensic Sci 2010;55(1):71-76; Bush MA, Cooper HI, Dorion RBJ. Inquiry into the Scientific Basis For Bitemark Profiling and Arbitrary Distortion Compensation. J Forensic Sci 2010; 55(4):976-983.

[8] Geometric morphometric analysis is a statistical tool used for capturing information about the size and shape of biological structures using measured landmark points.

to many variables which make it an unreliable medium for recording what identifying features may be present in the dentition.[9]

The National Academy of Sciences Report

25. Our research is broadly in line with the conclusions drawn by the 2009 NAS Report. In writing this report, the NAS thoroughly reviewed the relevant bitemark literature and concluded that bitemark comparison has not yet been subjected to sufficiently rigorous scientific evaluation.

26. In particular, the NAS Report concluded that neither the uniqueness of human dentition nor the ability of human skin to reflect any such uniqueness has been scientifically established. *NAS Report* at 175. Accordingly, the NAS found that there was no basis in science for forensic odontologists to conclude that a suspect is "the biter" to the exclusion of all other potential sources. *NAS Report* at 176.

27. The NAS Report further found that it even if a dentition cannot be excluded as the source of a mark, "there is no established science indicating what percentage of the population or subgroup of the population could also have produced the bite." *NAS Report* at 174.

28. These findings fall in line with our research, which has shown that the assumptions forming the basis of bitemark comparison cannot withstand scientific scrutiny and that statistical evidence for the likelihood of a random match is, as yet, unsupportable.

The Bite Mark Comparison Testimony Proffered at Mr. Chaney's 1986 Trial

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[9] Bush MA, Bush PJ, Sheets HD. A Study of Multiple Bitemarks Inflicted in Human Skin by a Single Dentition Using Geometric Morphometric Analysis. Forensic Science International 211 (2011) 1-8.

29. The two forensic odontologists, Drs. Jim Hales and Homer Campbell, and the forensic pathologist, Dr. James Weiner, gave testimony at trial addressing the discriminatory abilities of bitemark comparison evidence, and their related abilities as forensic odontologists that is no longer accepted or supported by science. As an initial matter, all three testified that bitemark comparison evidence permitted an odontologist to determine that a particular dentition created a particular mark left in human skin (i.e., individualization). But as our research and the NAS report shows, such conclusions are not supported by science. Indeed, we know from our research that the distorting effects of skin can result in random matches of non-biting dentitions to bitemarks. Likewise, Dr. Hales's assertion that there was "one to a million" chance that anyone other than Mr. Chaney created the mark has now been entirely discredited by our work and by the work of the NAS; there is simply no scientific support to offer that, or any other figure, regarding the likelihood of a random match. Our scientific understanding today of bitemark comparison evidence would not support the testimonial conclusion offered by these experts at Mr. Chaney's trial.

Conclusion

30. The fundamental tenets of bitemark analysis are not supported by science. Our research, confirmed by the NAS report, suggests, moreover, that they cannot be. Our work indicates that the biting surface of teeth, i.e., the human dentition, is not unique. Even if it were, skin cannot accurately record that uniqueness. Unless and until these premises can be scientifically demonstrated, bitemark comparison evidence should not be admitted in criminal proceedings.

Dr. Mary Bush

Sworn to me this 26th of March, 2015.

Jill G. Uebelhoer

Notary Public

Erie New York, Buffalo

County State

08/02/2016

My commission expires:

03-26-2015

Date

JILL G UEBELHOER
NOTARY PUBLIC STATE OF NEW YORK
NO. 01UE6113793
QUALIFIED IN ERIE COUNTY
MY COMMISSION EXPIRES AUG. 2, 2016

Peter Bush

Sworn to me this 26th of March, 2015.

Jill G. Uebelhoer

Notary Public

Erie New York, Buffalo

County State

08/02/2016

My commission expires:

03-26-2015

Date

JILL G UEBELHOER
NOTARY PUBLIC STATE OF NEW YORK
NO. 01UE6113793
QUALIFIED IN ERIE COUNTY
MY COMMISSION EXPIRES AUG. 2, 2016

Exhibit

F

JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, January 2011, Vol. 56, No. 1
doi: 10.1111/j.1556-4029.2010.01531.x
Available online at: interscience.wiley.com

PAPER

ODONTOLOGY

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Statistical Evidence for the Similarity of the Human Dentition

ABSTRACT: Recent scrutiny of forensic science has focused on unreliability of expert witness testimony when based on statements of individuality. In bitemark analysis, assumptions regarding uniqueness of the dentition have been based on use of the product rule while ignoring correlation and nonuniformity of dental arrangement. To examine the effect of these factors, two separate sets of scanned dental models (n = 172 and n = 344) were measured and statistically tested to determine match rates. Results were compared to those of a prior study. Seven and 16 matches of the six anterior lower teeth were found in the respective data sets. Correlations and nonuniform distributions of tooth positions were observed. Simulation tests were performed to verify results. Results indicate that given experimental measurement parameters, statements of dental uniqueness with respect to bitemark analysis in an open population are unsupportable and that use of the product rule is inappropriate.

KEYWORDS: forensic science, forensic odontology, bitemarks, bitemark research statistics, dental uniqueness

It has often been stated that bitemark analysis is founded on two postulates: that the arrangement of the human anterior teeth is unique among individuals and that individual characteristics that define dental uniqueness transfer to and are recorded on the bitten substrate (1). The corollary to these premises is that the biter can be included or excluded by pattern comparison. This form of argument is known as an existential fallacy. Neither of the postulates guarantees the outcome, and if either of the postulates is untrue, then the argument is void (2).

Recent research on the second postulate suggests that distortion encountered on bitten human skin limits resolution of detail transfer. It was found in these and other studies that detail transfer may not readily occur (3–6). This forces re-examination of the claim of dental uniqueness and the measurement parameters of the dentition. Distortion from skin properties effectively reduces the resolution of measurement that can be used to compare the dentition to the bitemark. Unlike fingerprint analysis, in which details bordering on the microscopic scale are compared, a bitemark typically consists of a pattern on a larger scale that has a distortion component significant enough to include unrelated dentitions (4).

The 2009 National Academy of Science report, in its criticism of bitemark analysis, lists the concern that "the uniqueness of the human dentition has not been scientifically established" (7). This may be interpreted to indicate that efforts should be made to establish a level of uniqueness of the human dentition. However, in the critical writings of Saks, Koehler, and Cooley, the argument is made that individualization is an abstraction and that demonstration of uniqueness is unattainable (8–10). Cole's (2) treatise entirely dismisses uniqueness as a viable descriptor.

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Therefore, it would appear that the correct approach is to first establish whether dental matches can be found in an open population and to specify the measurement parameters under which the match is found.

Several recent studies that claim to support the uniqueness of the dentition based on metric traits show data that demonstrate its similarity, contrary to the claims of dental uniqueness by the authors (11–13). These studies also lacked a formal statistical approach.

An often-cited attempt to statistically confirm the unique nature of the human dentition using a large population was published in 1984 by Rawson et al. ([14]; hereafter referred to as Rawson). In this study, a strong claim was made that the large number of possible tooth locations (states) observed in their data set indicates that the "human dentition is unique beyond any reasonable doubt". It was argued that the very large number of states seen preclude any possibility of matches to a given dentition, under their measurement protocol.

There are three primary weaknesses to this argument. First, it was not reported whether any specimens under their protocol actually matched. Second, it was assumed that specimens are equally or uniformly distributed over the possible tooth positions and that there was no bunching or gathering of individuals into common patterns of dentition. Last, the effect of correlation of dental traits was not considered (i.e., the idea that if an individual had a wide arch, then all the coordinates of the teeth positions across the arch would reflect this common property of being wide, and all possess unusually large x-coordinates of position along the width of the arch). Furthermore, the product rule was used, without incorporating any measure of correlation, to make the claim that the number of possible combinations of human tooth positions in the lower jaw alone is on the order of 6.08×10^{12} or effectively infinite.

Therefore, given the current scrutiny of impression evidence and the lack of scientific studies in this area, we address in this paper the issue of similarity of the human dentition using metric analysis and statistical methods. Rather than attempt to prove the uniqueness of the dentition, the approach taken is to establish a match rate, given definition of measurement parameters. The methods used by

Rawson were replicated, to show that our results are not based on more sophisticated approaches to measurement, but are a feature of the data sets. Unlike Rawson, we take the additional step of examining the data for similarity. Simulation tests were also used to both validate the statistical procedures used and investigate effects because of both nonuniform (clustered) distributions and correlation.

Methods and Materials

Two data sets of the human mandible were randomly collected. Human Subject Institutional Review Board exemption was approved for each set. One set consisted of three-dimensional (3D)-laser-scanned models. In this case, the models had been taken for the purpose of construction of occlusal appliances (mouth guards). The second set combined scanned dental models collected from the patient pool at the University at Buffalo Dental School clinic and from patient pools of two private practitioners. No other information was known about the data sets, including sex. The rationale for keeping the data sets separate was to reveal whether any data or programming flaws existed in the analysis.

Given access to these data sets, it was possible to repeat the study conducted by Rawson. Unlike Rawson's approach in which tooth positions were measured from a bitemark, our study measurements were taken from casts of the teeth themselves. The spatial resolution of the 3D-laser-scanned models was nominally 10 microns (hereafter referred to as Set 1). In the 2D data set (Set 2), casts were placed on a flatbed scanner, and a digital image was obtained with a spatial resolution of 85 microns (300 dpi). One hundred seventy-two specimens were measured in Set 1 and 344 specimens measured in Set 2 using landmark methods. In these data sets, we focused only on the lower jaw.

Landmark points were first measured on our specimens, from which the same information utilized by Rawson could be extracted. The center position of each tooth and the angle the tooth made in a horizontal plane was calculated. The 2D or 3D nature of the source was immaterial as the information extracted was independent of the third dimension. The arches were oriented such that the distal of the canines touched a baseline and a perpendicular line was drawn from the baseline to the mesial of the right central incisor. This resulted in a set of three measurements per tooth, x- and y-coordinates measured with a resolution of ±1 mm and angles measured to ±5 degrees, as per Rawson.

Rawson calculated from 384 dentitions the range of possible values of each measurement for each tooth, and then the total possible number of distinct values (or states) of these measurements, using a simple product rule, multiplying the number of states appearing to determine a total number of possible states.

It was then argued that the number of possible states is simply the product of the states of the individual teeth, and that the probability of a given dentition matching any other dentition is then one over the number of possible states or measurement values. We repeated this analysis using our data sets, to see if the number of possible states in our data sets matched that reported by Rawson.

In addition, we also compared all the teeth within each data set to determine if there were any matches in the dentition, using the criteria defined by Rawson. A match is defined as conditions such that the x- and y-coordinates within ±1 mm and an angular value within ±5 degrees, so that the two specimens did not differ in any variable within the experimental accuracy of the system. We also tested the predictions of the method by looking for the number of matches of a single specific tooth at a time, and for matches of two specific teeth at a time, then three at a time and so forth.

We did not expect to see a match of an entire dentition, but we did expect to see matches of individual teeth or pairs or trios of teeth at a time. The incidence of such matching single, double, or triple teeth groupings allows us to determine if the statistical model of the probability of matches as presented in Rawson reasonably describes our results. While our data sets had only 172 and 344 specimens, respectively, we made $n(n-1)/2$ different comparisons with n specimens, which is 14,706 and 58,996 comparisons, respectively, yielding some level of statistical power. Rather than merging our two data sets into a single larger set, we chose to work with them independently, to produce two distinct replicates of Rawson's study for the rationale stated earlier.

Simulation-based Tests

Two different simulation-based tests were run for dual purposes. The first was to determine if there were errors in the software used in the analysis that might have produced the observed results. By simulating data sets with known properties, we can determine if the results produced by the software are consistent with the known properties of the data set. Second, by forming different types of simulations, we can determine the extent of the influence of several factors that produced the deviations of the observed number of matches from the number of matches appearing in the simulations or the number of matches predicted by the Rawson model.

The first simulation used was a permutation test (15). In this procedure, a simulated data set was created using the original tooth measurements but randomly assigning measurements to specimens using a random number generator. The x, y, and angle measurements were permuted independently. This process is akin to mixing and matching teeth specimens from individual specimens to create new possible specimens. This procedure preserves the distributions of individual measurements, so that histograms of the individual measurements (x, y position or angle values) are identical to the histograms seen in the original data. However, the permutation test as used here destroys all the correlation between measurements that was present in the original data. So the permutation test allows us to see how important correlation was in producing the matches seen in the original data.

As an illustration of this process, imagine we extract all the teeth in the study and replace them in the correct (but flexible) sockets in different mandibles while retaining the distribution of positions. For example, if there are 75 left canines in the center of the mean x-position, they will be replaced in that x-position but in different mandibles. This removes the effect of correlation in which those 75 would have had right canines also close to the mean in their original mandibles, but because of swapping, they now do not. Then you observe how many matches are made (repeating the swap 1000 times), and because you have removed correlation, the only remaining reason why you might have matches is the nonuniform distribution, meaning that most people have teeth in similar positions.

The second simulation used was a Monte Carlo simulation that assumed uniform distributions of all measurements over the observed measurement ranges, which is the assumption made implicitly in Rawson's model (16). To generate such a simulation, the range of possible tooth positions was calculated from the empirical observations in Rawson's and the current data sets (see Tables 1–3). Then simulated specimens were assigned measurements randomly distributed over the observed range with no correlation between measurements. This approach produced simulated data matching Rawson's assumptions of uniform distributions with no correlations. As in the permutation test, the simulation was repeated 1000 times.

TABLE 1—*Number of states for each tooth in the lower dentition, as per Rawson's table 3. Shown is the number of states found for the* x *and* y *positions and tooth angle, as well as the total states for each tooth under the product rule.*

Tooth Number	*x*	*y*	Angle	Total Positions
22	4.3	2.9	8.6	107.2
23	4	5.1	10	204.0
24	2.5	5.1	9.1	116.0
25	3.1	5.5	9.0	153.5
26	4.0	4.0	9.4	150.4
27	4.1	2.5	10.1	103.5

TABLE 2—*Number of states found in the current study using 172 measurements of the lower dentition (Set 1).*

Tooth Number	*x*	*y*	Angle	Total Positions
22	6.0	2.0	12.7	154.6
23	4.3	5.3	15.1	343.8
24	1.2	6.7	13.6	107.3
25	3.6	6.0	9.8	212.1
26	5.8	7.0	9.7	391.7
27	10.4	2.2	12.8	297.3

TABLE 3—*Number of states found in the current study using 344 measurements of the lower dentition (Set 2).*

Tooth Number	*x*	*y*	Angle	Total Positions
22	7.8	2.5	14.9	291.9
23	5.8	9.9	15.6	903.1
24	1.9	9.6	13.4	246.3
25	6.1	8.3	21.4	1083.3
26	9.1	9.0	19.7	1616.1
27	9.0	4.3	24.3	937.6

Continuing the extraction analogy, in the Monte Carlo simulation, all teeth are extracted but position information is discarded, and the teeth are replaced in a manner that fills all the possible space that a tooth could be in a uniform distribution. This removed both correlation and nonuniform distribution. Now no matches are observed after 1000 random repeats, as predicted by the use of Rawson's methods.

So our two tests, permutation and Monte Carlo, are implementing mathematically interesting ideas about features of the data set, that allow us to see the disturbing effects that arise when we neglect to incorporate correlation and uniform distributions into our models of biologic systems.

Results

Table 1 lists the data from Rawson (table 3) and shows the number of states of each variable for each tooth in the lower mandible, while Tables 2 and 3 show the number of states found in the current study.

Sixteen six-tooth dentition matches appeared in the 58,996 possible comparisons in Set 2, indicating that these specimens had *x*- and *y*-coordinates of the midpoints that were within 1 mm of each other and all angles were within 5 degrees. Set 1 displayed seven distinct six-tooth matches. The results of looking at the number of matches of between 1 to 6 teeth at a time are shown in Table 4. In contrast to these observed results, the independent uniform distributions implied in Rawson's method were used to calculate the number of expected matches for each grouping of teeth given the sample size. This calculation was made using both Rawson's original state calculations and our state calculations, illustrating the difficulties posed by the use of the product rule as applied to this type of data.

TABLE 4—*Predicted numbers of matches between groupings of 1 to 6 teeth at a time, using Set 2. The expected columns are the expected numbers of matches using Rawson's product rule, given a total of 58,996, using an assumption of a uniform distribution of teeth over states. The number of states used was taken from both Rawson's table 5 and the larger number of states seen in our data set. The actual column indicates the number of matches (±1 mm or ±5 degrees) per tooth actually observed in this data set.*

	58,996		
n total	Expected Under Rawson	Expected under Current Data	Actual
Tooth 22 only	550.1	202.1	8900
Tooth 22+23	2.7	0.22	1196
22–24	0.02	0.00091	241
22–25	0.00015	8.4E-07	99
22–26	1.0E-06	5.2E-10	32
22–27	9.7E-09	5.5E-13	16

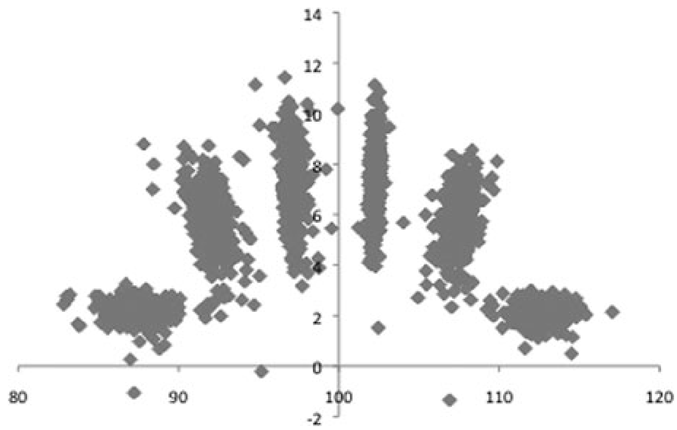

FIG. 1—*This plot replicates figure 5 in Rawson, produced using our data set, Set 2, lower dentition, 344 dental arches shown. The clusters of points represent the midpoints of the six anterior teeth. The clustering of the data points is notable and indicates strong nonuniform distribution and correlation between relative tooth positions. Axes are in mm.*

The question might then be asked, why are there so many more matches than expected, given the number of states in the data? The explanation lies in the fact that the specimens are not uniformly distributed over the states, or in other words, the occupation of the states is not uniform. Consider the *x*-coordinate values of tooth 22 in Set 2, Fig. 1. The *x*-coordinates range over 6 mm, so given our measurement resolution of ±1 mm, we have roughly six states in this variable. We might expect the chance that two randomly picked specimens would match on this measure are 1 in 6, and that of our 58,996 possible pair wise comparisons, 9832 of these should be a match. But when we actually do the counting of our data set, we find 30,431 matches or a rate of over 50% matches (Table 5)!

This can be explained by examination of a histogram of our data split for this particular measurement, Fig. 2, in which we find that the distribution is far from uniform. In this histogram, if the distribution were uniform, each bar would have the same height. However, it is closer to a normal distribution with a mean of 112.5 and standard deviation close to 1. So if we have a tooth with an *x*-position close to the mean and if we believe the normal distribution is correct, then roughly 66% of all specimens will be within ±1 mm

TABLE 5—*Matches for groupings of 1 to 6 teeth, using the 172 specimens in Set 1. Columns calculated as per Table 4.*

	14,706		
n total	Expected Under Rawson	Expected under Current Data	Actual
22	137.1	95.1	2453
22–23	0.67	0.47	482
22–24	0.0058	0.0040	147
22–25	3.8E-05	2.6E-05	51
22–26	2.5E-07	1.7E-07	15
22–27	2.4E-09	1.7E-09	7

of the specimen. Obviously, not all randomly drawn specimens will be near the mean, but most of them are close, and thus have a number of other specimens within ±1 mm. The same nonuniform distribution can be seen in Rawson's figure 6. The fact that the match rates are much higher than expected in a single tooth indicates that correlation between the teeth is not the sole source of the matches.

Correlation Structure

When we compute the probability that two independent events both occur, we can use the familiar product rule. So if event A occurs with odds 1/6 and B occurs with odds 1/10, the chance that A and B both occur is 1/6*1/10 = 1/60, the familiar product rule.

But most biologic systems have correlations, which mean that the events or variables are not independent. Suppose we report an account of a mugging by a tall robber, tall enough (say 6′4″) that the chances of a random man being that tall are 1/100. Now suppose we also know our mugger weighed over 300 pounds, and that only one man in 100 weighs that much (these values are examples only, the probabilities of heights and weights quoted are not accurate). Are the odds that a random man is that tall and than heavy then 1/100* 1/100 = 1/10,000? No, probably not, because men over 6′4″ are all pretty heavy individuals, as human weight and height are correlated.

If we examine the *x*-positions of teeth 22 and 23 in our Set 2, we find they have a correlation of 0.75, which is relatively high, meaning that the value of the *x*-position of one of them is highly predictive of the other. We can examine this using a biplot as shown in Fig. 3*a*. It is clear from this plot that if two specimens are similar in the *x*-location of tooth 22, then the *x*-position of tooth 23 is also probably similar as well. Figure 3*b* shows the same data after permutation, with correlation removed. The data is still clustered but no longer has the diagonal correlation. The horizontal spread of the points is simply an indication that the canine has a larger spread of possible positions in the *x*-axis (arch width).

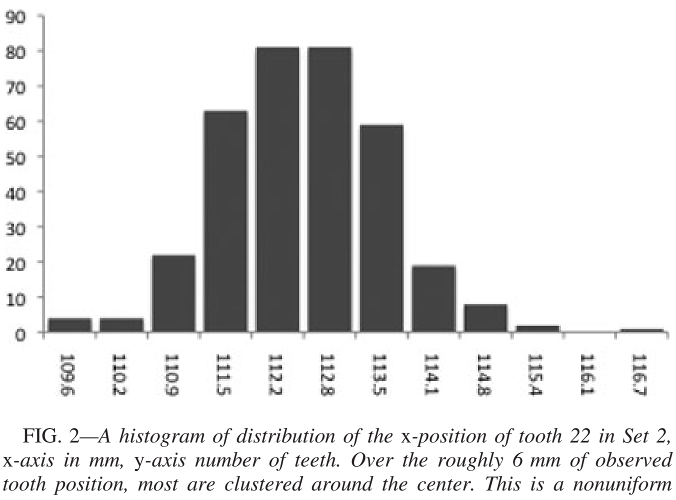

FIG. 2—*A histogram of distribution of the* x*-position of tooth 22 in Set 2,* x*-axis in mm,* y*-axis number of teeth. Over the roughly 6 mm of observed tooth position, most are clustered around the center. This is a nonuniform distribution. Had the tooth positions been evenly distributed, each histogram bar would have the same height.*

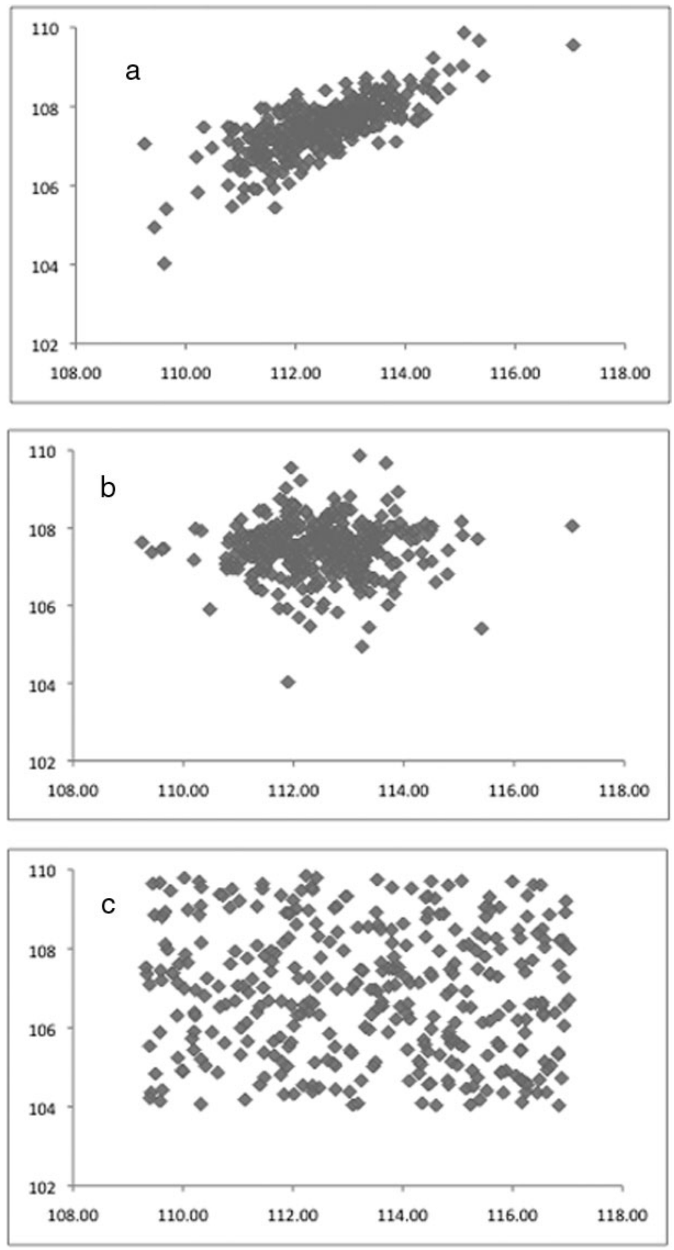

FIG. 3—*The upper plot (a) shows the* x*-positions of teeth 22 and 23 plotted against each other. These coordinates have a correlation of 0.75, so there is a general diagonal pattern to this data. The middle plot (b) is a permuted version of the same data on the same axes, which still shows clustering of the data in the center of the plot, no longer having a general diagonal pattern. The correlation has been removed. The horizontal elongation is because the canine (tooth 22) has a greater range of positions in the* x*-axis (narrow vs. wide arch). The final plot (c) shows a Monte Carlo simulation of the same data, using a uniform, noncorrelated model, as implied by Rawson's calculations. Notice the lack of both clustering of the data points and any diagonal structure in the last plot, which clearly reduce the number of overlapping points in the plot.*

Figure 3*c* shows the data after a Monte Carlo simulation. The data are now distributed in a uniform manner over the available space, and the number of overlapping points is clearly reduced.

Simulation-based Test Results

The permutation test allowed us to see how important correlation was in producing the matches seen in the original data. When we performed 1000 such permutation simulations based on Set 2, we could see that in 66 simulations of the 1000 total performed, there was one matched pair of lower dentitions, and in five simulations there were two such matches. In the same number of simulations using Set 1, there were 52 instances of a single-matched pair and in four cases there were two matches.

Using the Monte Carlo simulation that assumed uniform distributions, one thousand simulations of both Sets 1 and 2 were performed and no matches were found.

In evaluating the results of these simulations, we find that the Monte Carlo simulations produce exactly the expected results. This simulation mimics the assumptions of Rawson's model, and as expected, produced no matching lower dentitions. We take this as an indication that our software is performing as expected, and that using both assumptions of Rawson's model, there are indeed no matches. The permutation tests did show evidence of some matches, although never as many (16 matches in Set 2, seven in Set 1) as in the original data. From this, we conclude that the correlation structure in the original data set was a major factor in producing the observed matches, as we never saw this many matches over 1000 simulations per set without the correlation. The complete lack of matches in the Monte Carlo simulation also indicates the problem with assuming uniform distributions. We do not currently have a clear method of determining which feature (correlations or nonuniform distributions) is really the dominant factor.

Discussion

The assumption that the human dentition is unique has been examined from a metric statistical approach using a data set of reasonable size, replicating prior methodology but with consideration of correlation and uniformity of distribution of dental characteristics previously ignored. Rather than attempting to prove uniqueness, this paper simply reports analysis of dental characteristics in two open populations. The number of possible states is indeed vast, but human teeth occupy relatively few of them, so that matches are far more common than is implied by the number of states.

From a practical forensic perspective, empirical studies have shown distortion in skin on a scale of several millimeters with sometimes dramatic angular changes (4,6). The results in this study represent the minimum match rate using measurements from dental models with a resolution of ±1 mm and ±5 degrees. If distortion because of impression in the skin is considered, worsening measurement resolution, the match rate will increase, with the added possibility of inclusion of false positives. Our results show that given our measurement parameters, statements concerning dental uniqueness with respect to bitemark analysis in an open population are unsupportable.

Simulation tests were performed in this study as internal controls, and results indicated that correlation and nonuniform distributions of dental features significantly contribute to the frequency of match.

It is rational to conceive that the human dental arch shape would fit within a finite boundary as determined by our species. It is also rational to anticipate that the number of matches will increase as the database size is enlarged. That conclusion is borne out by this empirical study. This important concept can be stated simply. Had we combined our two data sets, there would have been many more pairwise comparisons and thus more possibilities for a match. The number of matches increases geometrically with database size as the number of possible comparisons of n specimens increases with the square of n as the number of possible comparisons is $n(n-1)/2$. In a closed population when comparing a small number of dentitions, the likelihood of a match is low, but still possible. The implication of this study is that given a large enough population the next dentition compared to the database will be highly likely to match an existing sample.

It may also be anticipated that in an open population more common dental alignments may match more frequently than rare malalignment patterns. This article does not address this. More robust geometric shape analysis methods would be needed to study this issue. The socioeconomic status of the populations in this study is unknown as is the dental reason for an individual's presence in the data set. Further studies could include demographic or dental treatment information to investigate the effect of these variables. These factors do not affect the conclusions reported here, as the goal was simply to compare a large number of dentitions as a preliminary approach to estimating dental match rate.

Studies using the types of statistical approaches common in medicine or elsewhere in the biologic sciences are extremely rare in the bitemark literature (1). Confidence in the notion of dental uniqueness in bitemark analysis has been based on anecdotal knowledge, the use of inappropriate statistics, and precedence of admission in the courtroom. In contrast, other areas, such as DNA comparison, have evolved out of scientific research, with an extensive statistical framework accompanying the biochemistry of the genome. This tight linkage of statistical methods to pattern information (expressed as DNA sequences) has resulted in an extremely robust forensic tool.

Isolation of forensic experts from the statistical community can result in the failure to communicate about the implications of both statistics and biologic structure. Research is needed about sameness versus difference, measurement resolution and error in the context of forensics, and in the context of biologic structures (2). Critically important is the concept that forensic dental experts should not only know how to perform a procedure but also recognize the limitations of the procedure. This is vital to ensure that forensic odontologists deliver the best possible service to the criminal justice system. Therefore, it is imperative that the individuality of the human dentition is realistically depicted.

The individuality fallacy, as described by Saks and Koehler, suggests that uniqueness cannot be demonstrated (8). Even if it was possible to adequately conclude that uniqueness could be determined, uniqueness does not imply that mistakes in identification could not be made between similar individuals. The debate spurred by the legal community and the National Academy of Sciences report concerning individualization and uniqueness will no doubt require a tightening of scientific rigor in the fields of forensics. However, existing expertise and knowledge can readily be applied. In Saks and Koehler' words, "forensic identification scientists can help themselves…by forswearing exaggerated, definitive conclusions in favor of humbler, scientifically justifiable and probabilistic conclusions" (8). This article attempts to provide the basis for this in bitemark analysis.

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Dental Shape Match Rates in Selected and Orthodontically Treated Populations in New York State: A Two-dimensional Study*

ABSTRACT: Forensically identifying a suspect's dentition from a bitemark in an open population requires the supposition that every person's dental alignment is different. There have been few studies that have tested this claim. Four hundred and ten lower anterior dentitions from a selected population and 110 lower anterior dentitions from one that was orthodontically treated were measured using geometric morphometric analysis, allowing comparison of arch shape. Dental match rates of 1.46% and 42.7% of individuals were found in the respective populations, given an established measurement error. Orthodontic treatment had a strong effect on match rate suggesting that treated or naturally well-aligned dentitions may be indistinguishable. Sexual dimorphism was found to be only slightly significant. Principal shape variation in both populations was degree of arch curvature. Results of studying these populations show that dental matches can occur, and that statements of certainty concerning individualization in such populations should be approached with caution.

KEYWORDS: forensic science, forensic odontology, bitemarks, dental uniqueness, geometric analysis, morphometric analysis, orthodontic treatment

Bitemark analysis has received attention in the debate over reliability of forensic methodology (1). In disputed cases, there have been diametric disagreements between experts over the nature of the evidence. This prompts the question as to whether problems lay with the data in question or the fundamental principles that guide the interpretation. Bitemark analysis has continued to be introduced in the courtroom, and it appears very likely that more stringent examination of the scientific basis of bitemark evidence may be anticipated in the light of the current debate (1).

The primary tenets of bitemark analysis are that there are individualizing details in the dentition that transfer to and are recorded in the skin, allowing identification of the perpetrator. Current criticism of bitemark analysis focuses on the fact that the uniqueness of the dentition has not been established (1).

There are relatively few studies in the forensic odontology literature that investigate the issue of individuality of the human dentition. Those that have, either used flawed statistical treatments or argue uniqueness based on small differences in metric or shape measurements (2–4).

Rawson et al. in their much-cited 1984 study used a single point (x,y position and angle) to represent each anterior tooth, and by calculating possible tooth positions arrived at the conclusion that the "human dentition is unique beyond any reasonable doubt" (5, p. 252). Recently, Rawson et al.'s methodology has been revisited with consideration of nonuniform distribution and correlation of dental structure (6). Using the same measurement resolution as Rawson et al., significant numbers of dental matches were found within the data sets studied. This contrary finding is consistent with the intuitively sensible concept that as members of a single species, human dentitions fit within a defined biological shape space, and because this space has finite boundaries, there will be overlap (6). Indeed, it may be anticipated that as a dental database grows, the number of matches increases geometrically with database size (6). Other factors can lead to an increase in match rate, such as individuals who have received orthodontic treatment.

One result of orthodontic treatment is alignment of the anterior teeth. The anticipated effect of this is that there is less variation of tooth position in a treated population, with the teeth occupying a more restricted shape space. It may be further anticipated that such treatment will produce a higher dental match rate.

Other studies using a metric approach have measured mesial/distal tooth width, intercanine width, and tooth angulation. Two recent investigations with respective population sizes of $n = 300$ and $n = 410$ reported these measurements as falling into three categories: common, uncommon, and very uncommon (2,3). However, this approach did not address the issue of uniqueness of the dentition, nor did it provide any useful statistical comparison of dental shape.

In Bernitz et al.'s article, it was stated that "It is important to realize that when comparing the measurements of a suspect's dentition with the tooth marks present on the skin of the victim, an exact match will seldom be found" (2, p. 196). This raises the

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question, *why make metric measurements if this is the case?* Although Bernitz et al. do not explain the basis of their statement, the concept is supported by recent empirical studies showing that due to distortion, exact metric dimensions of the dentition do not reliably transfer to human skin (7–10). The inherent qualities of the tissue, visco-elasticity, anisotropy, and nonlinear nature of skin all contribute to the distortion seen in a bitemark (7). The degree of distortion in a bite can exceed the measurement differences that distinguish one dentition from another and can result in an increased probability of more than one possible dental match (8,9).

If metric measurements are unreliable, it may be more pertinent to consider the arrangement of teeth in the arch and their relative alignment. By looking at the overall shape differences of the anterior dentition, we can study the frequency of a given dental shape or (mal) alignment pattern in a given population.

A well-developed method to describe shape variation between biological specimens is Geometric Morphometric analysis (11–13). Geometric Morphometric analysis involves placement of landmark points, curves or outlines on either two- or three-dimensional images. The landmark data can be extracted and analyzed statistically as a unit, removing rotation and size effects, but retaining shape. The size standardization is a scaling process rather than a removal of differences associated with biological form. Under this definition of shape, images that can be exactly overlaid are said to have the same shape. Subsequent to the alignment process of removing nonshape variation (the Procrustes Superimposition Process), shape variance analysis and statistical treatment of populations can be performed and match rates derived (11–13).

Among the tools available for statistical analysis is principal component analysis (PCA) with which the principal variations of shape can be plotted and visualized. This allows for determination of which shape aspect is responsible for the most variation. Canonical variate analysis (CVA) is another statistical tool that determines relationships between groups of variables. Shape information can be visualized by plotting landmark positions in superimposition. Procrustes distance is a measure of the closeness in shape of Procrustes superimposed specimens and is recognized as a general-purpose measure of specimen similarity in the geometric morphometrics framework. Procrustes distances can be used to summarize variations in populations, or express the degree of similarity of individual specimens, or means of populations.

Kieser et al. (4) were the first to use these tools in the forensic odontology context. That study involved landmark placement on six anterior teeth in 33 maxillas and 49 mandibles in an orthodontically treated population. A Procrustes distance between the two most similar maxillas was reported to be to be 0.0444 and the two most similar mandibles to be 0.0387. The differences in shape were thus very small. It was concluded, however, that this small difference in shape “supports the notion of the individuality of the human dentition.” Results suggested no sexual dimorphism and PCA determined that the principal shape variation in his population was curvature of the arch. A criticism of this study was that the sample size was limited, and that the measurement resolution (repeated measure error) was not reported (14). It was not shown whether the minimum observed Procrustes distance between specimens fell within measurement error of this study.

None of the prior studies investigated the issue of similarity of the dentition or the likelihood of finding a close match in a given population. Given consideration of the concept of increased matches as a function of database size, and that of human dentitions occupying a finite shape space, it was considered important to repeat analysis with a larger selected population and an expanded orthodontically treated population using the same Geometric Morphometric methods. Thus, the goals of this study were first to reexamine the question of sexual dimorphism in a larger population, second to compare match rates between orthodontically treated and nontreated sets, and third to understand the dental causes of the principal shape variations.

Materials and Methods

All necessary Human Subject Institutional Review Board protocols were completed for this project and exemption was granted. Three different model populations were obtained.

The first set consisted of 290 dental models (145 sets of maxillary and mandibular sets) were collected from the dental clinics at the State University of New York at Buffalo School of Dental Medicine. This group of models served as a test group to determine how relevant gender was in differentiating alignment pattern. The second group was comprised of 176 maxillary models and 265 mandibular models collected from the patient pools of several private practice dentists. These two groups were pooled for the purpose of shape comparison in a larger population resulting in 321 maxillary and 410 mandibular specimens. A third group of 110 maxillary and mandibular orthodontically treated patient models were collected from SUNY School of Dental Medicine.

The criteria for inclusion in all groups (University and private practice) were that there was a full complement of anterior teeth from canine to canine. Although both maxillary and mandibular models were collected and analyzed, this study reports only mandibular results as it was considered that fewer matches would result in the mandibles due to higher incidence of crowding and malalignment. In all cases, the sample size was one of convenience. The data sets may also be regarded as being selected, because of the criteria employed. Clearly the models are evidence that the patients had been under dental care and that they thus represented a certain cross-sectional demographic in New York State.

The models were scanned on a flat bed scanner at 300 dpi (Canoscan 8600F; Canon, Lake Success, NY) with an ABFO #2 scale in place for each scan, resulting in digital images of each arch. Fourteen Landmark points delineating mesial to distal extension of each anterior tooth (canine to canine) as well as the center point of each canine were placed using tpsDIG Freeware (15). Two additional landmark points were placed on the ABFO scale in each image, delineating a reference distance of 50 mm. The *x/y* coordinates of the landmarks were saved in data files that were statistically analyzed using IMP freeware (16).

Inter-operator error was measured by five operators placing landmarks on the same 15 dentition images. Intra-operator error was assessed with a single operator repeating landmark placement on the same set of images 10 times. This established a Procrustes distance threshold, that of the obtained measurement error, which was used to determine whether dentitions matched. When the Procrustes distance of two dentitions was equal to or less than this threshold the dentitions were considered a match. Procrustes plotting, PCA, and CVA were performed.

Results

Inter- and intra-operator error measurement for landmark placement resulted in a Procrustes distance threshold of 0.03. This value is twice the root-mean-square of distances of specimens about their mean, which is analogous to a standard deviation measurement (but noting that these data were not normally distributed). This was taken as the minimum shape difference below which two samples were considered a match. Procrustes distances are dimensionless, so to relate this distance to more familiar units, a translation was made that indicated that inter- and intra-operator error was approximately 1.2 pixels, or 102 microns (0.102 mm) per measured landmark coordinate. This seems intuitively reasonable as it makes the claim that the typical error made was a shift of roughly one pixel on a 300 dpi image. In other words, there was high accuracy and precision in landmark placement both between operators and on repeated measures with the same operator. A check of the distances among the repeated measures specimen indicated that 94% of the pairwise matches were within this resolution limit, very close to the familiar 95% confidence interval commonly used to indicate statistical significance.

Gender Differences

Analysis of the test group of 58 male and 87 female participants for gender shape differences revealed a small difference between male and female participants in alignment of the mandibular anterior teeth. Figure 1 shows results of CVA analysis. The Procrustes distance between means was 0.0257, which was below our measurement error distance. Figure 2 is a Procrustes plot showing the comparison of the two as submitted to bootstrapped *F* test (testing the utility of our statistical method) revealing that the male and female data sets in general closely overlap. The difference in shape between genders was only slightly better than chance, thus male and female participants were combined into one group for the remainder of the study.

Match Rates

For the open population of 410 mandibular models, three matched pairs of the lower anterior dentition were found, comprising six individual specimens, resulting in a match rate of 1.46% of this population. As the data set increased in numbers, the landmarks for each dentition overlapped with limited spread, as might be considered consistent with the concept of a common biological form. Clustering (nonuniform distribution) of the data points was strongly evident. Figure 3 is a histogram of distribution of the Procrustes distances between all 83,845 possible pairwise comparisons in the 410 mandibular dentitions. The histogram appears similar to a Poisson distribution, with few specimen pairs at very small distances, a large number at intermediate values and a long tail at large distances. The bold vertical line on the histogram indicates the error measurement threshold established as described. Clearly as measurement error increases, and the threshold moves to the right, large numbers of dentitions would be considered a match. The *x*-axis on the histogram is a measure of similarity, with most similar dentitions to the left, and less similar to the right.

Another way of understanding how similarity develops with data set size is to examine the mean nearest neighbor distance, a measure of the closeness in space of the data points (17). For the first 20 dentitions, the mean nearest neighbor was 0.081. When the data set had reached $n = 400$, the distance was 0.056. Further increase of the data set size would have the effect of this distance approaching our measurement resolution threshold (0.03), at which point each additional dentition would have a strong probability of

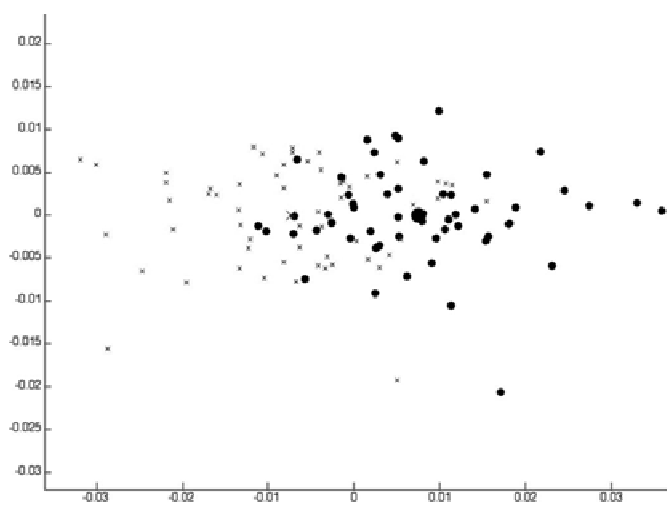

FIG. 1—*CVA plot of male (dots) versus female subjects (crosses). The means of the populations are in large symbols. The distance between means was 0.0257, which was below our measurement error of 0.03. Had there been significant sexual dimorphism, the two sets of symbols would have been more separated.*

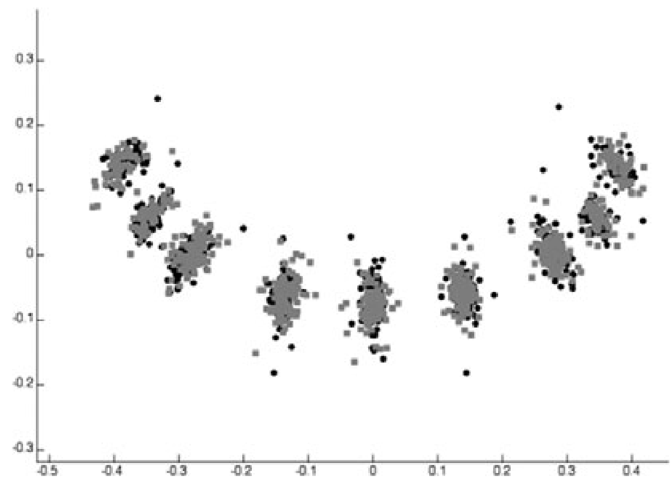

FIG. 2—*Procrustes plot showing results of a bootstrapped* F *test (testing the utility of our statistical method) revealing that the male and female data sets in general closely overlap.*

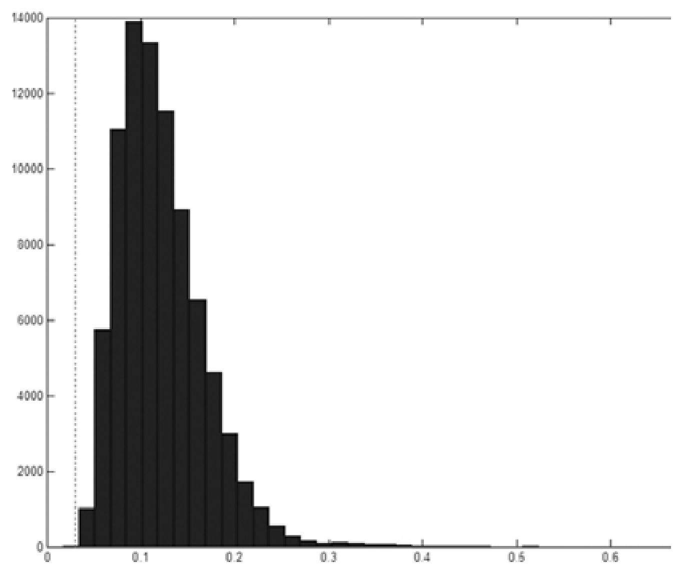

FIG. 3—*Histogram of distribution of the Procrustes distance in the 410 mandibular dentitions. The* x*-axis on the histogram is a measure of similarity, with most similar dentitions to the left, and less similar to the right. The vertical line is our measurement error threshold. Clearly, as our error worsens and the line moves to the right, more dentitions would be considered a match.*

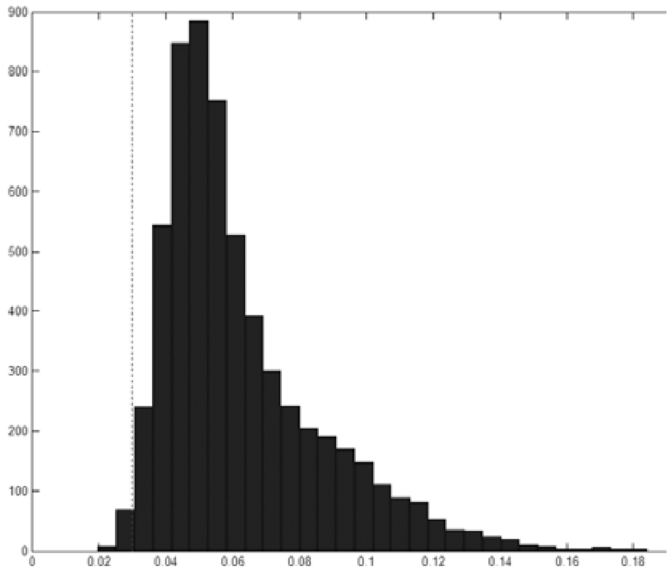

FIG. 4—*Histogram of distribution of the Procrustes distance in the orthodontically treated population. Note horizontal axis units are an order of magnitude smaller than in Fig. 3, denoting a considerable increase in similarity. Comparison of the distance numbers shows that when the Procrustes distance approaches 0.1, large numbers of the general population will match, but nearly all of the orthodontically treated population will match.*

matching an existing dentition. This effect will appear as the commonly occupied dental positions become more and more densely populated.

The match rate in the orthodontically treated mandibular data set (n = 110) was 42.7% of the individuals, with 54 matches of paired specimens among 47 distinct individuals occurring using the established threshold. Unlike the nonorthodontically treated specimens, many specimens in this collection had more than one match to another individual. Figure 4 shows the histogram of distance distributions for the 5995 possible pairs of orthodontically treated mandibles. Note that now the peak of the distribution of pairwise distances has shifted downward, closer to the measurement error threshold, meaning that there is more similarity in these dentitions.

Dental Shape Analysis by PCA

PCA of the general population showed that arch width is the biggest variable. Figure 5 is a PCA plot in which the first axis is plotted horizontally, and the second axis vertically. The first axis explains 36% of the variance in shape, whereas the second vertical axis explains 12.9%. The position of the specimens from left to right represents degree of arch curvature, whereas the position on the vertical axis represents lingual movement of central incisors and labial displacement of lateral incisors. This can be visualized by plotting the relative shifts of points, as in Figs 6 and 7. In these figures, the arrows show the relative movements in shape space of the landmark points according to the PCA plot axes. This shows that the two principal dental variables for this collection of human mandibles are curvature of the arch, and lingual movement of central incisors and labial displacement of lateral incisors.

PCA of the orthodontically treated population shows a much higher percentage of variance explained by change in arch curvature, 50.6%. The second most significant variation in shape following orthodontic treatment is lateral movement of the anterior teeth, explaining 7% of the shape variance. In both populations studied, the third most significant shape variation is rotation of the canines (7.2 and 5.0% respectively).

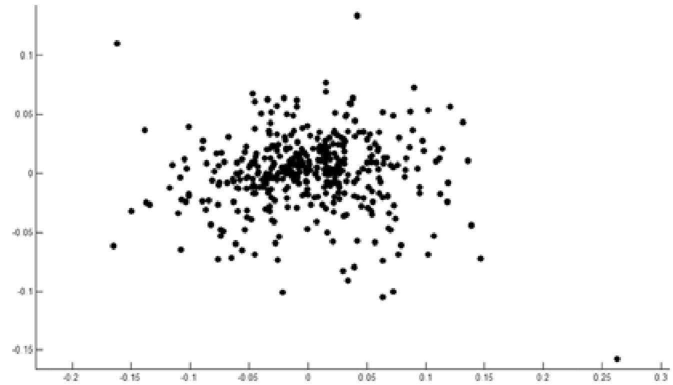

FIG. 5—*PCA plot in which the first axis is plotted horizontally, and the second axis vertically. The first axis explains 36% of the variance in shape, whereas the second vertical axis explains 12.9%. The position of the specimens from left to right represent degree of arch curvature, whereas the position on the vertical axis represents lingual movement of central incisors and labial displacement of lateral incisors.*

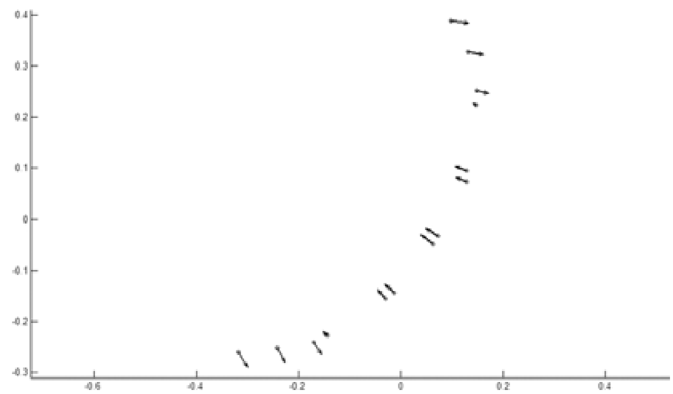

FIG. 6—*Plot of landmark movement in the positive direction of the horizontal axis of Fig. 5, showing flattening of the arch.*

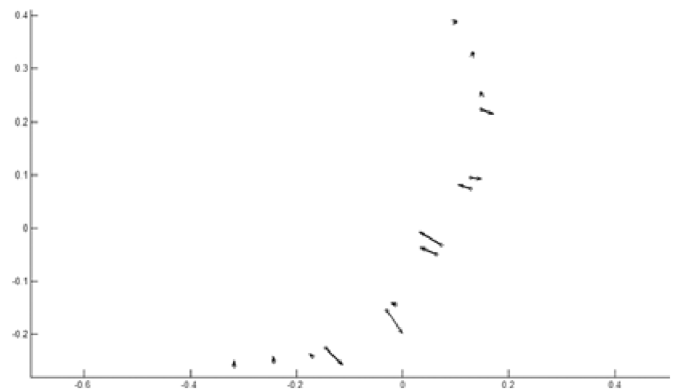

FIG. 7—*Plot of landmark movement in the positive direction of the vertical axis of Fig. 5, showing lingual movement of central incisors and labial displacement of lateral incisors.*

Shape Similarity

The shape variance within each group was calculated. The variance measure is the summed squared Procrustes distances of all specimens in a group from the mean of that group divided by (n−1), where n is the number of specimens. The computation is thus very similar to the familiar univariate statistical approach. The variance for the general group was 0.00835, and the orthodontic group 0.00224. In other words, there was much less variation in dental shape among the orthodontically treated group.

Discussion

This study confirms earlier studies in finding only small shape differences between male and female participants (4). The implication of this finding is that in bitemark casework, statements concerning gender differences may have little basis. Effects of racial differences were not considered in this study.

The match rates reported here were based on a measurement error threshold developed under ideal laboratory conditions using measurements on dental casts. This resulted in a high level of accuracy and precision in landmark placement and thus description of dental shape, certainly higher than can be expected for bitemarks in skin. Under these laboratory conditions for assessing dental uniqueness, our general population showed a low but positive match rate (1.46%) given the threshold parameter derived from repeated measurement trials that we used to designate a match. The majority of the general population studied was known to have not received orthodontic treatment. If the measurement error had been higher, or had more of this population received orthodontic treatment, larger numbers of dentition would have been candidates for a match. Even so, given our measurement resolution, the dentition was found to be not unique.

As may be anticipated, orthodontic treatment had a very strong effect on dental shape similarity. The match rate in the known orthodontically treated set was 42.7% of individuals using the same threshold parameter in only 110 specimens. This confirmed that when orthodontically treated or naturally well-aligned, dentitions may be indistinguishable. This result is also a measure of how successful orthodontic treatment is at producing homologous dental arch shapes. The orthodontically treated human dentition is not unique, as measured here with high accuracy and precision.

The match rate in both populations was determined by the threshold, which in turn was determined by measurement error. As discussed above, dental metric detail is not transferred faithfully to the skin, so measurement of a bitemark in skin would result in an increase in measurement error. Thus, the match rates reported here for the lower anterior are minimal, and do not reflect the anticipated increase in match rate when considering skin distortion. Therefore, in circumstances in which comparison measurements are made on a diffuse bruise, one may expect reduced accuracy and precision. Thus, in a large population more (or the wrong) dentitions may be found to be match candidates. Adding the inevitable distortion of bitemark impression in skin, forming an opinion as to bitemark perpetrator identification with any degree of certainty when only a diffuse bruise exists, must be called into question.

The principal source of human dental shape variation is degree of curvature of the arch. This was true for both a general population and an orthodontically treated population. In the general population, the second cause of dental variation was displacement of the incisors (malalignment of the centrals), whereas in the orthodontically treated it was lateral movement of the teeth, as may be expected. The finding of central incisors displaced lingually to the lateral incisors can be related to eruption patterns, as these teeth tend to erupt lingually in the arch and drift forward. There are many variables that can affect this such as eruption sequence and size of the teeth versus room for eruption. Therefore, it is likely that this can be a common malalignment pattern.

The third principal shape variation was in angulation of the canines in both populations. Dental alignment patterns can also be affected by other parameters. There is an influence from environmental factors with regard to malalignment, such as caries and trauma, that might affect the normal developmental sequence of eruption.

The shape similarity numbers derived here are quantitative measures of similarity of the dentition, and provide the first insight into the variability of the human dentition and the effect of orthodontic treatment. These findings are a step forward in understanding what constitutes shape difference in the human dentition, and therefore what might be the largest variables when considering how teeth may interact with the skin. It should be noted that this study only looked at matches in populations. It did not answer the question of the likelihood of matching a particular alignment pattern. Certain alignment patterns will obviously be more frequent than others.

This study was performed using a patient pool of convenience relevant only to the demographic locality. Extrapolation to other areas or countries in which dental care may be minimal or lacking entirely is not intended. In such regions there may be large proportions of the population with gross malocclusions and other dental defects that result in a broader range of possible individualizing dental characteristics. Furthermore, this study reports only mandibular results. The combination of matching both maxillary and mandibular shape deserves further investigation.

Due to so many variables, it could be argued that analysis procedures cannot be standardized due to the circumstances of the individual event that constitutes a bitemark. It can be stated now, however, that dental matches can occur, at least with regard to the anterior dentitions studied here. The shape variation of the human dentition, with regards to bitemarks, does not match the proposed level of individuality of fingerprints, and certainly can never be compared to statistical frequencies of molecular repeats that constitute DNA analysis.

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ORIGINAL ARTICLE

Similarity and match rates of the human dentition in three dimensions: relevance to bitemark analysis

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Abstract Uniqueness of the human dentition is a fundamental premise in bitemark analysis. Despite the importance of this key aspect of bitemark methodology, systematic studies of large populations have been limited. Furthermore, there have been no investigations of the significance of the third dimension with regard to dental uniqueness. One hundred digitally scanned mandibular models were analyzed in both 2D and three dimension (3D) using Landmark software. Additionally, 500 3D maxillary and mandibular sets were investigated for determining dental match rate. Statistical analysis was performed with geometric morphometric methods. Results show that measurements in 3D preserve more information about the dentition, reducing but not eliminating random matches in a sample population of 100 mandibular dentitions. Examination of pairs of maxillary and mandibular dentitions showed a substantial number of random matches (197 maxillary, 51 mandibular, one of both maxillary and mandibular). Conclusions indicate that a zero match rate cannot be claimed for the population studied.

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Keywords Forensic science · Forensic odontology · Bitemarks · Dental uniqueness · Geometric morphometric analysis · 3-dimensional analysis

Introduction

In the 2009 National Academy of Sciences (NAS) report, the discipline of bitemark analysis was heavily criticized. Lack of fundamental research that explores the scientific basis of this technique was one of the main concerns [1, 2]. There are two core premises in this area; first that the human dentition is unique and second that the characteristics that individualize the teeth transfer to the bitten substrate [3, 4]. This study focuses on the first premise.

Critics of the concept of individualization state that this theory cannot be proven and that the idea of uniqueness is an erroneous belief [5–7]. Therefore, with regard to bitemark analysis, it would appear correct to investigate the possibility of finding a "random dental match," in other words, determining the likelihood of finding a sufficiently similar dentition such that the two cannot be distinguished within measurement resolution error.

Prior studies exploring the probability of finding matching dentitions in a given population have been conducted [8, 9]. These studies have determined that it is possible, within measurement of experimental error, to find dentitions that match in the population considered; however, these projects were performed in two dimensions (2D) only. The criticism could be made that a 2D examination is inadequate and that including the third dimension or *z*-axis would decrease the chances of determining a dental match.

Prior studies have also investigated three-dimensional (3D) aspects of bitemark analysis [10, 11].

In other studies, metric dimensional parameters have been used to assess variation in human dentition [12, 13]; however, this method may not be appropriate to describe dental uniqueness within the context of bitemark analysis. Describing the dimensions and angulation of individual teeth in the dentition does not help to promote an understanding of the dependant (i.e., highly correlated) relationships of teeth and the comparative shape of the dental arch as a whole [8].

If metric measurements are insufficient as descriptors, it may be more pertinent to consider the arrangement of teeth in the arch and their relative alignment through shape change analysis.

One well-established means used to describe and compare biological forms is geometric morphometric analysis (GM) [14–18]. GM methods allow for a quantitative analysis of shape by capturing the geometry of morphological structures of interest and preserving this information through statistical analysis.

Shape information can be visualized by plotting landmark positions by a Procrustes superimposition process that will give a value in Procrustes distance. Procrustes distance is a measure of the closeness in shape of Procrustes superimposed specimens and is recognized as a general-purpose measure of specimen similarity in the GM framework. The use of this type of shape change analysis software allows for a multivariate statistical approach to explore the concept of dental uniqueness.

Advances in 3D digital imaging have facilitated the use of landmark placement as coordinates. The software allows placement of landmark points, curves, and surfaces in three dimensions that are used to delineate dental features including intercanine widths, mesial–distal lengths, rotations, as well as tooth height variation.

Our goals were first to determine how important the third dimension was in determining a match rate for the human dentition, comparing 2D and 3D measurements in the same dataset. Secondly, to determine the match rate in a population of maxillary and mandibular sets of 3D digitally scanned models.

Methods and materials

All necessary Human Subject Institutional Review Board protocols were completed for this project and an exemption was granted. Five hundred maxillary and mandibular sets (1,000 total) of 3D laser-scanned digital dental model images of patient dentitions were obtained from a dental laboratory. All patient identifying information was stripped from the file. The 3D datasets were collected for use in fabrication of occlusal guards (night guards) from private practice dentists from across the United States. Thus, the data represented a sample of convenience from a cross section of patients of unknown provenience. The alignment patterns ranged from relatively straight to severely mal-aligned.

2D/3D comparison methodology

One hundred of the mandibular 3D laser scans were randomly selected for use in the comparison of 3D measurements to 2D measurements. The criterion for inclusion was a full complement of anterior teeth (canine to canine). In actual bitemark casework, it is typically the six anterior teeth that impress the skin [3]. Therefore, this study used these teeth for analysis.

The models were oriented in a fixed occlusal view position and landmark placement was performed using a Landmark freeware [19]. The landmarks were placed on the mesial to the distal end points of each incisal edge and also the midpoint of each canine. This resulted in a total of 14 landmarks in 3D (hereafter referred to as 3D-14). The *z*-axis information for each point was discarded, forming now, a

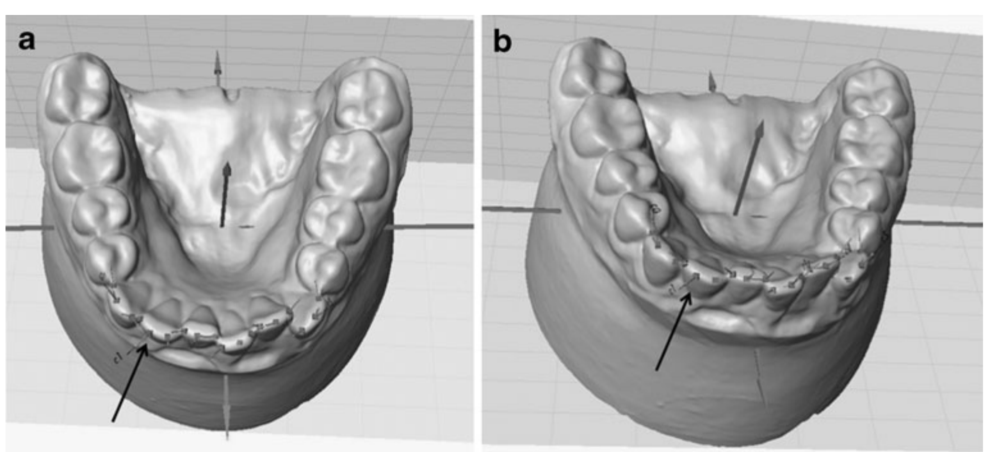

Fig. 1 **a** Landmark placement of the incisal edges of the 3D model digital scans. It is uncertain if the landmark on the lateral incisor is correctly placed (*arrow*). **b** Using the rotational capabilities of the program, it can be seen that the landmark was placed too far to the facial of the incisal edge (*arrow*). This is easily correctable with the program

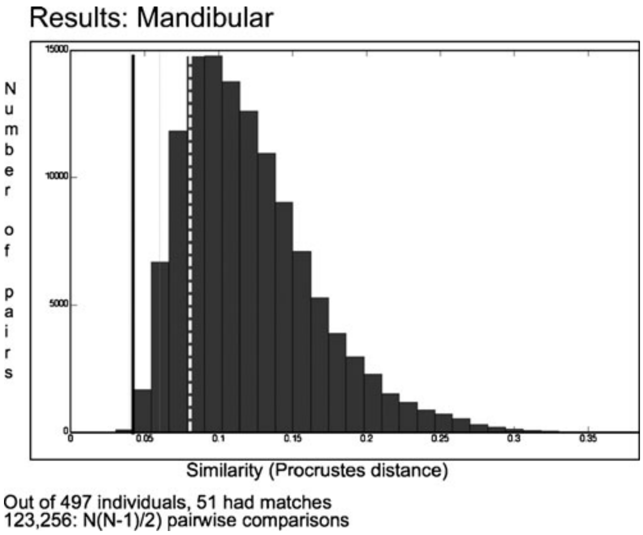

Fig. 2 The histogram shows the distribution of the Procrustes distance for the mandibular dataset. The vertical axis is the number of pairwise comparisons. The specimens at the left are very similar and to the right they become increasingly dissimilar. Clustering or non-uniform distribution is clearly evident and the clustering is around an intermediate value. The *solid dark line* is at a Procrustes distance of 0.04, our error measurement threshold. The *dashed white line* shows 100% degradation of resolution (.08)

2D dataset with 14 landmarks (hereafter referred to as 2D-14). These data were compared to the same 100 dentitions analyzed in 3D using the ability to rotate the image.

For the 3D analysis, landmarks were again placed on the 100 3D models, this time using the rotational capabilities of the software to ensure that the true incisal edges were delineated (Fig. 1a, b). Instead of two data points that described each tooth, a curve consisting of 10 data points was placed on the incisal edges to capture the 3D data. This resulted in 60 points per arch describing mesial to distal width, angulation, incisal edge shape of each tooth (for example, the height of the canine cusp tip), and relative tooth position in the arch in 3D (hereafter referred to as 3D-60). The 3D-60 set, thus differs from the 3D-14 set in that is has more measured points (60 vs. 14) and in that the landmark placements in 3D-60 were made using the ability of the software to rotate the specimen in 3D as the landmarks were placed.

The error rate was also determined for the 2D and 3D data sets using the root mean square (RMS) variation around the mean shape obtained in repeated measurements of a single specimen. Variation of the dentitions was measured as the mean summed squared Procrustes distance about the mean shape in the data set (i.e., the population mean or the mean specimen shape if using repeated measures). The square root of this variance measure is the RMS scatter about the mean, which is somewhat similar in nature to a standard deviation, although done in a multivariate sense using Procrustes distance, rather than in the more familiar univariate sense [9].

However, when working with different numbers of landmarks or from landmarks in 2D to 3D, there is a shift from one high dimensional statistical space to another. This is equivalent to going from length to area to volume. These are very different types of measurements and it is difficult to directly compare variances. To remove this difficulty, the ratios of variances was calculated, specifically the ratio of the repeated measures variance to the population variance, as a way of comparing variances from one set of measurements to another. This ratio established more reasonable grounds for comparison than the variances themselves.

3D match rate methodology

The population of 500 hundred maxillary and 500 mandibular model 3D sets was used for this portion. Four maxillary models and three mandibular models were dropped from the study. Thus, the final number was 496

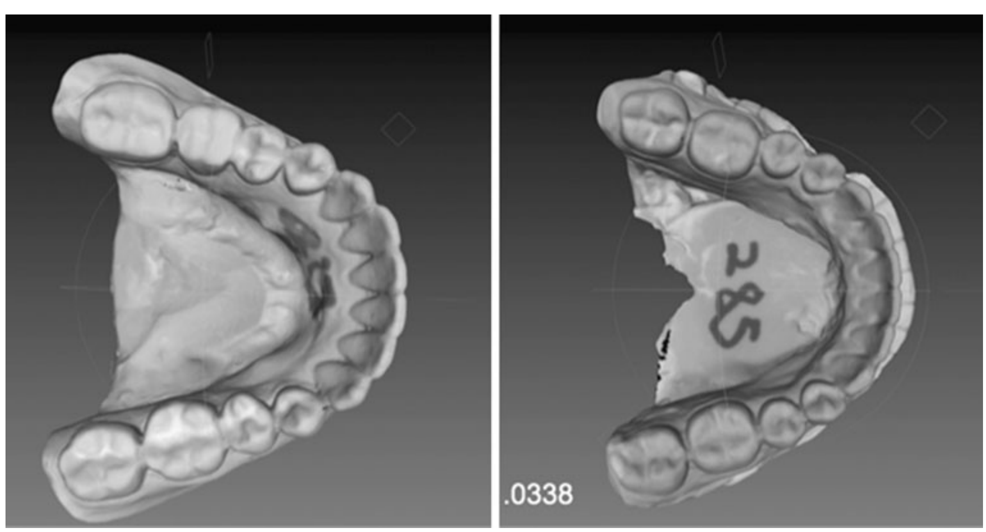

Fig. 3 Illustration of the two most similar mandibular dentitions. The match is at a Procrustes distance of 0.0338

maxillary and 497 mandibular models. One mandibular model did not have a corresponding counterpart.

Following landmark data point extraction, statistical analysis was completed to describe the configuration of the human dentition and to determine match rates in the population studied. An RMS scatter of.04 Procrustes units was used as error threshold (0.04~95% confidence or two standard deviations) for finding match rates in the 3D population.

Results

2D/3D comparison

For the 2D-14 data, out of 4,950 possible comparisons [N (N−1)/2], there were 22 matches within error measurement threshold and nine matches in the 3D-14 data set. The same number of comparisons in the 3D-60 set resulted in one match. Simple inclusion of the third dimension reduced the match rate by over 50%, and the inclusion of 60 landmarks and the ability to rotate the specimen while placing landmarks greatly reduced the rate.

The RMS scatter for the 2D-14 data was 0.021, for the 3D-14 data, 0.0228, and the 3D-60 data, 0.020, which appear identical; however, when the RMS scatter is expressed as a percentage of the total population variance, the 2D-14 data showed 6.49%, the 3D-14 data was at 6.11%, and the 3D-60 set was at 4.7%. The change in these ratios of variance is due to the changes in dimensionality and in the number of landmarks present.

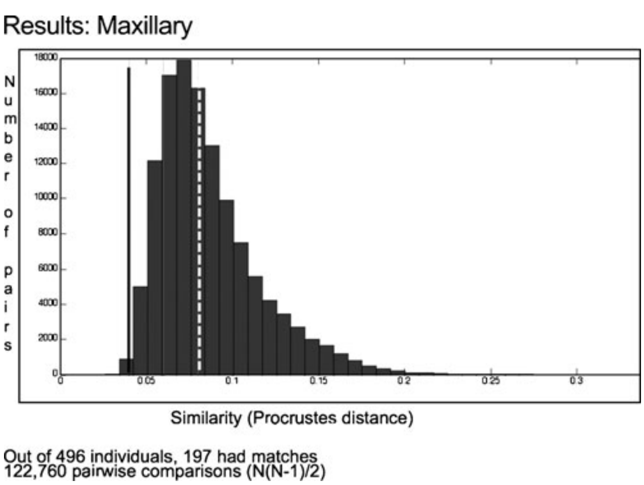

Fig. 4 Procrustes distance distribution for the maxillary dataset. Again, the *solid dark line* depicts our error measurement threshold. The *dashed white line* shows 100% degradation of resolution (0.08). Comparison of this figure to Fig. 2 shows that for maxillas, the distribution is tighter and shifted to the left, meaning that there is more similarity between maxillas

Table 1 Match distribution in the mandibular arch

Number of individuals	Number of matches
42	1
5	2
3	4
1	6

3D analysis

The RMS scatter for the 3D-60 data was 0.020 and a Procrustes distance of below 0.04 was used as the cutoff point for matches (0.04~95% confidence based on examination of all pairwise distances in repeated measures data).

Analysis of the 497 mandibular dentitions showed that out of 497 individuals, 51 had matches [123,256 to (N(N-1)/2) comparisons] with a RMS below.04. Figure 2 depicts the histogram resulting from the data. Some model dentitions had more than one match. Figure 3 shows two of the most similar matching dentitions.

Analysis of the 496 maxillary dentitions showed that out of 496 individuals, 197 had matches (122,760 comparisons (N(N-1)/2) with an RMS below 0.04. Figure 4 shows the histogram of data distribution. Some model dentitions had more than one match in the maxillary population as well. Tables 1 and 2 show match distribution for both maxillary and mandibular arches. Figure 5 illustrates two of the most similar matching maxillary dentitions.

Importantly, the more densely sampled 3D-60 set showed one match of both maxillary and mandibular dentitions between two individuals in the sample population.

It can be seen that many more matches were found in the maxillary dentition. Comparison of the histograms (Figs. 2, 4) illustrates this finding as the histogram is more densely populated towards the left side (similarity). The right hand tail in the histogram indicates increasing dissimilarity. It must be stressed that these maxillary and

Table 2 Match distribution in the maxillary arch

Number of individuals	Number of matches
117	1
29	2
21	3
5	4
6	5
6	6
3	7
6	8
1	9, 11, 13, 16

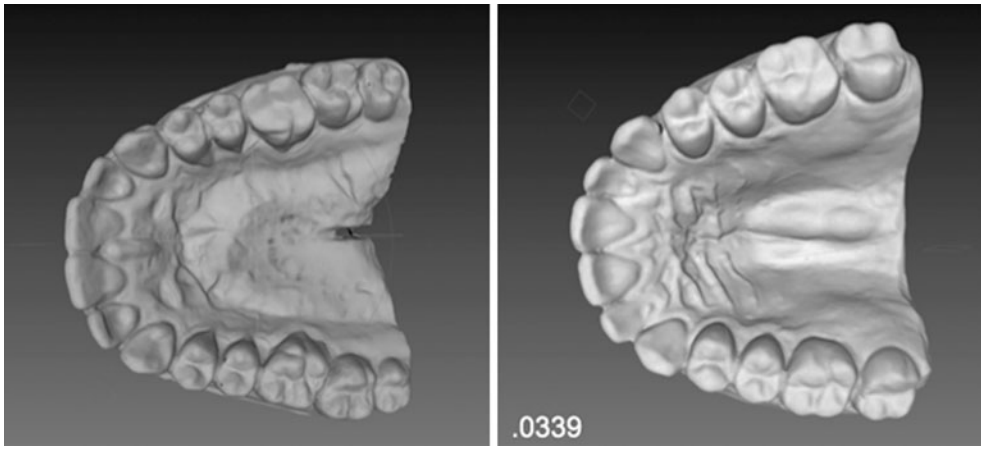

Fig. 5 Illustration of the two most similar matching maxillary dentitions. The match is at a Procrustes distance of 0.0339

mandibular model samples are sets and not independent populations. This finding illustrates that for most people, the majority of mal-alignment of teeth may be found in the mandibular arch.

Discussion

This study suggests that with regard to the shape of the six anterior teeth of the maxilla and mandible (12 teeth total), there is not enough variation in the alignment pattern to make statements of confidence regarding dental uniqueness. The position and angulation of the human dentition is far from individual on this scale. The authors acknowledge that in actual bitemark cases, it is possible that more than the six anterior teeth will leave an impression.

It must be stressed that this study only sought to find a match rate in a certain population of convenience, and as expected, all of the matching pairs consisted of relatively straight dental alignments (Fig. 6). Investigation of the

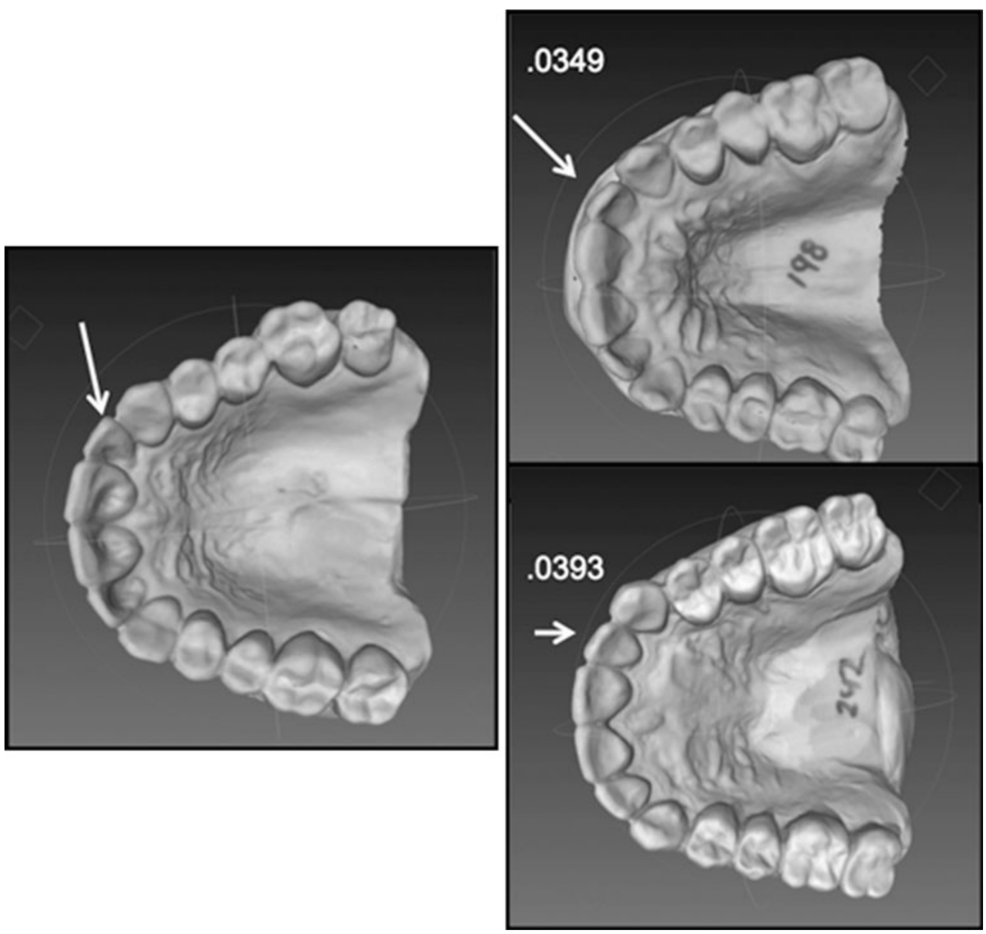

Fig. 6 Most of the matching dentitions had a relatively straight alignment. The examples here are the most mal-aligned matching maxillary dentitions. The mal-alignment seen is slight rotation of the lateral incisor (*arrows*). Procrustes distances are given for the two dentitions (*right*) that match the one in question (*left*)

likelihood of finding a match to a particular dental alignment pattern and the frequency of occurrence of any one mal-alignment pattern are not addressed in this paper. Obviously, some configurations will occur less often than others, and there may be population-specific effects (more possible mal-alignments in geographic regions where dental care access is limited).

A previous study showed that orthodontic treatment increases the match rate as it reduces the variation significantly in the teeth [9]. It was unknown what percentage of the current population had undergone orthodontic treatment, and it was possible that the population was biased in this direction, but this was considered acceptable as representing a certain cross section of society. Given that the data was collected from patients having occlusal guards constructed, there is no guarantee this data set is free of socioeconomic bias.

The hypothesis tested in this study was that dental match rates would decrease when going from the two to three dimensions. This was found to be the case. The simple inclusion of 3D information without any other alteration of the measurement protocol reduced the match rate significantly, as seen in the comparison of the 2D-14 data to the 3D-14 data. Inclusion of more data points going to 3D-60 further reduced the match rate.

The current work explores the effect of incorporating the 3rd dimension on the dental match rate. It may be further argued that the appearance of a bitemark on the skin has a relationship to the 3D shape of the dentition. That issue is not addressed in this study.

The difference noted between mandibular and maxillary match rates noted here was a novel but not unexpected finding, lending credence to the concept of higher incidence of crowding in the lower arch. In addition, this is the first report of a match in shape of both arches between two individuals. It is imperative therefore, that a probabilistic approach is taken in order to avoid unfounded statements of certainty in the courtroom. The American Board of Forensic Odontology (ABFO) reference manual states detailed guidelines with regard to bitemark analysis [20]. The guidelines suggest that without statistical analysis, research may be less than credible [20]. This paper supports the ABFO position.

Conclusions

This study expressly focused on one of the odontological research queries of the NAS report, namely is there proof of the identification of individuals from the arrangement of their teeth? [1]. The current study suggests that there may not be a scientific basis for a *general* expression of dental uniqueness when the incisal edges of the six anterior teeth are considered, as significant match rates were determined.

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A study of multiple bitemarks inflicted in human skin by a single dentition using geometric morphometric analysis

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ABSTRACT

Criticisms of the forensic discipline of bitemark analysis state that the range of distortion in the shape of bitemark impressions in skin has not been scientifically established. No systematic statistical studies exist that explore this problem. As a preliminary investigation of this issue, a single dentition was mounted in a mechanical apparatus and used to create 89 bitemarks in human cadaver skin, both parallel and perpendicular to tension lines. Impressions of the same dentition were also created in wax. 2D scanned images of the biting dentition were obtained.

Locations of incisal edges of all 6 anterior teeth as well as the midpoint of the canine were captured as landmarks in all specimens. This set of landmark data was then studied using established geometric morphometric methods. All specimen shapes were compared using Procrustes superimposition methods, and by a variation of Procrustes superimposition which preserves scale information. Match criteria were established by examining the range of variation produced by repeated measurements of the dentition for each class of specimen. The bitemarks were also compared to a population of 411 digitally scanned dentitions, again using the match criteria. Results showed that bitemarks in wax had lower measurement error than scanned images of the dentition, and both were substantially lower than measurement error as recorded in skin. None of the 89 bitemarks matched the measured shape of the biting dentition or bitemarks in wax, within the repeated measurements error level, despite the fact that all bitemarks were produced by this dentition. Comparison of the bitemarks to the collection of 411 dentitions showed that the closest match to the bitemarks was not always the same dentition that produced the bitemarks. Examination of Procrustes plots of matched shapes showed non-overlapping distributions of measurements of bitemarks in skin, wax, and the dentition. All had statistically significant differences in mean shape. Principal component analysis (PCA) and canonical variates analysis (CVA) both showed clear segregation of the three types of data. The patterns of variance revealed by PCA showed several distinct patterns produced by skin distortion; alteration of relative arch width, and varying displacement of non-aligned teeth in the dentition. These initial results indicate that when multiple suspects possess similar dentitions, bitemark analysis should be approached with caution.

1. Introduction

Distortion in a bitemark in human skin is unavoidable and the extent of skin distortion is poorly understood. In the 2009 National Academy of Sciences report (NAS), this concern was listed as "one of the basic problems inherent in bite mark analysis and interpretation" [1].

Furthermore, in the NAS report it was noted that "the ability of the dentition, if unique, to transfer a unique pattern to human skin and the ability of the skin to maintain that uniqueness has not been scientifically established." The report went on to state, "The ability to analyze and interpret the scope or extent of distortion of bite mark patterns on human skin has not been demonstrated" [1]. This study is a direct, initial attempt to address these fundamental concerns.

Skin is a less than optimal recording medium, as it undergoes visco-elastic, anisotropic, non-linear response to stress [2,3]. Prior studies have shown that these factors create a situation in which distortion will produce both intra and inter arch variation in multiple bites, even if all are created with the same dentition [4]. Previous methods of exploring deformation of skin when bitten have used metric measurements in an attempt to quantify mesial to distal, intercanine and angulation differences of the teeth within the bite [4–6]. However, metric measurements provided no overall description of shape changes of the dental arch once impressed in skin. Nor did they provide any formal statistical analysis with

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regard to range of distortion possible or to the comparative biological form of the dentition.

One well-established statistical shape method used to describe biological form is landmark-based geometric morphometric analysis (GM) [7–12]. GM methods allow for a quantitative analysis of shape by capturing the geometry of morphological structures of interest and preserving this information through statistical analysis. GM analysis involves placement of landmark points on images. The landmark data can be extracted and analyzed statistically as a unit, preserving all geometric information within the measurements. Shape information can be visualized by plotting landmark positions in Procrustes superimposition, a method of optimally matching one shape to another. Procrustes distance is a measure of the closeness in shape of superimposed specimens and is recognized as a general-purpose measure of specimen similarity in the geometric morphometric framework. Procrustes distances can be used to summarize variations in populations, to express the degree of similarity of individual specimens, means of populations, or to search for matches between bitemarks and dentition [7–12].

The standard Procrustes approach rescales both the bitemark and the dentition to a size of 1 in dimensionless units, by dividing the values of all measurements by the centroid size of the specimen [10,13]. GM methods arose out of fields where there was interest in separating differences due to size or scale from those due to structural changes, thus Procrustes methods were designed to remove scale information from data [7,9]. In forensic studies, information about size is generally important, so it is also necessary to explore an approach that preserves size. To this end, a size-preserving Procrustes approach (S-P Procrustes) was also used, in which the superimposition was done using only translations and rotations [10,13].

Among the tools available for statistical analysis is principal component analysis (PCA) with which the principal variations of shape can be plotted and visualized [7–12]. This allows for determination of which shape aspect is responsible for the most variation. Canonical variates analysis (CVA) can also be used to determine if shape information can distinguish between different categories of data.

Thus, the goal of this project was to use statistical analysis of shape change to explore the questions raised by the NAS report; *does the human dentition shape transfer reliably to skin and what is the scope or extent of the distortion seen on bitemark patterns on human skin?*

This was accomplished by, (1) comparing the shape changes between a single dentition and 89 bites created by that dentition on human cadaver skin, (2) comparing shape changes of the same single dentition to bites created in wax by that dentition, (3) comparing the similarities/differences in shape change between the bites themselves, (4) comparing the 89 bites against an acquired population of 411 digitally scanned dentitions to determine if other dentitions would match more closely than the dentition that caused the bite.

2. Materials and methods

All necessary Human Subject Institutional Review Board (HSIRB) procedures were completed and exemption was granted. Eighty-nine bitemarks were created on un-embalmed cadavers. The cadavers were stored at 4 °C and allowed to come to room temperature prior to bite infliction. The cadavers were acquired based upon availability and thus sex, age, cause of death were not a factor in this study.

Experimental bites were created by the same examiner on the upper arm, forearm, lateral thoracic wall, and upper thigh of each cadaver. Bites were created both perpendicular and parallel to skin tension lines. Sixteen bites parallel, and 73 perpendicular to tension lines were produced. The discrepancy in the number of bites was due to the difficulty in creating a clear impression of the dentition on skin in the parallel direction. Bites that did not create a clear indentation were eliminated from the study. Four bitemarks were also created in dental wax for comparative purposes.

A single dentition was used for bitemark infliction. The dentition of a volunteer was impressed with polyvinylsiloxane and then poured in light viscosity metallographic epoxy resin. The models were mounted on a hand held vice grip. The opening diameter was set to 40 mm (opening diameter of the volunteer). The maximum anterior bite force capable of the vice grip was tested with a bite force transducer and found to be within the range of maximum anterior human biting capacity. This range was established by a volunteer's in vivo test biting on the bite force transducer giving an average of 190 N. All 89 bites were created with this one dentition. Each bite was digitally photographed with a #2 ABFO scale in place. To minimize photographic distortion, the maxillary and mandibular arches were photographed separately.

This study focused only on the lower (mandibular) dentition. The shapes of all specimens in the study were quantified using landmark (measured point) methods [7–12]. Landmark points were also placed on an ABFO scale included in each image as an internal reference. Points were placed at the mesial and distal endpoints of the incisal edges of all 6 anterior teeth, plus the midpoint of each canine, in digital images of the bitemark or scanned dentition using the tpsDig program [14] (Fig. 1a and b). This resulted in a set of 14 landmarks recorded as cartesian coordinate pairs. In addition to using this set of 14 landmarks, we also repeated all the analyses omitting the landmarks at the mesial and distal incisal edges of the canine, which reduced the measurements to 10 landmarks. The midpoint of the canine was still included. This repeated analysis was carried out due to the concern that the mesial and distal extent of the incisal edges of the canine appeared to be very difficult to

a

b

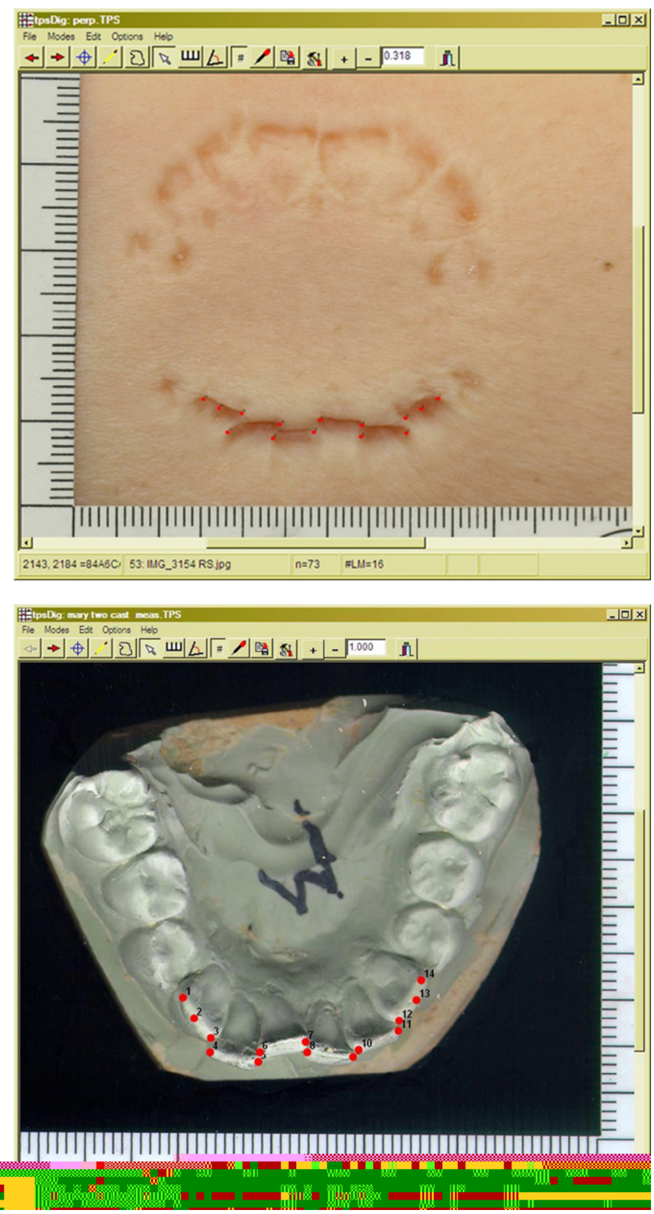

Fig. 1. (a) Landmark placement on a bitemark image. (b) Landmark placement on a model of the dentition used to create the bites.

reliably locate in the inflicted bitemarks. Due to the conical shape of the canine, mesial and distal endpoints were not reliably discerned in all of the digital images. This was evidenced by repeat measures and scatter plots of the data. The midpoint was interpreted as the center region of the indention of the tooth. This was fairly reliably transferred as determined by repeat measure and scatter plots. Thus this was repeated with midpoint only.

An acquired sample population of 411 mandibular dentitions, scanned on a flatbed scanner, (408 plus 3 separate scans of the biting dentition) was also utilized for comparison purposes to determine if other dentitions would match more closely than the dentition that caused the bite. This sample population was collected for a previous study [15]. This population consisted of 145 dental models collected from the dental clinics at the State University of New York at Buffalo School of Dental Medicine and 265 models collected from the patient pools of several private practice dentists in New York State. Thus this was a sample of convenience.

To establish operator error rates, ten *repeated measurements* were made for each of the following specimens, (1) 3 different bitemarks in cadaver skin, (2) 2 bitemarks made by the bitemark apparatus in wax, (3) 2 bitemarks in wax made by the volunteer in the study and (4) a scanned image of the biting dentition.

2.1. Analysis methods

After digitization, all datasets were superimposed on one another by matching the landmark points to minimize the summed squared distances between corresponding landmark points on each specimen. When specimens are matched by rotating, translating, and rescaling one specimen to optimally match one another the specimens are said to be in Procrustes Superimposition [10,9,11,12].

Procrustes superimposition has four steps. First, it was required that the centroid size of the two specimens, which is the summed squared distances of all the landmarks from their centroid (average position), is the same. The centroid size was rescaled to 1 by dividing all positions by the size. This step meant that the landmark positions were now in dimensionless units, since they had all been divided by a linear size measure. The positions were thus expressed as fractions of the total size. Next, it was required that the centroid, the average of all the landmark locations of the two specimens, coincide at the origin. Finally, the specimens were rotated about the centroid to minimize the summed squared distances between corresponding landmarks. The two specimens were said to be in Partial Procrustes Superimposition, which is a standard approach for shape comparison [10,9,11]. This simply means that the two specimens were required to be the same size, and then matched as closely as possible by rotating and translating (sliding) the two specimens to match. This allowed investigation of shape change only within the dataset.

Once the specimens had been superimposed, Procrustes plots were produced, showing the differences in two or more specimens as patterns of landmark positions. When comparing many specimens on such a plot, all specimens are typically superimposed on an estimated mean specimen in what is called a generalized least square (GLS) Procrustes procedure.

It was also possible to calculate a measure of the net difference between two shapes once they had been superimposed. When two specimens are placed in a Partial Procrustes Superimposition with one another, the square root of the summed squared distances between corresponding landmarks is called the Partial Procrustes Distance (Fig. 2a and b), often simply called the Procrustes Distance, which is in dimensionless units that represent a fraction of the original object's centroid size. If the specimens are a perfect match, then all the landmarks will overlay one-another exactly and the Procrustes Distance will be zero. When landmarks on the specimens do not overlap, the Procrustes Distance will increase with the degree of mismatch. Procrustes Distance is a summative univariate measure of difference in shape, allowing a simple means of quantifying the difference between sets of landmark measurements.

In forensic work, size information is typically important as well as shape information. To this end, the data was also analyzed using a Size-Preserving Procrustes method (S-P Procrustes), in which the dentition and bitemark were superimposed using only rotation and translating, without altering the size of either set of measurements [10,13]. A distance measure between a set of landmarks can again be computed, which is now an S-P Procrustes distance. Coordinates in S-P Procrustes are in the original measurement unit, millimeters. Thus S-P Procrustes allows investigation of both shape and size within the dataset.

The RMS scatter served as an estimate of the measurement error. In a repeated measures study, the root mean square (RMS) scatter of the repeated measures specimens about the average of all these specimens, measured in Procrustes distances (or S-P Procrustes distances) can be computed. The RMS scatter is akin to a standard deviation, in that both are the square root of the mean squared departure from the average. The RMS scatter does not have the same statistical properties as a standard deviation, but it was observed that 93–96% of repeated measures specimens were typically within twice the RMS scatter of one another in several measured collections of dentitions [15]. Thus twice the RMS distance as a cutoff distance for matching specimens was adopted. The matching criterion was that two specimens are within twice the RMS scatter of repeated measures specimens. With this criterion and computer software for carrying out Procrustes Superimpositions, it was possible to readily search for matches between specimens, or groups of specimens.

Once specimens had been superimposed using Partial Procrustes Methods, a variety of statistical tests and ordinations of data collections was conducted. *F*-tests of differences in mean shape was carried out using a permutation-based version of Goodall's *F*-test [11,14,16] based on the Procrustes superimposition. Principle component analysis (PCA) was performed on shape data, using Procrustes data, to reveal patterns of covariance or correlated structure in data. Canonical variates analysis (CVA) was used to determine whether specimens may be identified as being members of specific groups based on Procrustes superimposed data, using both standard and S-P Procrustes methods. Both the PCA and CVA methods make use of Partial Warp Scores, linear transformations of the original measurements organized as patterns of shape change. The use of Partial Warp Scores is a statistical and graphical convenience, and involves no loss of information or distortion of the data, it is simply a mathematical convenience commonly employed in GM studies and software [10,9,11].

Procrustes distance was determined for each specimen, and was used to demonstrate the non-equality of measured images of the dentition, wax impressions, as well as the range of distortion of bitemarks in skin. In addition the bitemarks were compared to the population of 411 digitally scanned dental models to determine the closest match.

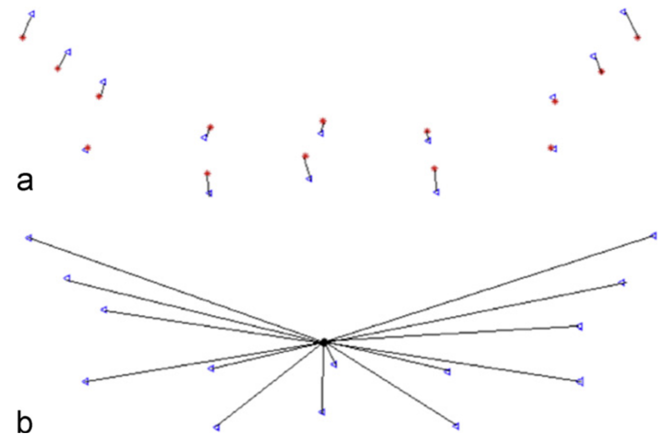

Fig. 2. (a) Calculation of Procrustes distance. The asterisk and triangle are measured landmarks in two lower dentitions. The lines indicate the separation of corresponding landmarks in the two images. The Procrustes Distance is the square root of the summed squared lengths of these lines. Procrustes Superimposition acts to minimize this distance, without changing the shape of the dentitions. (b) Calculation of Centroid size. The triangles are the measured landmark locations of a dentition. The central point is the average position of all the landmarks (the centroid), and the lines show the distance of each landmark from the Centroid. The Centroid size is the square root of the summed squared lengths of these lines.

3. Results

The repeated measures study allowed establishment of the Procrustes Distance between specimens that would form the criterion for a match in shape. Bitemarks in cadaver skin had the highest RMS scatter based on either 10 or 14 landmarks, using both Procrustes and S-P Procrustes. Bitemarks in wax had the lowest measurement, even lower than the digital scan of the dental model (Table 1). Twice the RMS scatter of repeated measures error in the bitemark in skin was chosen as the criteria for matching a bitemark to a dentition, yielding Procrustes matching distances of 0.052 for 14 landmarks and 0.054 for 10 landmarks. The equivalent matching distances in S-P Procrustes were 2 mm for 14 landmarks and 1.56 mm for 10 landmarks.

The centroid size of the actual dentition was 34.7 mm when all 14 landmarks are included and 24.7 mm when only 10 landmarks are used. The mean bitemark centroid sizes were 34.4 mm and 24.5 mm, respectively, with ranges of 29.2–38.7 mm and 20.7–27.2 mm. The mean size of the bitemarks was thus virtually identical to the dentition but varied by roughly ±12%. The 40 bitemarks in wax had mean sizes of 35.2 mm and 25.2 mm with ranges of 34.7 to 35.6 mm (±1.1%) and 24.8 to 25.6 mm (±1.6%). In the data set of 411 dentitions used for comparison purposes, the mean centroid sizes were 37.3 mm and 26.1 mm with ranges of 29.6–53.1 mm and 21–38 mm.

Table 1
Repeated measures results.

Data set	Procrustes		S-P Procrustes	
	RMS scatter		RMS scatter	
	14 LM dimensionless	10 LM dimensionless	14 LM (mm)	10 LM (mm)
Bitemark 1 (skin)	0.036	0.036	1.33	0.97
Bitemark 2 (skin)	0.019	0.021	0.75	0.63
Bitemark 3 (skin)	0.024	0.026	0.92	0.75
Mean of 3 bitemarks (skin)	0.026	0.027	1.00	0.78
Dentition	0.02	0.021	0.64	0.58
Bitemark 1 (model in wax)	0.012	0.014	0.42	0.4
Bitemark 2 (model in wax)	0.015	0.017	0.53	0.47
Bitemark 1 (wax)	0.012	0.013	0.43	0.4
Bitemark 2 (wax)	0.014	0.017	0.52	0.45
Mean of 4 bitemarks (wax)	0.013	0.015	0.48	0.43

Comparison of the centroid sizes of the dentition to the wax impressions and to the bitemarks in skin showed little change in the average centroid size from one recording media to another, however bitemarks in cadaver skin showed a variation in size of roughly plus or minus 12% vs. a variation of 1.6% or less in wax, indicating the substantial alterations in size possible in cadaver skin.

A plot of all repeated measurements of the dentition, of the repeated measures of the wax bitemarks and of all the bitemarks in cadaver skin (but not the repeated measurements in skin) in Procrustes Superimposition is shown in Fig. 3, and shows the disjointed nature of these measurements, as well as the relative variance in the bitemarks in cadaver skin as compared to repeated measurements of the dentition and of bitemarks in wax.

When the biting dentition was compared to the 89 bitemarks in cadaver skin using Procrustes methods, using either 14 landmarks or 10 landmarks, no matches of the bitemarks to the biting dentition were observed within the RMS error measures of 0.052 and 0.054 respectively. In both cases, there were near matches, at a distance of 0.056 for 14 landmarks and 0.055 for the 10 landmark set. Using size preserving methods produced the same results with minimum distances of 2.33 mm using 14 LM and 2.02 mm using 10 landmarks, relative to the matching distances of 2.00 mm and 1.56 mm respectively.

Similarly, there were no matches of the bitemarks in cadaver skin, using either 14 or 10 landmarks, when comparing them with the wax bitemarks using both Procrustes and S-P Procrustes.

The 40 repeated measures of bitemarks in wax were compared to the biting dentition itself. There were no matches within twice the RMS scatter seen in the repeated measurements of the wax bitemarks to the biting dentition, regardless of the number of LM or form of superimposition. The distances from the wax bitemarks to the dentition were generally lower than from those obtained from the cadaver bitemarks to either the dentition or the bitemarks in wax.

Comparison of the 16 bitemarks created parallel to tension lines revealed no pairwise matches of these bitemarks to another bitemark in the data set within the repeated measures error level, using 10 or 14 LM and both Procrustes and S-P Procrustes. Among the 73 bitemarks created perpendicular to tension lines, 34 of the bitemarks had one or more matches to other bitemarks in that set within the measurement error (using 14 landmarks) under the Procrustes superimposition, which decreased to 27 matches using S-P Procrustes. When all 89 bitemarks were examined as a single set, the same 34 and the same 27 bitemarks had one or more matches under Procrustes and S-P Procrustes respectively, so there were no matches between parallel and perpendicular bitemarks, even though all of these bites were created with the same dentition.

Inclusion of size information did not have as large an impact on the results as initially expected. Bitemark size varied substantially from bitemark to bitemark, therefore inclusion of size information did not improve the ability to match the biting dentition to the bitemark. It did reduce matches from one bitemark to another from 34 out of 89 to 27 out of 89, roughly a 20% reduction.

The bitemarks were then compared to a data set of 411 specimens measured from scanned dental models. The 411 specimens included two earlier scans made of the dentition that produced the bitemark along with a new scan of that dentition, resulting in 3 separate scans of the same dentition.

The software was first tested with these three scans. A test trial which compared the dentition responsible for the bitemarks against this 411 specimen set produced three matches of that dentition in the data set, thus it correctly matched the dentition to

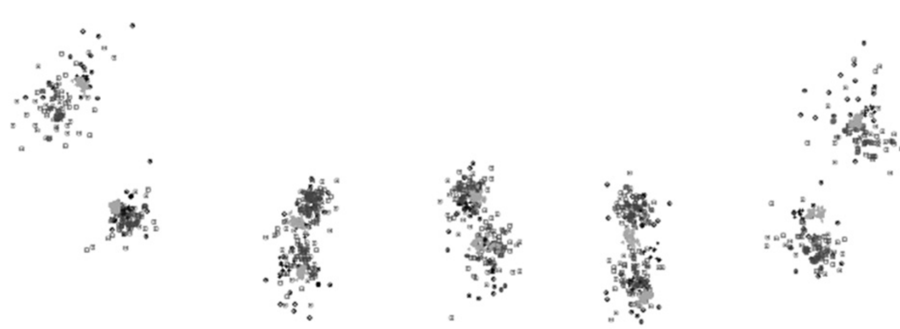

Fig. 3. Procrustes superimpositions plot of all bitemarks, the repeated measures of the dentition, and the repeat measures of the bitemarks in wax. Square boxes are bitemarks parallel to skin tension lines, circles are perpendicular, crosses are bitemarks in wax, the gray triangles are repeated measures of the dentition.

Table 2
Five specimens in the collection of 411 lower dentitions with the most matches to the bitemarks and the number of bitemarks to which each matched. The actual dentition that caused the bite and the 2 copies of it accounted for 28 best matches using 14 landmarks or 24 best matches using 10 landmarks out of 89 best matches using Procrustes methods, and 21 and 19 best matches when no scale changes were allowed. Specimen 254 has 27 and 29 best matches using Procrustes methods, and 31 to 39 matches when no scale changes were allowed, and so is as likely to be the best match as the actual biter.

Dentition	Number of matches			
	Procrustes		S-P Procrustes	
	14 landmarks	10 landmarks	14 landmarks	10 landmarks
Actual biter	18	10	15	8
Copy 1	3	12	5	11
Copy 2	7	2	1	0
Specimen 254	27	29	31	39
Specimen 214	13	16	3	13

the three measurements of this same dentition in the set of 411, indicating that the matching procedure worked correctly, under both Procrustes and S-P Procrustes.

In the comparison of the 89 bitemarks to the collection of 411 dentitions, there were no matches of any dentition to any bitemark within the measurement error (under any superimposition or number of landmarks). For each bitemark, the closest matches to the dentition were computed, and the number of closest matches for each dentition determined, as shown in Table 2. When size information was included, one of the other specimens (not the biter) became increasingly the best match to the bitemarks. Fig. 4a and b show the scan of the closest match dentitions that were not the biter.

The mean shapes obtained from the bitemarks, and from repeated measures of the dentition and bitemarks in wax were also compared (Fig. 5) using Procrustes methods. The mean shapes of the repeated measures of bitemarks in wax and the dentition were statistically significantly different at $p < 0.01$ in all cases ($F = 59.6$ for 10 landmarks, $F = 69.97$ for 14). Likewise the mean shape of the bitemarks in skin and the dentition itself were statistically significantly different at $p < 0.01$ ($F = 15.4$ for 10 landmarks, $F = 9.4$ for 14). The shapes of the mean bitemarks in skin and wax were also significantly different ($F = 26.67$ for 10 landmarks, $F = 46.8$ for 14). Degrees of freedom are not listed as a permutation test was used [11,16]. These F-tests indicate statistically significant differences in the mean shape of the dentition as recorded in skin, in wax or via a flatbed scanner, relative to the scatter within each set of measurements.

Principle component analysis and canonical variates analysis also support the clear differences in shape between the dentition and the two categories of bitemarks.

The PCA also shows clearly interpretable patterns of variance in the data. The first PCA axis shows that curvature of the dental arch

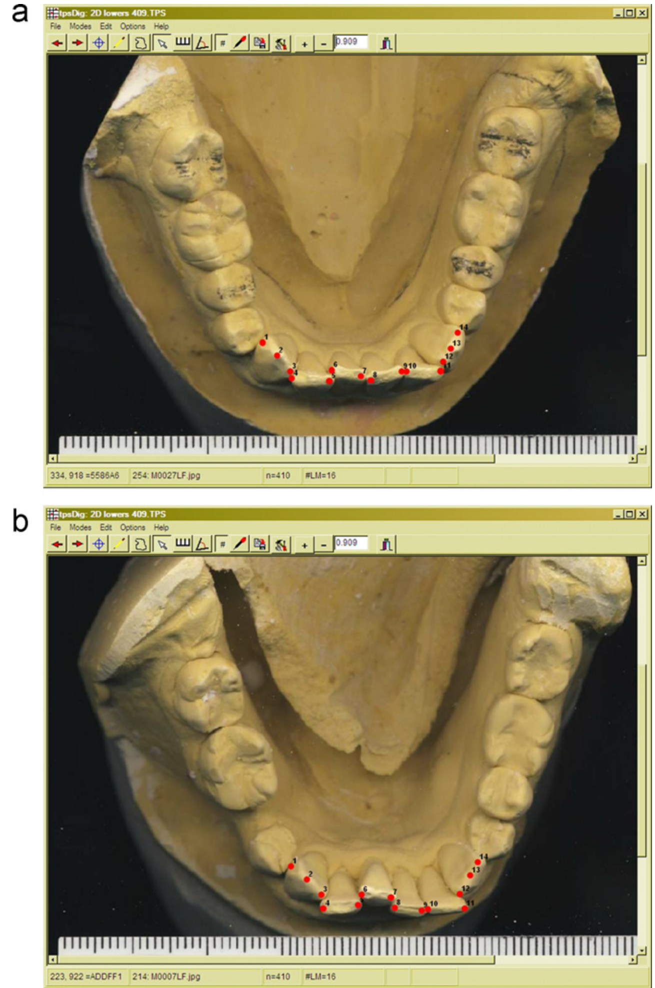

Fig. 4. (a) Specimen 254. This dentition had 27 matches to 89 of the bitemarks with 14 landmarks and 29 matches with 10 landmarks. Compare this dentition to the biting dentition shown in Fig. 1b. (b) Specimen 214. This dentition had 13 matches to 89 of the bitemarks with 14 landmarks and 16 matches with 10 landmarks. Compare this dentition to the biting dentition shown in Fig. 1b.

is the primary difference in individuals (accounting for 38% of the variance), while the second axis illustrates the alteration of the alignment pattern, as it appears that the dentition has become flatter with less lingual displacement of the right central incisor.

The PCA analysis of the Procrustes superimpositions of the 89 bitemarks combined with the 10 repeated measurements of the dentition and the 40 repeated measures of the bitemarks in wax showed a clear separation of bitemarks, wax bitemarks and the dentition along the 2nd PCA axes, whether 10 or 14 landmarks were used (Fig. 6a and b). A PCA study of the bitemarks alone

Fig. 5. Procrustes superimpositions plot of the mean shapes of bitemarks, and the repeated measures of the dentition, and of the bitemarks in wax. Square boxes are the mean bitemark parallel to skin tension lines, circles are the mean bitemark perpendicular, crosses are the mean bitemarks in wax, the gray triangles are the mean of repeated measures of the dentition.

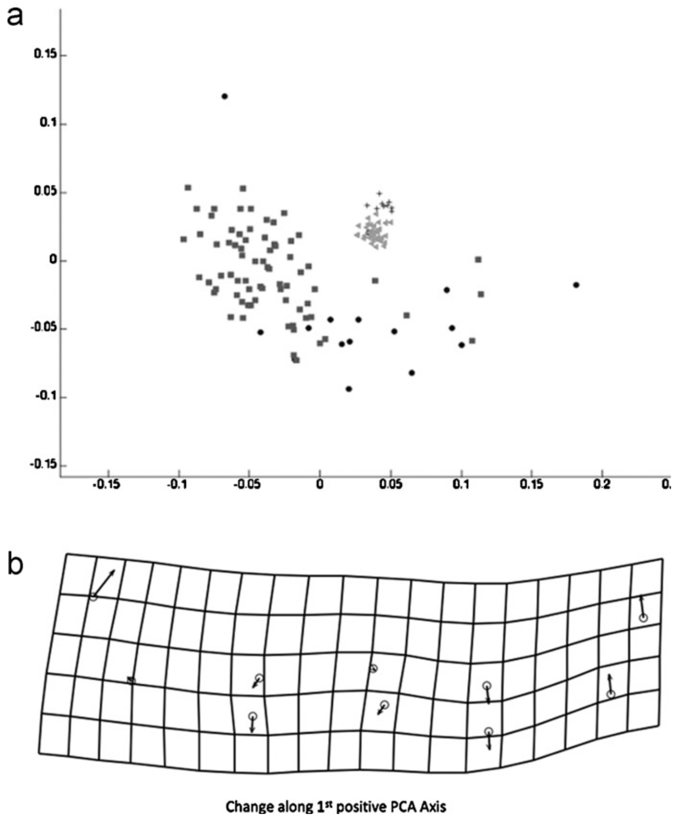

Fig. 6. (a) PCA plot of bitemarks, and the repeated measures of the dentition, and of the bitemarks in wax. Square boxes are the mean bitemark parallel to skin tension lines, circles are the mean bitemark perpendicular, crosses are the mean bitemarks in wax, the gray triangles are the mean of repeated measures of the dentition. (b) Plot of deformation in the positive direction on the first axis, showing narrowing of the arch. The negative direction shows widening of the arch.

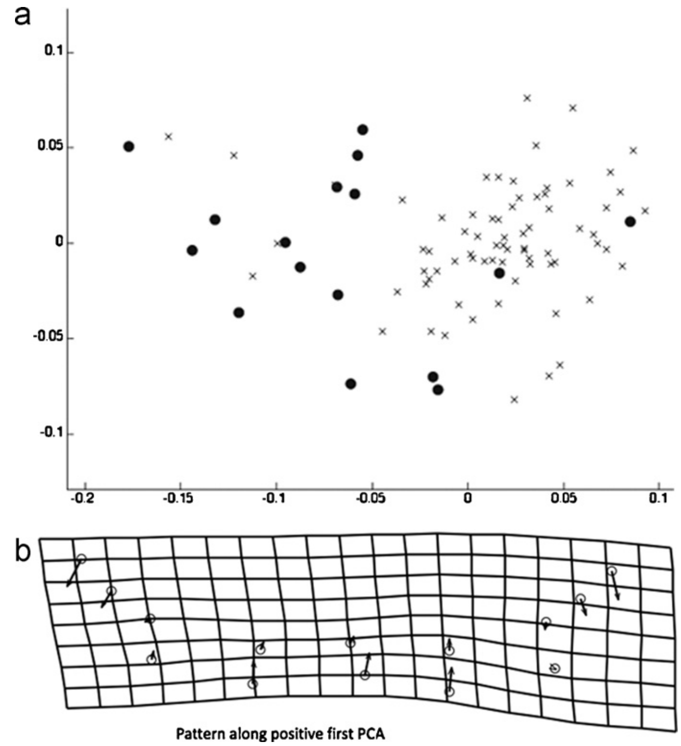

Fig. 7. (a) PCA of bitemarks only, parallel are solid dots, perpendicular are crosses. (b) Deformation plot in the positive direction of the first PCA axis, showing flattening of the arch.

revealed interpretable patterns of variance in the bitemarks (Fig. 7a and b).

Bitemarks parallel to skin tension lines did appear to produce slightly different results that those perpendicular to skin lines. The clustering appearing in the PCA appears to indicate that bites parallel to skin lines produced narrower patterns than those perpendicular to skin tension lines.

Similarly a CVA analysis (using both Procrustes and S-P Procrustes) also readily separated all the specimens (including the wax bitemark and dentition repeated measures data) into bitemarks in cadaver skin, bitemarks in wax and dentitions (Fig. 8). There were three statistically significant CVA axes ($\chi^2 = 427.98$, df = 48, $p < 2.2e{-}16$, $\chi^2 = 185.86$, df = 30, $p < 2.2e{-}16$, $\chi^2 = 75.25$, df = 14, $p = 2.13e{-}10$, for the Procrustes-based analysis). A jackknife test of specimen assignment [11,16,17] showed that the landmark measurements could be used to identify a specimen as a bitemark in skin, in wax or as a dentition with a 96% rate of correct assignment to these three categories (Table 3). Results were nearly identical when S-P Procrustes methods were used (not shown). There were a lot of mistaken assignments among the parallel vs. perpendicular bitemarks, meaning that it was difficult to tell if a given bitemark was parallel or perpendicular to skin tension lines, but that it was, however, a measured bitemark in cadaver skin, and not a measured dentition or bitemark in wax.

4. Discussion

Bitemarks impressed by a single dentition in cadaver skin showed substantial change in shape from the dentition that

Table 3
CVA group assignments, 10 Landmarks.

10 Landmarks, but not allowing scale changes				
Procrustes Methods	Assigned group membership			
True group membership	Parallel bitemark	Perpendicular bitemark	Dentition	Wax bitemark
Parallel bitemark	12	1	2	1
Perpendicular bitemark	9	62	1	1
Dentition	0	0	10	0
Wax bitemark	0	0	0	40
True group membership	Parallel bitemark	Perpendicular bitemark	Dentition	Wax bitemark
Parallel bitemark	12	1	2	1
Perpendicular bitemark	9	61	1	2
Dentition	0	0	10	0
Wax bitemark	0	0	0	40

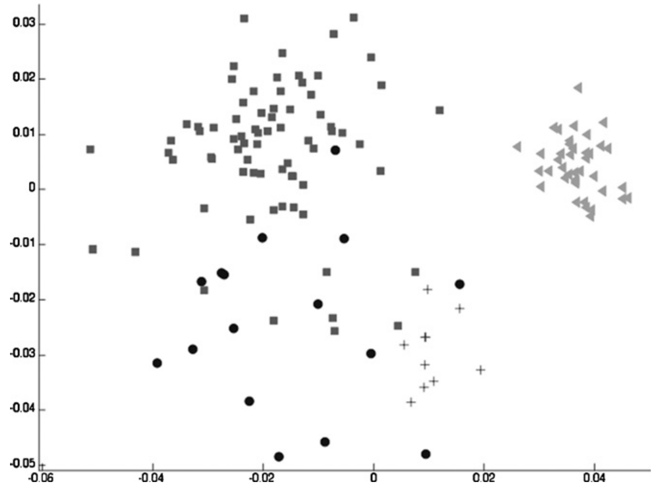

Fig. 8. CVA plot of bitemarks, and the repeated measures of the dentition, and of the bitemarks in wax. Square boxes are the mean bitemark parallel to skin tension lines, circles are the mean bitemark perpendicular, crosses are the mean bitemarks in wax, the gray triangles are the mean of repeated measures of the dentition.

produced them. Bitemarks impressed in cadaver skin by this dentition also showed more variability in the distortion of shape than appeared in bitemarks in wax or in repeated measurements of the dentition.

Repeated measurements of bitemarks in skin produced higher levels of repeated measurement error, indicating the difficulty of reliably locating the edges of the incisal surfaces in a bitemark in skin (relative to bitemarks in wax, or on a scanned dentition). Repeated measurements indicated that bitemarks in wax produced less variation in repeated digitizations than scanned image of casts of a dentition, suggesting bitemarks in wax might be a more reliable approach to measuring the shape of the biting dentition.

When a bitemark produced by the specific dentition used in this study was impressed in cadaver skin, or in wax, there was variation in the measured positions of the incisal edges of the lower dentition (Fig. 3). There was a systematic shift in the mean position, as evidenced by the statistically significant differences in the mean shape of the measured locations of the edges of the dentition, bitemarks in wax and bitemarks in cadaver skin, as is evident in Fig. 5. There was also a large variation in shape of the bitemarks produced by this single dentition in cadaver skin, so large that none of the bitemarks matched the dentition or the bitemark impressed in wax within the known measurement resolution. Despite this large variation, measurements can be reliably determined to be bitemarks in cadaver skin, in wax or as direct measurements of the dentition, as evidenced by the CVA results. This result indicates that there are identifiable and systematic differences in the shape of the dentition as directly measured, as measured in wax and as impressed on skin.

The closest matches of the bitemarks to a large collection of measured mandibular dentitions indicated that many of the bitemarks matched a relatively limited number of specimens. The most prominent matches occurred either to repeated measurements of the dentition that produced the bite, or to dentitions that were similar to the biting dentition, but differed largely in having a wider or narrower arch and loss of lingual displacement of the right central incisor. These results are consistent with the PCA results (Figs. 6b and 7b).

The comparison of methods obtained using Procrustes methods (which removed differences in size) and S-P Procrustes (which preserved size information) were somewhat interesting. Including size did not improve the ability to match the bitemark to the dentition that produced it. This is an expected result, in that if the shapes do not match, adding the information about possible size differences will not alter the shape information, but may result in the two objects not matching due to size differences. Rather interestingly though, including size information actually decreased the number of instances in which the actual dentition was the best match out of the 411 lower dentitions compared to the bitemark (Table 2), and led to increased cases where the closest match was not the dentition producing the bitemark.

The static cadaver model used here may eliminate some of the variables associated with bitemarks. It is impossible to reproduce a violent altercation and this may have affected results.

It is acknowledged that some of the remaining skin variables may have also affected the results. It was found in previous studies that the bites were each unique events, in that individual skin sites and skin condition may have had some effect on macroscopic appearance [5,6]. Examination of individual skin sites is beyond the scope of this study and is the basis for future work.

While these results are illuminating, particularly by producing a quantifiable measure of the degree of variation in the bitemarks, as well as a characterization of the typical patterns of distortion, the results have to be viewed with some caution in that they were produced by not only a single dentition, but a single arch. This study focused only on the lower arch with the goal of collecting baseline data on skin distortion. Incorporation of the maxillary data would necessitate evaluation and interpretation of two sets of data. Future work will need to include a series of dentitions, representing a range of typical dentition shapes and malalignment patterns.

The authors also acknowledge other limitations to this study. The vice grips used do not perfectly replicate the human biting mechanism. The use of vise grips however, did allow a reproducible means of impressing the skin. The 3D aspect of the dental arch was not explored, although consideration of this might be made in actual casework. It is also acknowledged that cadaver tissue lacks the vital response. However, limitations of the use of living subjects though Human Subject Institutional Review Boards point to the need for an experimental model that replicates at minimum correct anatomy and biomechanical properties. The variables of sex, age, mass and cause of death were beyond the scope of this study. The authors recognize the potential significance of these factors. Future work could consider these parameters and the statistical consequence of each.

5. Conclusions

The ability of the CVA method to distinguish between scans of the dentition, bitemarks in wax and bitemarks in cadavers was intriguing, in that is does indicate some degree of systematic, rather than random, alteration of shape as the bitemark is impressed on cadaver skin. This may indicate that future work on quantifying distortion in skin might identify the nature of this systematic alteration in shape.

With further study, the results may point to an approach to determining the conditions under which it will be difficult to distinguish between possible suspects in a closed population. For example, the Procrustes distances between the suspects dentitions, and between the suspect's dentition and the bitemark may be determined. If the suspect's dentitions are too similar to be distinguished given the repeated measurements criterion in bitemark measurement, then it might appear inadvisable to make a claim of exclusion of either biter. Knowing that the primary type of shape distortion produced by bitemarks is variation in arch width, investigators might exercise particular caution in a case where the major difference between suspects was an apparent difference in arch width.

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PAPER
ODONTOLOGY

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The Response of Skin to Applied Stress: Investigation of Bitemark Distortion in a Cadaver Model*

ABSTRACT: Knowledge of distortional properties of skin is important in bitemark analysis. Thus, the response of skin to stress from bites was investigated. Four sets of models were created from the dentition of one individual. Anterior teeth were systematically removed to vary contact surface area. A biting apparatus was constructed with an integrated load cell. Forty-six bites were created perpendicular to Langer lines on six cadavers. Rate of force application and bite pressure were controlled. Metric/angular measurement and hollow volume overlays were employed. Distortion produced by each dentition was calculated and assessed. Results showed that as teeth impressed loose tissue, mesial/distal distance increased, angles of rotation flattened, and inter-canine distance lengthened. An opposite effect was seen in tight tissue. When the surface area of the dentition was reduced, a mixture of these effects was observed. Conclusions indicated that stiffness of the tissue was the most important variable in bitemark distortion.

KEYWORDS: forensic science, forensic odontology, bitemarks, bitemark research, skin, distortion

Distortion is inevitable in a bitemark (1). Knowledge of how distortion arises, and the extent possible, is important for the forensic odontologist. How skin deforms in response to applied stress of a bite is dictated by biomechanical properties of skin in the bitten area, coupled with the three-dimensional properties of both skin and teeth (2,3).

There are many factors that influence how distortion arises in a bitemark (1). They can be summarized into two categories: those associated with the biter, and those associated with the victim. Some variables associated with the biter include maximum anterior bite force, surface area of the dentition, alignment pattern of the dentition, height discrepancy between teeth, and sharpness of each tooth.

The more complicated set of variables are associated with the victim, mainly biomechanical properties of the skin and underlying substrate. Skin is complex due to its nonlinear behavior in response to stress (4). Stress is a measure of the amount of force exerted per unit area. Therefore with a bitemark, bite force and available surface area of the teeth define stress.

At low stresses, skin is fairly elastic. There is a large elastic extension of skin that takes place at very low stress. This allows for everyday movement and joint range of motion (5,6). As stress is increased or maintained, skin rapidly becomes stiffer (more viscous) (7,8). At this point, large additional increases in applied stress will produce little further extension (9). Due to the combination of its elastic and viscous nature, skin is defined as a visco-elastic material. This visco-elastic property will dictate how teeth can impress the tissue. Once teeth engage the skin and exert enough stress, extension will become limited and the teeth will not be able to further indent the skin. It will then absorb the stress until teeth are released or until it reaches the rupture point.

Therefore, when the first tooth engages the skin, a local change in its biomechanical properties results as tissue tightens in the contact area. As subsequent teeth make contact, they will encounter skin that is less elastic. As a result, each tooth progressively impresses a substrate that is becoming harder. The pattern of resulting tension in the skin can thus be complex, depending first on the three-dimensional configuration of the dentition, including presence or absence of teeth, and second on the underlying consistency of the tissue.

Figure 1 depicts a typical stress/strain curve for skin and illustrates the nonlinear response of skin to stress. This curve is divided into three phases, each phase describing changes in the visco-elastic properties of the skin. Phase I illustrates rapid elastic extension under very low stress. As the stress increases through stage II, the tissue stiffens and further elongation becomes limited. In phase III, skin will absorb the stress, depending on underlying structures, until it ruptures (4,7,9). Elongation in phase III is very small; however, the resistance to fracture is quite large. This is illustrated by the almost linear rise of the slope of the curve in phase III. This slope rises as a logarithm of strain rate (9).

These properties are also influenced by existing pre-tension. Depending on the direction of tension lines (Langer lines), skin is pre-stretched to a certain degree. As a result, it is inherently tighter in one direction versus another. This determines how quickly skin exceeds its elastic limit and enters the viscous stage in any given direction (10–17).

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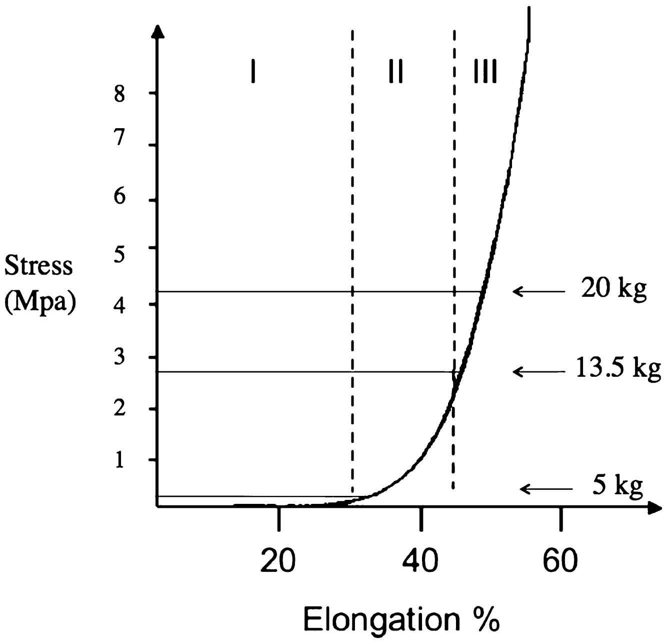

FIG. 1—*Example of a standard stress/strain curve. The theoretical load required to enter phase II (5 kg) and III (13 kg) is displayed along with the stress obtainable at 20 kg. These calculations are based on the surface area of the lower dentition, Model 1 of the volunteer.*

Given that stress is expressed as force per unit area, as contact area of the dentition is reduced, stress applied locally to the skin increases. Given the same biting force, a dentition with fewer teeth or less surface area will inflict more stress on the tissue. Therefore, if the parameters of the biter's dentition and mechanisms of bite infliction are controlled, an exploration of how the skin responds can be studied.

The goals of this study were: To investigate how skin deforms during application of stress, to appreciate how variation of the contact surface area of the biter's dentition can influence distortion in various tissue types, and to explore the damage that occurs to skin at different stress levels.

Materials and Methods

Human Subject Review Board exemption was granted for this project. Six cadavers were used. The cadavers were acquired after the passage of rigor mortis. They were stored at 4°C, allowed to warm to room temperature and any condensation on the skin was removed.

Polyvinylsiloxane (PVS) impressions were taken of a single individual who served as the biter. This individual had a class one occlusion, with mild mal-alignment of the upper and lower arch. Models of the upper and lower dentition were poured under vacuum in low viscosity epoxy resin (Buehler Epo-Thin, Lake Bluff, IL) according to manufacturer's directions. This material has hardness qualities similar to natural teeth and also reproduces detail to sub-micron scale.

Four sets of epoxy models of the biter were created. One set had a complete dentition. In the other sets, the teeth were systematically removed in order to vary the contact surface area. Figure 2 depicts Models 1–4. The resultant models are described as:

Model 1: Complete dentition

Model 2: Missing one central incisor from both the upper and lower arch (#8 and 25)

Model 3: Missing both central incisors from the upper and lower arch (#8, 9, and 24, 25)

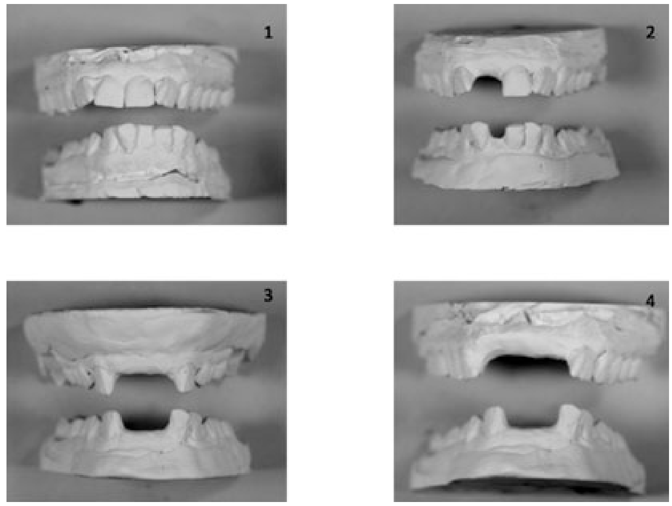

FIG. 2—*Models 1–4.*

Model 4: Missing both central incisors and one lateral incisor from both the upper and lower arch (#7, 8, 9, and 24, 25, 26)

The area of the biting surfaces of each dentition was measured with Image J freeware. The values, reported in mm^2, are listed in Table 1. Each set of models was scanned on a flatbed scanner, sized 1:1, hollow volume overlays were constructed and metric/angular measurements obtained using Adobe Photoshop®.

A custom biting apparatus was fabricated that allowed for each set of models to be interchangeable on the apparatus. This device articulated the teeth into centric occlusion. The maxillary member had an integrated force transducer (Loadstar, Fremont, CA) to allow for constant monitoring of the applied bite force. Bite force was generated by a clamping mechanism to provide for a steady, controlled application. The force transducer was connected by USB cable to a PC and the controlling software allowed visualization of the force application rate and maximum force attained. The force applied was recorded per second. The range of time needed to reach the target load of 20 kg was 13–19 sec, as the load was applied in a slow, steady pace.

Force, which is defined as mass (kg) times acceleration (G) was calculated and reported in Newtons (N).

This calculation was expressed as:

$$N = kg \times G.$$

Since these were static bites the gravity constant (G) = 9.81 m/sec^2 was used. Stress, described in pascal units (Pa), was calculated by dividing force by unit area:

$$Pa = N/m^2$$

This value was then reported in megapascals (MPa). The stress obtainable with the four sets of dentitions at loads of 20, 30, 40 and 50 kg is reported in Table 2.

TABLE 1—*Surface area of each model in millimeters squared.*

Upper Dentition		Lower Dentition	
Model 1:	61.69 mm^2	Model 1:	46.12 mm^2
Model 2:	51.37 mm^2	Model 2:	38.15 mm^2
Model 3:	41.40 mm^2	Model 3:	28.82 mm^2
Model 4:	31.54 mm^2	Model 4:	23.39 mm^2

TABLE 2—*Stress, expressed in MPa, capable of each dentition at loads of 20, 30, 40, and 50 kg.*

20 kg (44 lbs)		30 kg (66 lbs)		40 kg (88 lbs)		50 kg (110 lbs)	
Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Model 1							
3.2	4.2	4.75	6.4	6.34	8.5	7.96	10.64
Model 2							
3.8	5.15	5.74	7.7	7.65	10.3	9.56	12.87
Model 3							
4.8	6.8	7.11	10.21	9.48	13.6	11.8	17.03
Model 4							
6.2	8.4	9.34	12.5	12.46	16.8	15.57	21.05

Loads of 20, 30 40, and 50 kg were tested to evaluate range of tissue damage achievable with the various pressures.

A load of 20 kg was used for the experimentation of distortional capabilities of skin, as this range was previously established by *in-vivo* volunteer's test bites on a bite force transducer and was consistent with published mean maximum human bite force achievable in the anterior region (18–22). Once the load of 20 kg was reached, it was held in place for 5 sec and then released.

Each of the four sets of models was used to bite seven tissue types, each with increasing stiffness. These were: Loose skin alone, loose skin overlying soft muscle, skin adhering to soft muscle, skin adhering to stiff muscle, skin over fat, tight skin over stiff muscle, and tight skin over bone. Simple pinch tests evaluated the looseness or stiffness of the tissue. The opening diameter of the apparatus was set at 40 mm as this was consistent with the volunteer's actual opening capability. Forty-eight bites were created perpendicular to Langer lines.

The resultant bites were photographed with an ABFO scale in place. The upper and lower dentition was photographed separately, as needed, based on radius of curvature of the area bitten. Each photograph was sized 1:1 and analyzed with Adobe Photoshop® software. The distortion was then assessed and calculated. This was accomplished via metric/angular measurements (Johansen and Bowers method) and hollow volume overlay comparison (23–25). The inter-canine distance, mesial to distal distance, and angle of rotation between teeth was determined. Each parameter was measured three times and the average used. The intra-observer experimental error was 0.2 mm for calculation of mesial to distal distortion and inter-canine distortion and ±2° for angle of rotation between teeth.

Results

As with previous work, no two bites were identical; as a consequence each bite was considered a unique event (2). Therefore, statistical comparisons between bites were not appropriate. However, overall trends can be observed.

When teeth engaged loose elastic tissue, there was a trend of increasing mesial to distal width, flattening of the angles of rotation and elongation of the inter-canine width. As the tissues became stiffer, the reverse was seen as mesial to distal widths became smaller, angles of rotation became steeper, and inter-canine widths shortened. A combination of these changes, related to individual teeth, resulted as the stress on tissue was varied.

The applied stress rose dramatically as the number of teeth was reduced (Table 2). Stress is inversely related to surface area, thus as surface area is reduced, stress increases. Stress is higher for the lower dentition as opposed to its upper dentition counterpart due to the smaller teeth. There was a complex interplay between the variables of the dentition and tissue types.

Mesial to Distal Changes

As the stress was increased in the first five tissue types (loose skin through skin over fat), tooth height became an important factor to determine if the mesial to distal width increased or decreased. Teeth #23 and #26 were the highest teeth in the lower arch by 1 mm. Therefore with the lower dentition, for the majority of bites, it was seen that the mesial to distal width of #23 and #26 increased. This was due to the elasticity of the skin when these teeth engaged first. As these teeth impressed the tissue, it caused a local tightening. As the next teeth engaged, the tissue was becoming stiffer. As a consequence, it was seen that tooth #24, the shortest tooth in the arch by 1 mm, created an indentation that was smaller than its actual width. In some of these instances this decrease was substantial at more than 25%.

The relative height of each tooth was an important biter variable as well as angle of approach as this dictated which teeth engage tissue first. As higher teeth engage tissue first, they not only create a pattern, but also begin to further pull or distort the medium before the next teeth can engage. As these teeth pull and tighten tissue it was seen that the shorter teeth tended to leave an impression that was smaller than the actual tooth dimension. This left a patterned injury less consistent with the two-dimensional dental overlay. An earlier study emphasized the importance of recording a frontal view of the anterior dentition for variation in horizontal heights as part of a protocol in comparing the dentition to a bitemark (1).

The upper teeth were fairly consistent in height. There was no trend witnessed with the increase or decrease of the mesial to distal width in the first five tissue types, loose skin alone through skin over fat, as a result of a change in stress.

In tight skin over muscle and tight skin over bone all of the mesial to distal widths decreased, regardless of increasing stress.

Inter-Canine Changes

The inter-canine widths tended to increase significantly in the first five tissue types except for Model 4 in loose skin overlying soft muscle and Model 3 in skin over fat, where they decreased.

Figure 3 demonstrates the increase in inter-canine width created in skin adhering to soft muscle. Though tissue is tightening in the

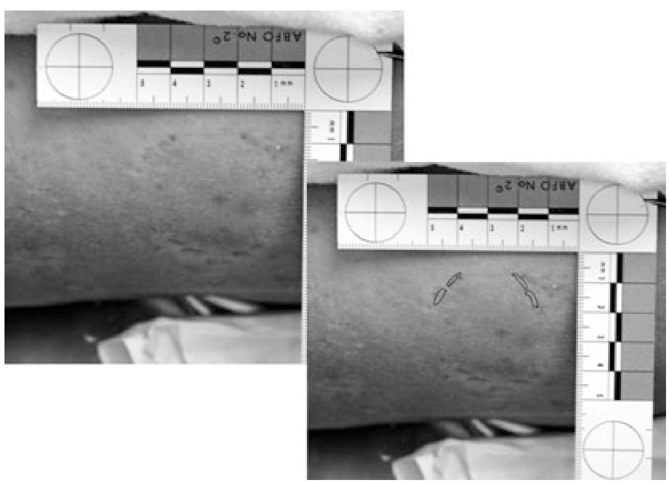

FIG. 3—*The resulting indentations made with upper model #2, Notice the increase in inter-canine width.*

contact area, creating local changes that alter mesial to distal widths, the overall bitten area has been pulled and elasticity of the tissue allows for a general elongation. Thus as the first teeth engage the tissue, they stretch and pull tissue inward. The canines impress skin that is displaced. Upon release, the inter-canine distance is increased.

In the two tightest tissue types, tight skin over muscle and tight skin over bone, inter-canine widths were reduced (<1 mm). Figure 4 illustrates the lack of elongation to the inter-canine width in tight skin over bone. Due to the stiffness of the tissue, the tissue cannot be pulled enough to create an overall lengthening of the inter-canine distance.

Angulation Changes

As stress was increased, the angles of rotation between teeth changed from flatter to steeper from Model 1 through Model 4 in the first five tissue types. In these tissue types, bites created from Models 1 and 2 made the angle of rotation between the teeth flatter but Models 3 and 4 made the angles steeper.

In tight skin over muscle and tight skin over bone, all of the relative angles of rotation became steeper regardless of increasing stress.

Other Observations

It was difficult for Models 3 and 4 to create a bite as the tissue types tightened. Indeed, Models 3 and 4 could not create a bite in tight skin over muscle. This was due to the inability of the remaining teeth to engage enough tissue to create a bite. Without all of the incisors, the teeth merely slid together, not engaging tissue.

Models 3 and 4 were able to impress a bite in tissue type tight skin over bone. However, this was made possible due to the small radius of curvature of the bitten area. These bites occurred on the leg of a thin individual, in the area overlying the femur and tibia. The leg of this individual was small and the teeth were able to engage and hold, without sliding.

The tissue type also had an influence on the edentulous area with the bites created with Model 2. In the first three tissue types, it appeared as if tooth #25, a tooth that had been removed, is still present. Figure 5 illustrates this effect in tissue type loose skin overlying soft muscle. In the looser tissue types the lower dentition is able to take hold of the skin and pinch it together, making it appear as if the missing tooth is present. This was seen in the first three loose tissue types with the lower dentition only. This trend was not seen in the upper arch in any of the tissue types. The upper arch stabilized tissue while the lower arch engaged, pulled, and gathered the skin.

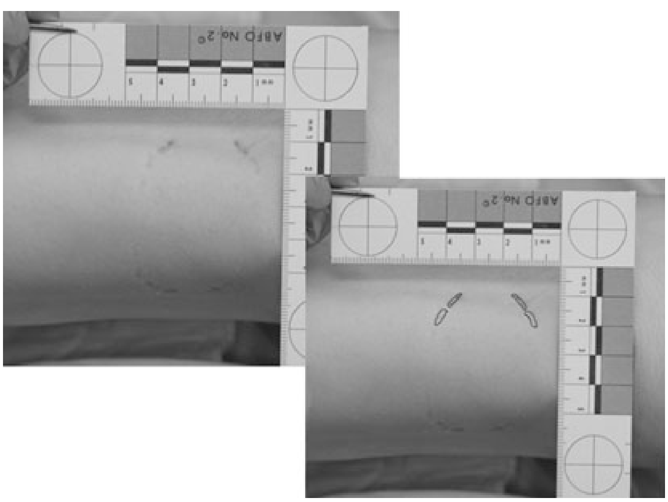

FIG. 4—*The resulting indentations illustrating the lack of elongation to the inter-canine width. This bite was created in tight skin over bone.*

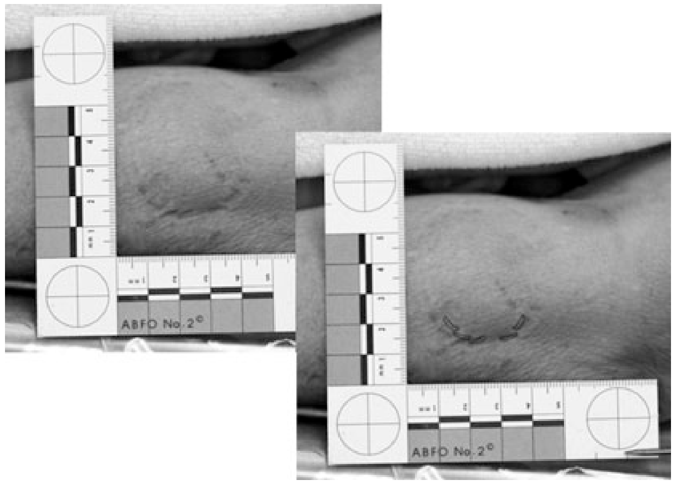

FIG. 5—*The resulting indentations demonstrating the increase in inter-canine width that can result. This bite was created in skin adhering to soft muscle.*

Tissue Damage

Increasing loads from 20 to 30–50 kg gave mixed results for tissue damage. Figure 6 illustrates bites created with loads of 30, 40, and 50 kg on the forearm. Note differences in appearance of the bites while the amount of tissue damage appears the same. There is no laceration in any of these three bites. The appearance of the bites is not due to the difference in the load applied but rather to the variability of the tissue, even within the same body part. This finding was consistent with an earlier study (2). Figure 7 illustrates three bites created at the same load of 25 kg. Note again, the difference in the appearance of the bites while the tissue damage appears the same.

The loads of 40 and 50 kg produced a bite force greater that the maximal reported bite forces in the anterior dentition. The bite force capable at 50 kg is 490.5 N, whereas the typical maximal anterior bite force range is reported to be 90–370 N (19,22).

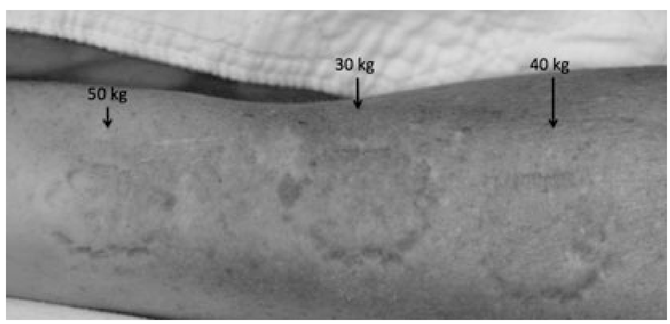

FIG. 6—*Bites created with three different loads: 30, 40, and 50 kg. Note that while the overall appearance of the arch appears different, the damage to the tissue appears the same.*

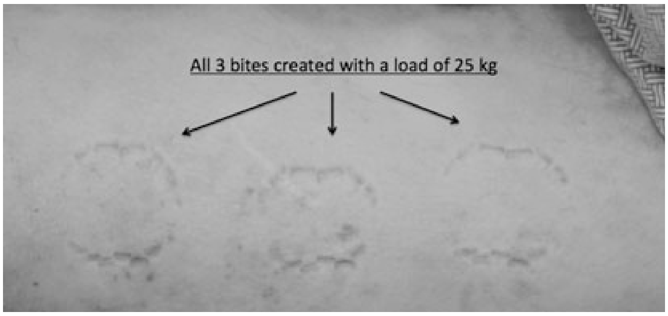

FIG. 7—*Bites all created with the same dentition and the same load of 25 kg. Note the difference in appearance in the three bites.*

It was anticipated that reducing the surface area, thus increasing stress substantially, would lead to recording of the laceration point for skin. However, laceration was highly variable and rarely achieved, even at this high stress. Laceration only occurred in three bites, two of which had loads of 40 kg and one was at 30 kg, illustrating the highly variable nature of laceration. Thus it would appear that laceration of skin may be related to complexities of tissue, victim/perpetrator movement, and sharpness of the teeth among other factors, rather than bite force.

Discussion

Skin responds to stress in a nonlinear fashion. It will extend under low stresses in the elastic range. The elastic extension can be large before skin begins to enter the viscous stage and tighten. As it tightens, elongation becomes limited. This will affect how teeth can impress the skin and consequently, dictate the resultant pattern that is created.

In skin, the level of stress generated from a bite is not only related to the surface area of the biting dentition and force applied, but also the rate at which the force is applied and held, and the rate at which the supporting tissue dissipates the force.

Altering the surface area of one single dentition permitted an examination of how the force per unit area (stress) relates to a bitemark, as well as how the biomechanical properties of skin alter at the moment of tooth contact. This allowed for an understanding of the dynamics of the juxtaposition of the dentition with the skin in bitemark analysis and a possible range of distortion capable under the circumstances examined.

It is acknowledged that some of the variables held constant in this experiment may be different than those occurring in an actual bitemark. The experimental situation describes dentition, skin and underlining tissue variables, while bite pressure and rate of application were controlled. Maximum human bite force can be reached in as little as 300 and 900 ms (22). This suggests a timeframe considerably faster than that used. A characteristic of visco-elastic materials is a time-dependent response to stress. The amount of time a stress is applied to a substrate will affect its elongation. In this experiment, time was controlled allowing comparison of stress.

Variation in bite force in the human population can be large (19). Maximum human bite force in the anterior region has been reported to be in the range of 90–370 N (18–22). This experiment suggested that bite force may not play as big of a role in distortion as may be theorized, as the majority of distortion was related to tissue type, not force applied. The stiffness of the tissue dictated distortion.

Tissue damage was variable and laceration was rarely achieved even at forces greater than that possible with a human dentition. Bite force influences bruising as does the vascular architecture, underlying tissue type, etc.

Bites were impressed into cadavers, therefore the level of stress to achieve bruising can only be theoretically calculated. It is reported that bruising should occur in stage II of the stress/strain curve (9). For example, based on force per unit area of the lower dentition of Model 1, theoretical bruising should occur at a stress under 3 MPa (load of 13.5 kg). This is illustrated in Fig. 1. Bruising is, however, highly dependent on underlying vascular architecture.

The authors understand that the use of cadaver skin may not replicate living tissue and the distortional capabilities may be different in vital vs. nonvital tissue. In the living, tissue responses to the wound infliction may also affect distortion.

The number of anterior teeth was extremely important in the ability of the dentition to engage the skin, especially tight tissue. Indeed bites were not achieved with Models 3 and 4 in tight skin over muscle nor were bites possible parallel to Langer lines. Though the experiment was performed perpendicular to Langer Lines, test bites were attempted with Models 3 and 4 in the parallel direction. None were achievable. Skin is pre-stretched in the parallel direction and much tighter inherently than that in the perpendicular direction.

The focus of this research was not to correlate a biter's dentition to a bite, but to perform an empirical study to understand the effect of applied stress and how this may contribute to the distortion range that is capable when teeth engage the skin. It is recognized that this represents very early work on the investigation of the skin in bitemarks and more research is needed in this area to gain an understanding of the distortional qualities of skin.

Acknowledgment

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PAPER

ODONTOLOGY

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Inquiry into the Scientific Basis for Bitemark Profiling and Arbitrary Distortion Compensation

ABSTRACT: Prediction of dental characteristics from a bitemark (bitemark profiling) and arbitrary photographic distortion compensation are two practices proposed in bitemark analysis. Recent research on the effect of inherent skin tension properties in bitemark analysis suggests that these practices are subject to review. A biting apparatus was used to create 66 bitemarks in human cadaver skin. The bitemarks were photographed, sized 1:1, and evaluated with Adobe Photoshop®. Metric/angular measurements and hollow volume dental overlays were employed. Distortion produced was calculated and assessed. Results showed distortional ranges were nonuniform both between bites, as well as within each bite. Thus, enlarging/decreasing the photograph uniformly would not correct the distortion that resulted. With regard to bitemark profiling, 38% of the bites created patterns that could be misleading if profiled. Features were present/absent that were inconsistent with the biter's dentition. Conclusions indicate bitemark profiling and arbitrary distortion compensation may be inadvisable.

KEYWORDS: forensic science, forensic odontology, bitemarks, bitemark research, anisotropy, skin tension

It is well known that distortion can occur in a bitemark (1). What may not be recognized is the limitation that this distortion can place on two potential tenets of bitemark analysis. The assumption that a bitemark photograph can be arbitrarily altered to account for the tissue distortion is one theory (2,3). In this situation, the 1:1 bitemark photographed may be enlarged/decreased by an arbitrary amount, while the overlay remains the same size. A second supposition is that a profile can be generated from a bitemark in an attempt to anticipate the dental configuration of a biter (1,4–6). Research on the properties of skin, however, has suggested that these may not be prudent practices in bitemark analysis (7–9).

A basic knowledge of human skin and its biomechanical properties is important in performing bitemark analysis. One of the properties of skin responsible for distortion is anisotropy, meaning that skin possesses different properties in different directions (10–12). Thus, in a bitemark, the transferred dental pattern can be distorted unequally in one direction, or another, because of the inherent pre-tension that exists in skin. Anisotropy itself can dictate the overall resultant configuration of a bitemark (7,9). Previous studies have shown that the degree of tightness of skin is one of the major variables that determine distortion (7,9).

Skin exists in a state of pre-tension (13–15). The direction of pre-tension is best described by skin tension lines, commonly referred to as Langer Lines after Karl Langer (16–18), one of the first to describe this property. Pre-tension is dictated by the mechanical demands of each part of the body, which will vary between individuals, and also differ with positional change (standing, lying, flexion, extension, rotation, supination, etc.) (17). Site-to-site variation is governed in part by movement, underlying tissue type, and joint articulation. Simple pinch tests can be used to indicate the pre-tension direction as the skin is easier to pinch perpendicular to tension lines and more difficult in the parallel direction (19).

Skin also exhibits a nonlinear response to stress that can be described in stress–strain curves (10,20). These curves illustrate the visco-elastic properties of skin. The *y*-axis represents stress, expressed in Megapascal units (MPa). The *x*-axis is strain (percent elongation). The initial portion of the curve depicts the rapid extension of skin under low stress (elastic phase). Under low stresses, the skin exhibits an elastic response to stress; however, as the stress increases, the skin becomes more viscous (stiffer) and elongation becomes limited. The curve thus begins to turn upward in the viscous stage, becoming almost linear in the final portion, illustrating the small amount of elongation possible in this phase.

Pre-tension in the skin dictates the curve's location on the *x/y* axis. The curve will shift to the left in tighter tissue types (7). As the curve shifts to the left, skin elongates less in the elastic phase given the same application of stress (20). Thus, it becomes stiffer more quickly (Fig. 1). Tissue type and tension direction can cause the bitemark to distort unevenly (7,21). Therefore, it would be inappropriate to apply a uniform enlargement or reduction to a bitemark photograph to create a better "fit" for a suspect dentition.

Also, because skin deforms, a bitemark may mimic a dentition other than the perpetrator's. This is particularly significant in cases dealing with an open population, children within the same family, or in which the dentition is either naturally well aligned or has received orthodontic treatment (1). In a study by Miller et al. (8) it was found that a number of dental casts "fit" the bitemarks better than the perpetrator's dentition. In some cases, gaps were noted between the individual tooth indentations in the bitemarks where there were no missing teeth or diastema in the perpetrator dentition.

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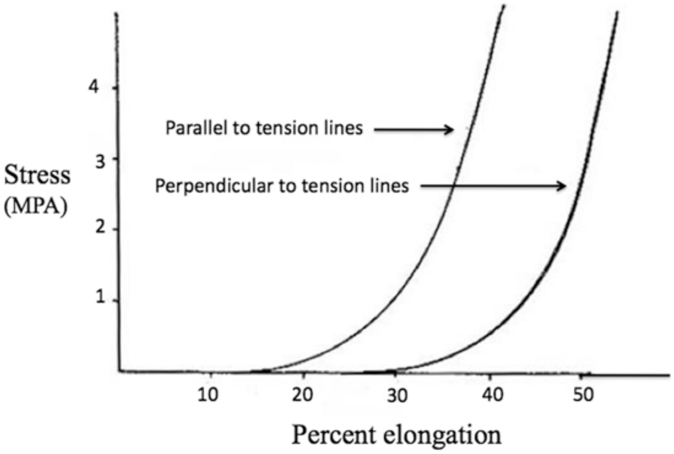

FIG. 1—*Stress–strain curves for skin parallel and perpendicular to skin tension lines. There is less elongation possible for skin parallel to tension lines.*

Features were noted in bitemarks such as lingual tooth displacement, tooth rotation, and arch flattening that were not present in the perpetrating dentition, but which could readily be found in an open population (8). In another study, several instances were found in which a missing tooth appeared to create an indentation (9). The discrepancies seen in these studies were mainly related to skin properties.

Consequently, unless the examiner is well acquainted with these potential problems, creating a biter profile may result in a significant misdirection for perpetrator identity. The distortion produced by the variables of skin may be of such magnitude that prediction of characteristics of the dentition from a bitemark would be imprudent.

The goals of this study, therefore, were to investigate the effect of arbitrary alteration of bitemark photographs and to determine limitations of profiling a biter from a bitemark photograph.

Materials and Methods

Human Subject Institutional Review Board (HSIRB) exemption was granted for all phases of this project. A total of 122 bites were created on 11 human cadavers. The cadavers were stored at 4°C and allowed to warm to room temperature prior to bite creation. The bites were inflicted during experimentation for several previous projects that were performed over a 2-year period (7–9). Bites were created with the dentition located directly above the skin. No bites were created with an angled approach. Sixty-six of these experimentally created bites were chosen for this project. The criteria for exclusion were bitemarks created to investigate issues such as postural distortion and laceration, as the distortion in these bites would have been more extreme.

TABLE 1—*Distortion pattern seen, and number of bites that depicted these changes.*

Type of Distortion Pattern	Number
Flattening of the arch	6
Constriction of the arch	5
Significant deviation in overall alignment	4
Missing tooth appears in the bite	3
Significant rotation of teeth	2
Significant buccal/lingual displacement of teeth	2
Questionable orientation of bitemark	2
Diastema appears when no diastema is present in biter's dentition	1

Polyvinylsiloxane (PVS) impressions were randomly collected from the patient population pool of the State University of New York at Buffalo School of Dental Medicine. The patient pool in the UB clinic represents a varied population of all ages, gender, race, and socio-economic status. PVS impressions were also taken of a single volunteer. Models were created from the PVS impressions.

Each set of models was scanned on a flatbed scanner at 300 dpi (Hewlett Packard 6100/CT), and using Adobe Photoshop®, the images were sized 1:1. Hollow volume overlays were produced and metric/angular analysis was performed on each model. The mesial to distal width of each tooth, the intercanine distance, and the relative angle between teeth was determined. The models were attached to a vise grip by a screw mechanism. The bites were then created with the hand-held vise grip.

The maximum anterior bite force capable of the vise grip was tested with a bite force transducer and found to be well within the range of maximum anterior human biting capacity. This range was

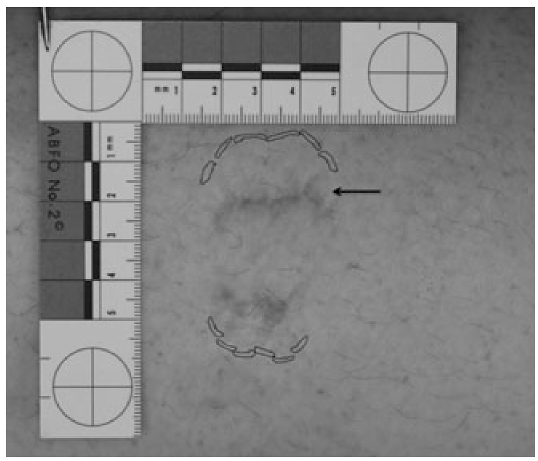

FIG. 2—*Both maxillary and mandibular impressions are far more constricted than the overlay of the biter. #7 (right lateral incisor) is labially positioned in the bite (arrow).*

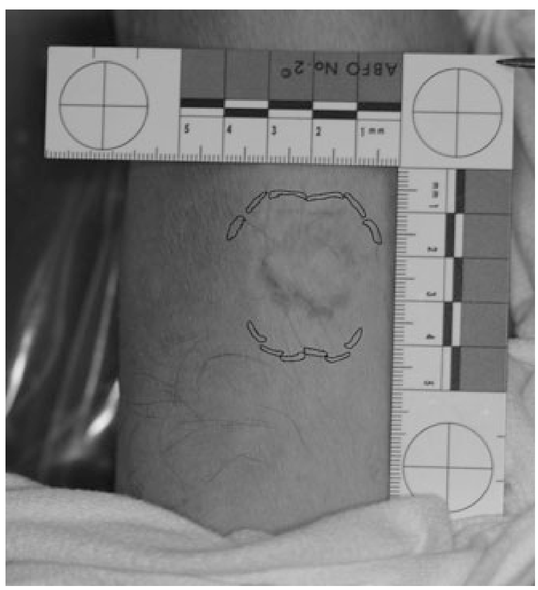

FIG. 3—*Notice significant constriction of the arch form in the bite compared to the dentition that created it.*

established by a volunteer's *in vivo* test biting on the bite force transducer giving an average of 190N. This range was also consistent with studies of mean maximum anterior bite force (22,23).

Photography was performed with a Canon Rebel XTi 10.1 Mp digital camera. An ABFO #2 scale was in place for each photograph. The maxillary and mandibular bitemarks were photographed separately, as needed, to minimize photographic distortion because of curvature in the surface of the bitten area. Using Adobe Photoshop®, each photograph was sized 1:1. For bitemark profiling, the photographs were analyzed and hollow volume overlays of the biter were created and compared to the resultant bitemark. Any bite pattern that had a deviation great enough from the dentition of the biter that could be misleading for an investigator was included in this study.

For arbitrary distortion compensation, three sets of three bitemarks (each set produced on the same body part) were created with the same dentition, and metric and angular measurements were made to calculate the distortion that resulted. The deviations for

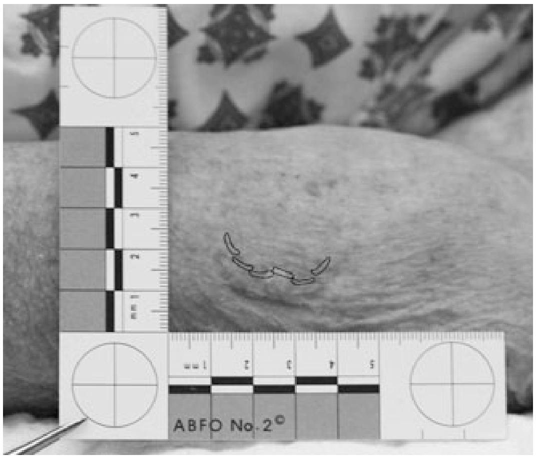

FIG. 4—*The bitemark appears to represent a relatively straight dentition. The overlay of the dentition that created it is above the bite. Note the lingual displacement of #25 in the overlay. This is not depicted in the bitemark.*

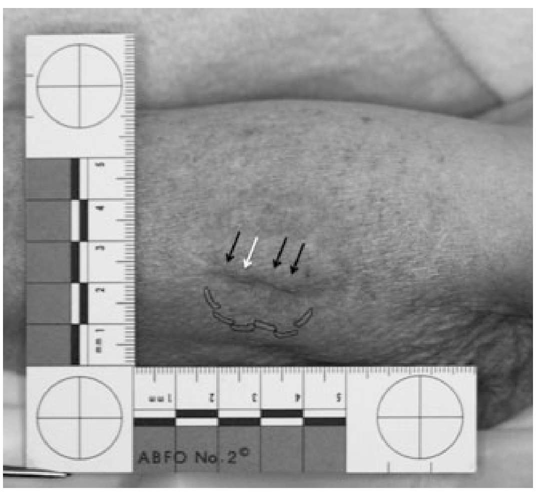

FIG. 5—*Again, there is significant straightening of the arch form. However, in this bite, #24 appears to be positioned slightly labially (white arrow), while #23, 25, and 26 are slightly lingual (black arrows). Also, #23 appears to have a disto-facial rotation (left black arrow). This is not the alignment pattern of the biter.*

angle between teeth, mesial to distal length, and intercanine diameter for the six anterior maxillary and mandibular teeth for each bite were tabulated. Hollow volume overlay comparison was also performed.

The experimental intra-observer measurement error was ±0.2 mm for the intercanine and mesial to distal distances, and ±2° for the rotational angle difference.

Results

Although some bite patterns reflected the biter's dental arrangement, in many instances, the bite pattern, if profiled, would misdirect an investigator to a person that had features not present in the perpetrator's dentition. Table 1 describes the type of distortion that resulted and the number of bites affected. As these bites were created for two previous studies and the deviations reported in those studies, metric/angular calculations were referenced (7,8). Of the 66 bites, 25 (38%) showed a change that could be misleading if profiled.

Figures 2–12 illustrate the changes that occurred. In Fig. 2, the mandibular dentition as seen in the bitemark appears far more

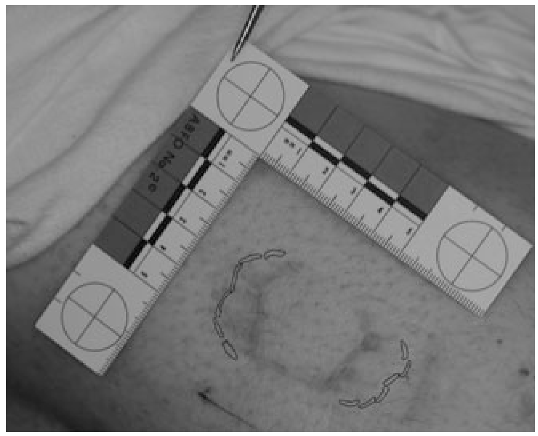

FIG. 6—*Notice discrepancy between the alignment pattern of the lower dentition in the bitemark compared to the dentition that created it.*

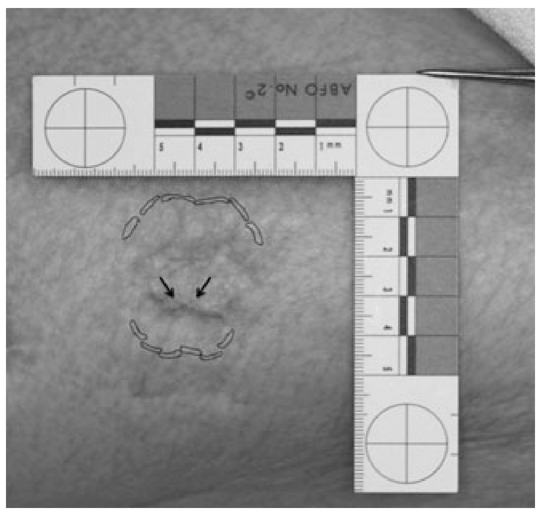

FIG. 7—*The mandibular incisors appear to have a mesio-lingual rotation. This feature is not present in the biting dentition. Also notice arch form constriction.*

constricted and mal-aligned than the dentition that created it. In this example, the maxillary dentition in the bitemark suggests a pattern in which #7 (right lateral incisor) is labially positioned. Bitemark arch width is constricted for the maxillary dentition as well. Figure 3 also illustrates a bitemark in which the arch shape is far more constricted than the biter's. Figures 4 and 5 show a flat, relatively straight bitemark impression. The dentition that created this bite is slightly mal-aligned with a lingually displaced #25. This dental feature is not present in the bitemark. The mandibular impression in Fig. 6 suggests a different alignment pattern than that of the biter. In Fig. 7, it appears as if the mandibular incisors may have a mesio-lingual rotation. The dentition that created this bite does not possess this feature. Figure 8 illustrates a significant deviation of the bitemark from the perpetrator's dentition. For Fig. 9, it appears as if #25 (lower right central incisor), a missing tooth, left an indentation. Figure 10*a,b* show two orientations of the same bitemark. This bite was created with three missing anterior teeth for the maxillary and mandibular dentition (upper and lower central

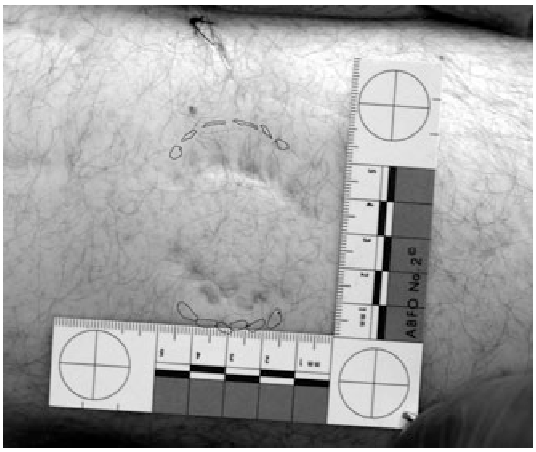

FIG. 8—*Notice the difference between the bitemark and the overlay of the dentition that created it. There is a significant overall discrepancy in the mandibular alignment pattern of the bite compared to the dentition that created it.*

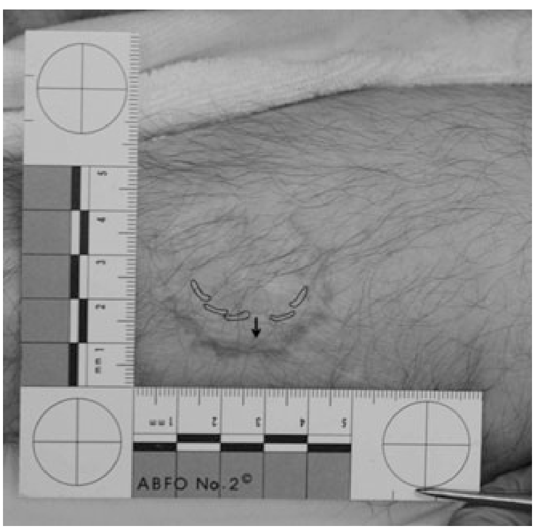

FIG. 9—*It appears as if there are no missing indentations in the bitemark. This bite was created with a dentition in which #25 (lower right central incisor) was missing (arrow).*

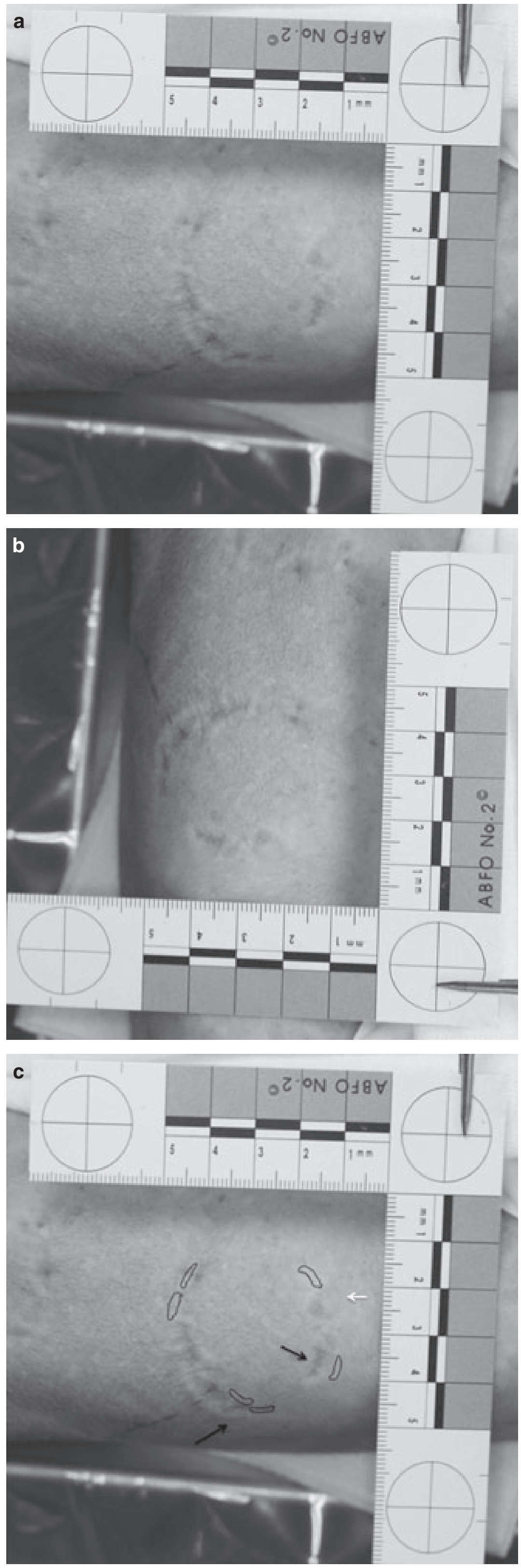

FIG. 10—*(a) The orientation of the bite may be questionable. This is the correct orientation of the bitemark. (b) Figure 10a rotated 90°. This figure suggests a more typical wider maxillary arch form. This is the incorrect orientation. (c) Overlay of the biter on the bitemark. Three teeth were missing on the maxillary and mandibular dentitions. Note the discrepancy of the upper right canine (white arrow). Also note the discrepancy of the lower overlay (black arrows).*

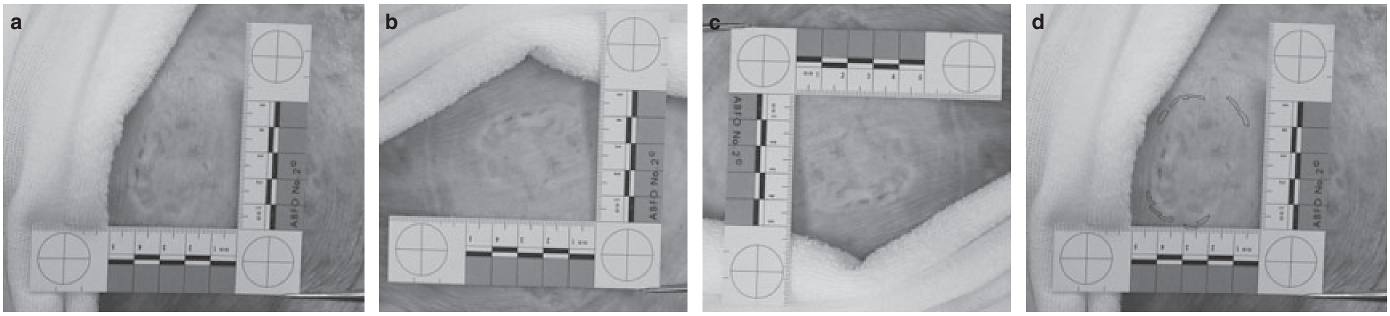

FIG. 11—*(a) Again, the orientation of this bitemark may be questionable. This is the correct orientation. (b) Rotation of Fig. 11a by 90° clockwise. The dentition appears to have a more typical wider maxillary arch form, however, these indentations appear to be small for maxillary teeth. (c) Rotation of Fig. 11a by 90° counter-clockwise. The dentition appears to have a more characteristic arch form and the small size of the indentations may be more typical of the mandibular teeth. (d) Overlay of the biting dentition placed around the bite in the correct orientation. Both maxillary and mandibular dentitions are missing one tooth.*

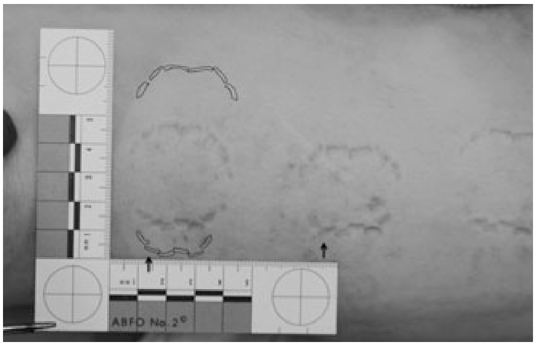

FIG. 12—*The overlay of the biter is placed around the bite on the left. This dentition created all three bites shown (Fig. 13 depicts the bite on the right completely). Notice variations in arch shape and form. Also note the change in orientation of tooth #23, in the middle bite, from the dentition that created it (arrows).*

incisors, upper left lateral incisor, and lower left lateral incisor). Bitemark orientation is clearly an issue as Fig. 10*b* suggests a more typical wider maxillary arch form. Figure 10*c* exhibits a north-south maxillary to mandibular bitemark orientation and the corresponding biter's overlay. The maxillary dentition is larger in intercanine width, and the mandibular smaller, than the biter's dental overlay. The question of correct orientation of the bite is further illustrated in Fig. 11*a–d*.

Enlarging or reducing a bitemark photograph made certain parameters "fit" better, but others worse. This is illustrated by bitemarks created adjacent to each other on the same limb. All three sets of bitemarks followed the pattern of inconsistent increases and decreases. Tables 2–4 describe the deviation in angles of rotation between teeth, mesial to distal length, and intercanine diameter between the bitemark and the biter's dentition. Note that the discrepancies are not only significant between bites, but also within a single bite.

Figure 12 illustrates three bites on the top of the thigh. The bite on the left depicts a maxillary intercanine width *decrease* of 0.7 mm with a mandibular *increase* of 0.8 mm compared with the dentition that created it.

Conversely, the maxillary dentition intercanine width in the middle bite in Fig. 12 *increased* by 0.5 mm while the mandibular also *increased*, but by much more, 2.5 mm. Comparing the two bitemarks, the angulation for #10 (upper left lateral incisor) in the left bite is not nearly as steep as for the middle bitemark. For the middle bite, the angulation for #23 is drastically different than the

TABLE 2—*Angle deviation between teeth in degrees for each of three series of bites created.*

	Angle Deviation Between Teeth in Degrees								
	Cadaver 1			Cadaver 2			Cadaver 3		
Teeth	Bite 1	Bite 2	Bite 3	Bite 1	Bite 2	Bite 3	Bite 1	Bite 2	Bite 3
6–7	+0.5	+8.2	−1.6	+9.3	+0.7	−5.8	X	+10.4	+4.2
7–8	−11.8	−15.8	−2.7	−10.1	−9.5	−6	−29.4	−21.3	−11.2
8–9	+8.7	+13.3	+7.6	+8.6	+21.6	−5.7	+14.1	+10.2	+5.7
9–10	−2.9	−16.5	−0.5	−13.1	−7.3	−5.2	−7.8	−20.2	−13.2
10–11	−9.6	+13.1	+7.2	+12.6	+0.1	+9	−0.3	X	X
22–23	−58.5	−56.4	−54.8	−54	+79.4	−67	−56.2	−70.4	−46.2
23–24	+19.1	+19.5	+25	+27.8	+30.5	+25.5	+25.1	+30.1	+8.2
24–25	+4.8	−1.3	−3.1	−2.9	−4.1	−5.6	−6.5	−9.7	+5.1
25–26	+7.6	+12.3	+13	+23.9	+17.1	+15.9	+13.9	+18.7	+19.6
26–27	−8.2	+6.7	+8.8	+7.3	+5.1	+19.2	+13.2	+3.8	−4.9

Note discrepancies not only between bites, but also between teeth within the same bite. X denotes an area that was not clear enough for measurement purposes.

dentition that created the bite. It now appears to be perpendicular to tooth #22 (lower left canine). The third bite in this series, shown in Fig. 13, depicts a maxillary intercanine width 3.6 mm *larger* and a mandibular width 2.9 mm *larger* than the dentition that created them. All three of these bites show a difference in overall arch shape from the dentition that caused them.

In Fig. 14, the maxillary overlay is slightly larger for the intercanine width but the mandibular overlay is smaller. In Fig. 15, the original bitemark photograph was enlarged by 10% while the dental overlay remained unchanged. While maxillary correlation improved when comparing bitemark to overlay, the mandibular correlation worsened. Uniform increase/decrease in resizing bitemark photographs while the dental overlay remained unchanged resulted in disproportionate differences. In this experiment, the causative dentition was known and represented a gold standard. The results refute the use of the technique of uniformly increasing/decreasing the size of only one of the two elements (bitemark photograph or dental overlay).

When comparing a perpetrator dentition to a more severely distorted bitemark, additional problems can arise. In Fig. 16, the biter's dental overlay is immediately above the bitemark. The bitemark pattern produced resulted in a much flatter and straighter appearance than the biter's dentition (this is the same bite from Fig. 4). A second, arbitrarily chosen dental overlay with a relatively straight alignment is placed above the biter's overlay. The straighter

TABLE 3—*Deviation in mesial to distal width for each of three series of bites created.*

	Deviation in Mesial to Distal Width								
	Cadaver 1			Cadaver 2			Cadaver 3		
Tooth	Bite 1, mm (%)	Bite 2, mm (%)	Bite 3, mm (%)	Bite 1, mm (%)	Bite 2, mm (%)	Bite 3, mm (%)	Bite 1, mm (%)	Bite 2, mm (%)	Bite 3, mm (%)
6	+0.1 (1.6)	+0.3 (4.9)	+0.5 (8.2)	+1.7 (27.9)	−0.4 (6.6)	−0.3 (4.9)	X	−0.5 (8.2)	−0.5 (8.2)
7	−1.2 (18.2)	−1 (15.2)	−0.8 (12.1)	−0.6 (9.1)	−0.6 (9.1)	−1.7 (27.8)	+0.2 (9.1)	−1.2 (18.2)	+0.1 (15.2)
8	−0.5 (6.3)	−0.3 (3.8)	−1.2 (15)	−0.5 (6.3)	−0.1 (1.3)	−0.2 (2.5)	−1.2 (15)	−0.6 (7.5)	−1 (12.5)
9	−0.3 (3.7)	−1.2 (14.6)	−2.4 (29.3)	−0.8 (9.8)	−0.3 (3.7)	−0.8 (9.8)	−1.3 (23.2)	−1.5 (18.3)	−2.2 (26.8)
10	+0.8 (13.6)	0	−1.2 (20.3)	−0.1 (1.7)	+0.4 (6.8)	0	+0.4 (6.8)	+0.4 (6.8)	−0.9 (14.5)
11	−0.3 (4.8)	0	−1.1 (17.7)	+0.3 (4.8)	−0.7 (11.3)	+0.2 (3.2)	−0.3 (4.8)	X	X
22	−0.7 (10.6)	−0.8 (14.3)	−0.6 (10.7)	−0.5 (8.9)	−0.4 (7.1)	−0.5 (8.9)	+0.3 (5.4)	+0.5 (8.9)	−0.2 (3.6)
23	+0.9 (17.3)	+0.7 (13.5)	+0.3 (5.8)	−1 (18.5)	+0.8 (15.4)	+1.6 (30.1)	+0.5 (9.6)	+0.3 (5.8)	−0.8 (15.4)
24	−1.3 (16.3)	−0.7 (13)	−0.7 (13)	−0.9 (16.7)	0	0	−0.5 (9.3)	−0.7 (13)	−1.6 (29.6)
25	0	−0.3 (5.8)	−0.6 (11.5)	−0.2 (3.8)	−0.2 (3.8)	−0.3 (5.8)	−0.4 (7.7)	+0.1 (19.2)	+0.5 (9.6)
26	+0.8 (16.3)	+1 (20.4)	+0.3 (6.1)	+0.6 (12.2)	+1 (20.4)	+1.3 (26.5)	+0.6 (12.2)	+0.5 (10.2)	+0.5 (10.2)
27	−0.9 (17)	+0.1 (18.9)	−1.4 (26.4)	−0.5 (9.4)	−0.3 (5.7)	0	+1.4 (26.4)	+0.8 (15.1)	+0.2 (3.8)

Note discrepancies not only between bites, but also between teeth within the same bite. X denotes an area that was not clear enough for measurement purposes.

TABLE 4—*Intercanine width deviation for each of three series of bites created.*

	Intercanine Deviation								
Teeth	Cadaver 1			Cadaver 2			Cadaver 3		
Arch	Bite 1, mm (%)	Bite 2, mm (%)	Bite 3, mm (%)	Bite 1, mm (%)	Bite 2, mm (%)	Bite 3, mm (%)	Bite 1, mm (%)	Bite 2, mm (%)	Bite 3, mm (%)
Maxillary	+1.8 (5.4)	+1.5 (4.5)	−2.8 (8.4)	−0.7 (2.1)	+0.5 (1.5)	+3.6 (10.8)	X	X	X
Mandibular	+2.4 (10)	+2.1 (2.1)	−1 (4.2)	+0.8 (3.3)	+2.5 (10.5)	+2.9 (12.1)	+2.5 (10.5)	+3.5 (14.6)	+2 (8.4)

Note discrepancies not only between bites, but also between teeth within the same bite. X denotes an area that was not clear enough for measurement purposes.

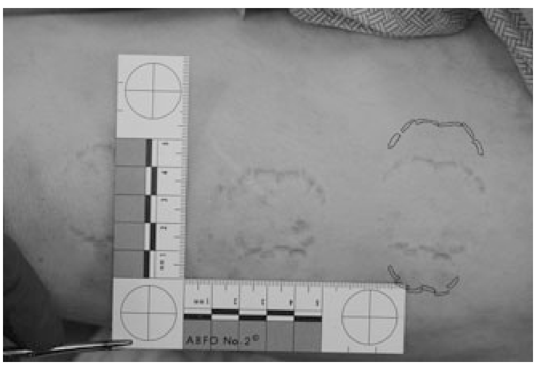

FIG. 13—*The overlay of the biter is placed around the third bite in the series.*

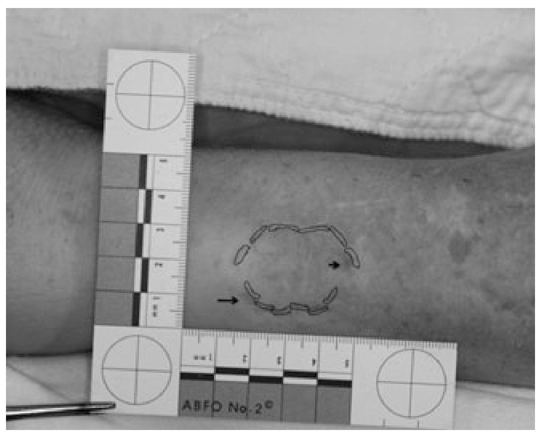

FIG. 14—*Notice discrepancies between the bitemark and the overlay of the biter (arrows).*

overlay does not, however, correlate well with the bitemark (Fig. 17). Increasing the bitemark photograph by 10% greatly improves the correlation with the straighter exemplar dentition (Fig. 18). The obvious concern with this technique is that this dentition did not create the bitemark. Use of this method can lead to exclusion of the perpetrator, or worse, erroneous biter identification.

Discussion

Skin pre-tension does not have a uniform distribution in a human body. Tension not only varies from person to person but also varies at a single site on the same individual. Tension is always greater parallel to tension lines and more relaxed perpendicular to them, resulting in anisotropy in skin. Therefore, the degree of distortion will not be uniform throughout a bitemark. There may be intra-arch as well as interarch distortion. The magnitude of these distortional changes can also vary considerably both within and between each arch. To the authors' knowledge, there have been no scientific studies that give direction as to whether an image of an overlay or bitemark should be increased or decreased and if so, to what extent.

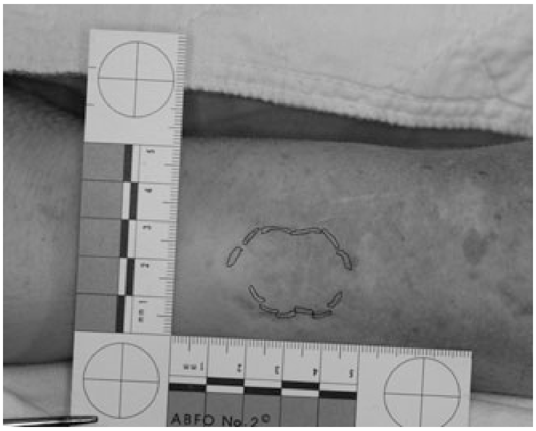

FIG. 15—*The photograph has been enlarged by 10%, while the overlay remained the same size. Note the better correlation with the maxillary dentition but the worsening of the lower.*

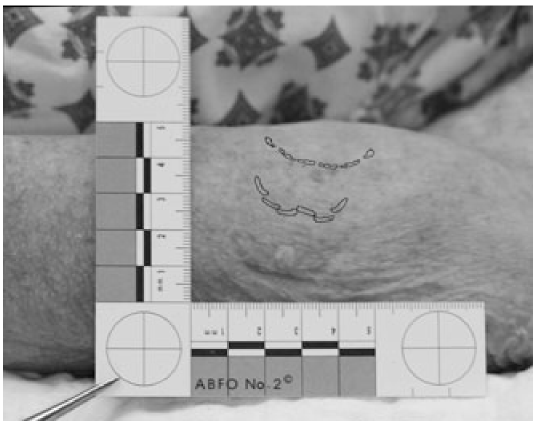

FIG. 16—*Same bitemark as seen in Fig. 4. The overlay of the biter is immediately above the bitemark. An arbitrarily chosen overlay of a relatively straight dentition is placed above the biter's overlay.*

The variables associated with the skin are too complex to allow prediction of a single distortion factor.

This study indicated that arbitrary distortion of a bitemark photograph to ''match'' a dental overlay in an attempt to compensate for tissue distortion is not an appropriate technique. The anisotropic nature of human skin cannot at this time be precisely anticipated to arrive at a percentage enlargement or reduction of an image in any given direction. Results showed distortional ranges were nonuniform both between bites, as well as within each bite. Thus, enlarging/decreasing the photograph uniformly would not correct the distortion that resulted.

The results of this study indicate that unless a closed scenario exists, it may not be prudent to profile a biter from a bitemark. Marked deviation from the biters' dentition occurred in 38% of the postmortem bites on adult cadaver skin because of distortion. There are two potential perils here for the forensic practitioner. First, distortion effects could lead to dental profiling an innocent person. Second, arbitrary interpretation of distortion could be used to explain discrepancies in a bitemark in order to include a presupposed suspect. This potential bias could steer an investigation into ways that might exclude entire populations or, worse, could lead to the arrest and conviction of an innocent person.

It is important to note that the bitemarks shown in this current project did not involve any postural distortion. Including the effects

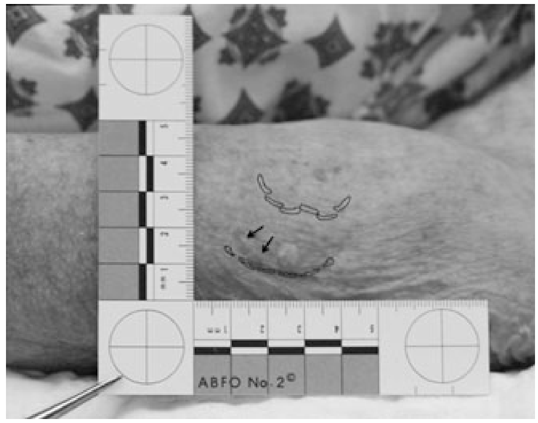

FIG. 17—*Notice poor correlation of the straight overlay (arrows).*

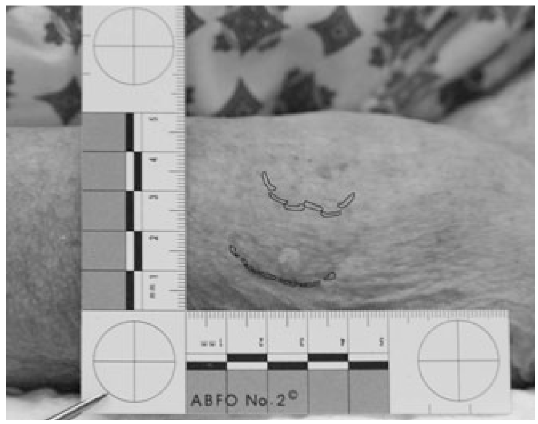

FIG. 18—*This photograph has been enlarged by 10% but the overlays are still the same size. Note improvement of the correlation of the straight overlay.*

of postural change may worsen distortion, creating a further deviation from the causative dentition (7).

It is acknowledged that experimentation occurred on cadaver skin and that results may differ on live tissue. However, cadaver models have been used in many fields to test biomechanical properties of the skin, and are accepted techniques. The use of cadavers was seen as an advantage as only clear indentations were studied as opposed to a diffuse bruise. In a complex field of analysis such as this, it is important to be able to control as many variables as possible. The use of cadavers can be regarded as providing the basic groundwork for scientific understanding of bitemark distortion. Restrictions imposed by human subject review boards may mean that there are aspects of bitemark analysis that may never be studied in living human skin, such as dynamic interactions and bruising.

Experimentally created bites allowed for a gold standard situation, as the biter was known. This permits investigation into skin properties, how a bite can be distorted, and comparison to other potential biting dentitions.

As in the pattern recognition process of fingerprint examination, it cannot be predetermined which features might be present either in the impressing object or the imprint. Thus, one cannot say *a priori* that features may be compared between the dentition and bitemark (24). It is during the comparison of bitemark and suspect's dentition that a prudent examiner identifies which characteristics are common and are clear enough to be recognized. A feature that was noted during examination of the dentition may not be accurately represented in skin or vice versa. Stipulating in advance what may or may not be present can lead to possible bias, inaccurate scenario account, or dental perpetrator misdirection.

As stated in an earlier study, every occasion in which a dentition comes in contact with skin can be considered a unique event (7). The data derived showed no correlation and was not reproducible, that is, the same dentition could not create a measurable impression that was consistent in all of the parameters in any of the test circumstances.

There may be compelling evidence associated with a bitemark, including the presence of DNA, crime scene context, corroboration of victim accounts, timing of injury/death, exclusion, perpetrator identification and other factors, which will continue to make bitemark evidence important in court. However, the authors of this article urge caution in presumptive unilateral alteration of photographic bitemark evidence to “fit” a suspect dentition as well as definitive dental profiling based upon the bitemark.

The goal of this research is to continue to establish the basis of scientific and objective bitemark analysis, thereby minimizing to the greatest extent possible the likelihood that forensic science will lead to an innocent person’s wrongful conviction, and worse yet, execution based on erroneous bitemark interpretation.

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Uniqueness of the Dentition as Impressed in Human Skin: A Cadaver Model*

ABSTRACT: Bitemark interpretation assumes that the human dentition is unique and that its attributes can be accurately transferred to skin. A cadaver model was used to investigate whether the correct biter could be determined from similarly aligned dentitions once the dentitions were impressed in human skin. One-hundred dental stone models, which were measured and determined to be unique, were divided into 10 groups based upon similarities of mal-alignment patterns. One model was randomly selected from each group and bites were produced on unembalmed human cadavers. Metric/angular measurements and hollow volume overlays of the models were compared with the bites made. The percentage of dentitions from each group as well as the 100 dental model population that could not be excluded as the biter was determined. Results showed difficulty distinguishing the biter from individuals with similarly aligned dentitions and in some cases, an incorrect biter appeared better correlated to the bite.

KEYWORDS: forensic science, forensic odontology, bitemarks, bitemark research, skin, dental uniqueness

Bitemark comparison is based on two fundamental assumptions. The first is that the human dentition has class characteristics of shape, size, and pattern, as well as individual characteristics within the arch alignment that render it unique (1). The second is that the skin records those characteristics with sufficient resolution to identify, include, or exclude the perpetrator (1–4).

Published studies on the uniqueness of the dentition stress differences between sample dentitions (5–7). Some of these differences can be minute (7). Indeed, some of the reported differences used to describe the individuality of the dentition can equate to a few degrees of rotation or small spatial measurements between teeth. The question then becomes whether these small differences are sufficient to distinguish between dentitions when the teeth are impressed on skin.

Previous work demonstrated distortion ranges of up to 80% in angle of rotation between teeth, 27% in inter-canine distance, and 42% in mesial to distal dimensions in a bitemark as compared with the dentition that caused the injury (8–10). Those studies showed instances of dramatic differences in bitemark appearance based upon body location and/or post-infliction postural movement (8,10). If, for example, the definition of uniqueness between two dentitions is a 5% difference in measurable parameters and the effective distortion is 20% for those parameters, then the distortion after impression in the skin exceeds the defining measurement of dental uniqueness; in other words, the defining measurement of uniqueness would be lost in this circumstance.

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Skin with its varying biomechanical properties is less than ideal to accurately record the dentition (10–16). Further, it is indisputable that a degree of distortion is always present in a bitemark on this medium. The amount of distortion can vary significantly based upon skin tension lines, anatomical location, underlying tissue structure, movement during and after bitemark infliction, and clothing among other factors (4,10–16). These variables can alter the transference of dental characteristics to skin including tooth size, inter-canine distance, and rotation of teeth (10,17–21). Thus, as a dentition is impressed into skin the resolution of the representation of the dentition is reduced. There is, therefore, a potential for bitemark perpetrator misidentification in a broad population of similarly aligned dentitions.

Studies have revealed the frequency of mal-alignment in a population (22). Dental crowding, especially of lower anterior teeth, is frequently encountered and may be classified into discrete common patterns. In a study of 7000 individuals, 15–50 years of age, it was shown that 50% of the population had a zero mandibular incisor irregularity index, 23% had clinically significant irregularity, and 17% had severe irregularity (23). Thus on the basis of the 2000 U.S. census, there may be *c.* 56 million individuals in the U.S. who are 15–50 years of age with clinical crowding and *c.* 24 million with severe crowding (23).

These numbers suggest a large population with the potential for similar dental patterns. Furthermore, following orthodontic treatment, the anterior dental pattern becomes much more homologous, creating a large group of similarly aligned dentitions. As orthodontic treatment is further utilized, one may expect this population to increase. This added difficulty in bitemark perpetrator identification from pre- to postorthodontic treatment was confirmed in a study by Dorion (4,24).

One goal of this study was to determine perpetrator identity within groups of similarly aligned dentitions. Does skin distortion allow for multiple suspects that cannot be excluded as perpetrator? The second goal was to determine how many individuals from a larger sample population of varied alignments could not be ruled out as perpetrator. Thirdly, is pattern distortion sufficient to rule out the biter, yet include a non-biter?

Materials and Methods

Human Subject Review Board (HSRB) exemption was granted for this project for both polyvinylsiloxane (PVS) impression collection and cadaver use. Three hundred and thirty-four upper and lower PVS impressions were randomly collected at the State University at New York School of Dental Medicine. These impressions were from the patient pool at the dental school clinic and were taken for fabrication of dental prostheses. The clinic patient pool represents a varied demographic cross-section of ages 18–90+ years. Because this was a random collection, age, gender, and race were unknown to the authors. Of these impressions, one hundred lower impressions were selected. The criteria for inclusion were an impression that satisfactorily recorded the lower anterior dentition (#22–#27) and that that the dentition had a full complement of teeth from #22 to #27.

All one hundred lower models were poured in Jadestone (Whip mix, Louisville, KY). The material was spatulated with a power driven mixer under vacuum (Vacuspat; Whip mix). Jadestone was selected for its accuracy of reproduction (50 μm ± 8) and compressive strength (97 MPa) (25). The models were allowed to set for at least 2 h prior to removal from the impressions. The models were scanned on a flatbed scanner (Hewlett Packard 6100/CT) at 300 dpi. Using Adobe Photoshop®, the scanned images were sized 1:1 and hollow volume overlays constructed (26–28).

Metric/angular analysis was performed with Adobe Photoshop® (26). Mesial to distal width, inter-canine arch distance, and angle of rotation was measured and recorded for teeth #22–#27. The angle was measured by differences in rotation of the mesial-distal axis between teeth.

Mal-alignment patterns were evaluated with frequency recorded ranging from a relatively straight dental arcade to severe lower anterior crowding. The models were then subjectively grouped by similarity of mal-alignment pattern by consensus of two investigators who were both dentists with dental experience of 10 and 24 years, respectively. The distribution resulted in 10 categories (Table 1).

One biter was randomly selected from each group. Each selected lower model was mounted on a hand held vice grip with a single upper cast used for all bites. The bite indentations of the upper model were not measured.

Three cadavers were acquired following rigor mortis, stored at 4°C, and allowed to warm to ambient room temperature with condensation removed. Bites were impressed on the arm, forearm, and thigh. Following bitemark infliction on naked skin, it was photographed in the same position of occurrence thus avoiding postinfliction distortion resulting from bodily movement. All photography occurred within 10 min of bite production.

The resultant indentations were photographed with a Canon Rebel XTi 10.1 MP digital camera with an ABFO No. 2 scale placed in all photographs. Using Adobe Photoshop®, metric and angular analysis was performed on each photographed bite (26). The buccal to lingual measurement was not used as many bites incorporated portions of the lingual surface that was at times difficult to delineate. The bite measurements were compared with the dentition in each test group and percentage differences in measured parameters calculated.

Each dental overlay from the group was compared with the bite. In addition, hollow volume overlays from the entire 100-model sample were compared with each bite. Bitemark overlays that closely resembled the biter's dentition were chosen by one examiner. A subsequent examiner was asked to determine which dentitions could not be excluded as the biter from the sample provided. The samples were shown to no less than 10 individuals whose experience ranged from dental student to dentists with many years' experience in forensic odontology. The percentage of suspects that could not be excluded is listed in Table 2.

TABLE 1—*Group number, number of models in each group, and mal-alignment type.*

Group Number	Number of Dentitions in Group	Mal-Alignment Pattern
1	7	Mesially rotated central incisors
2	9	Incisors alternating buccal and lingual
3	10	Central and lateral incisors with a left incisal slant
4	11	Mildly mal-aligned
5	8	Moderately mal-aligned
6	7	Significantly mal-aligned
7	9	Mildly mal-aligned with a rotated right canine
8	8	Mildly mal-aligned with significant occlusal wear
9	23	Relatively straight
10	8	Relatively straight with buccally displaced lateral incisors

Results

The degree of distortion varied between bites. Areas of the body were chosen to minimize distortion as determined in a previous study (10). Thus muscular areas such as the arm and leg were used as bites in muscle showed the least amount of distortion (10). Table 2 lists the degree of distortion for inter-canine width, mesial to distal width and angle of rotation between teeth. The percentage of individuals for each group as well as within the 100-sample population that could not be ruled out as the biter, was calculated.

In some instances, distortion merely constricted or elongated the bite pattern. Bites were inflicted both parallel and perpendicular to tension lines. The bites that appeared constricted were inflicted parallel to skin tension lines. Two of the bites were inflicted parallel to tension lines. Eight bites were inflicted perpendicular to tension lines. The distortion patterns were consistent with results from previous studies (10,29,30).

In some instances, the distortion was enough to suggest a different appearance to the biter's arch pattern. Figure 1 shows a bite inflicted by a dentition that appears to have the central incisors rotated mesially, giving a "v" shape configuration. Indeed, tooth #24 (lower left central incisor) appears to be almost perpendicular to the curvature of the arch. In Fig. 2, an overlay with a severely rotated #24 is placed on the bite. Figure 3 demonstrates a "v" shape central incisors' alignment; however, the bite was not produced by either dentition. Figure 4 shows the biter overlay to the bitemark photograph. Tooth #24 is only slightly mesially rotated while teeth #26 and #27 are slightly wider than the arch form of the bite. There is no distortion in the inter-canine width for this bite.

Figure 5 shows a bite with a lingually placed #25 and three "similar" dental overlays. Although the biter, as seen in Fig. 6, possesses a lingually placed #25, this is not as lingually placed as suggested by the bite.

TABLE 2—*Direction of bites inflicted according to existing tension in skin, changes in measurements, and percent of population that could not be ruled out as the biter.*

Bite Number	Parallel or Perpendicular to Tension Lines	Mesial to Distal Difference	Angulation Difference	Inter-Canine Difference	Percent from Group %	Percent from Sample Population %
1	Parallel	18% decrease	32% steeper	0%	86	12
2	Parallel	13% decease	23% steeper	4.2% decease	22	3
3	Perpendicular	15% decrease	16% flatter	8.5% decrease	50	11
4	Perpendicular	14% decrease	8% flatter	6% increase	67	16
5	Perpendicular	46% decrease	28% flatter	13% increase	71	7
6	Perpendicular	Could not measure	–	–	–	–
7	Perpendicular	4.2% decrease	0.5% flatter	0.7% increase	11	6
8	Perpendicular	Could not measure	–	–	–	–
9	Perpendicular	11% increase	11% flatter	11% increase	75	12
10	Perpendicular	10.3% increase	30.7% flatter	6.9% increase	19	4

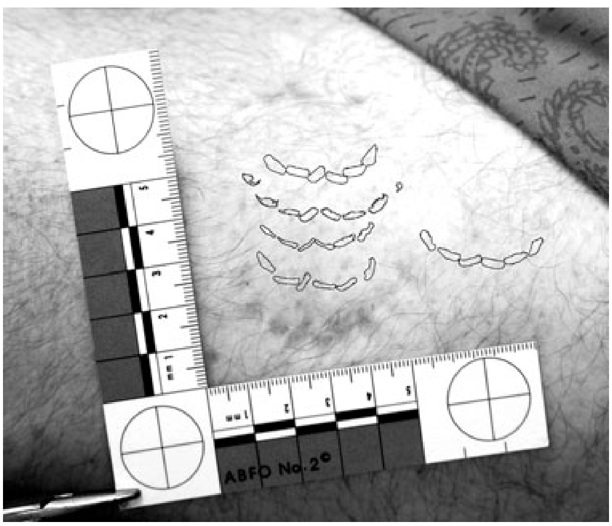

FIG. 1—*This bite suggests a "v" shaped appearance to the lower central incisors. There are four overlay patterns above the bite and one to the right of the bite.*

FIG. 2—*An overlay with #24 lingually angulated from the mesial is placed on the bite. This is not the biter.*

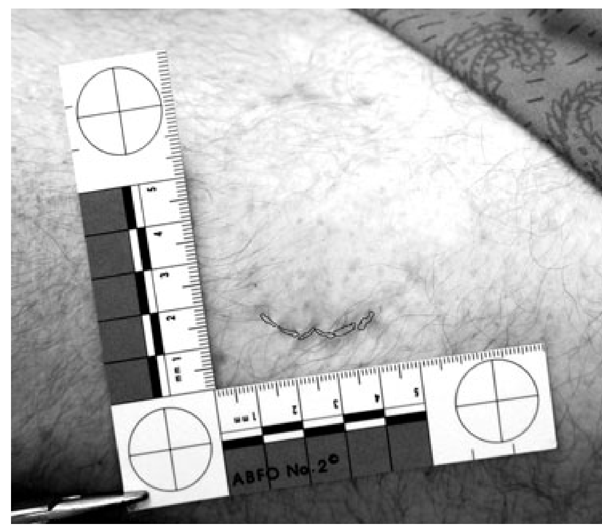

FIG. 3—*An overlay with a "v" shaped, mesio-angular mal-alignment to the central incisors is placed on the bite. This is not the biter.*

FIG. 4—*The overlay of the biter. Note only a slight mesio-angular rotation to the central incisors.*

Figure 7 suggests a diastema, missing tooth, or a tooth that does not meet the horizontal plane of adjacent teeth. In Fig. 8, one such pattern is placed on the bite with fairly good correlation, however this is not the biter. Figure 9 shows the actual biter who possesses neither a diastema nor a discrepancy of the occlusal plane. However, the biter does possess a pointed incisal edge to #23 that could account for bite appearance.

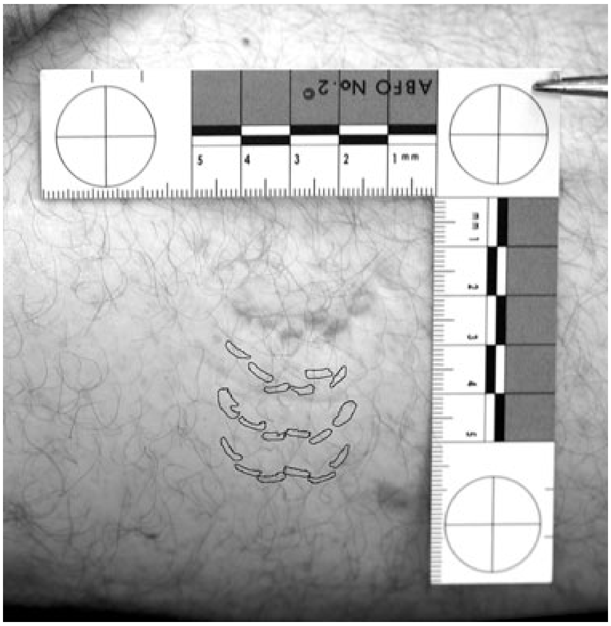

FIG. 5—*This bite suggests that the right central incisor has a significant lingual displacement.*

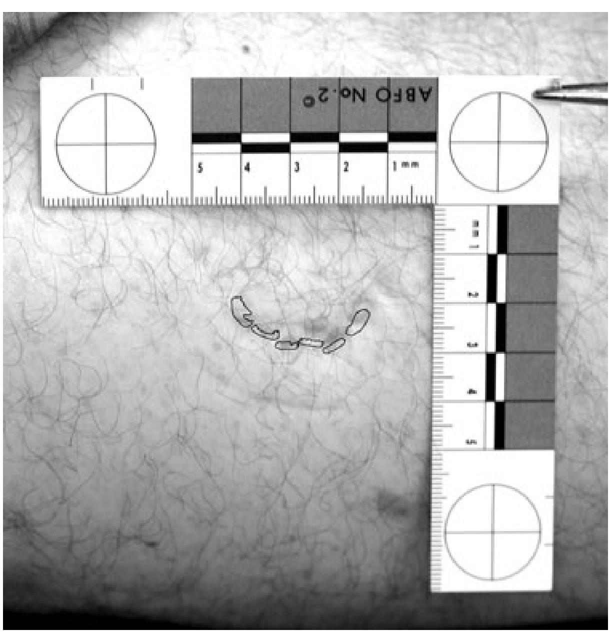

FIG. 6—*The overlay of the biter. Note the right central incisor is lingually displaced, but not on the scale suggested by the bite.*

Figure 10 demonstrates a confusing pattern. The dentition that caused the bite had incisal wear on teeth #22 to #27, creating a "ring" of enamel surrounding a depression of dentin. The resulting indentation pattern might suggest mal-alignment with a buccally displaced #24, or even a double bite. The overlay of the biter is placed above the bite in this figure.

Bite distortions in groups 6 and 8 could not be calculated. The bite created with the dentition from group 6 was highly mal-aligned and that from group 8 had significant occlusal wear. Both of these dentitions failed to produce, in multiple attempts, clear measurable indentations despite the ideal laboratory conditions.

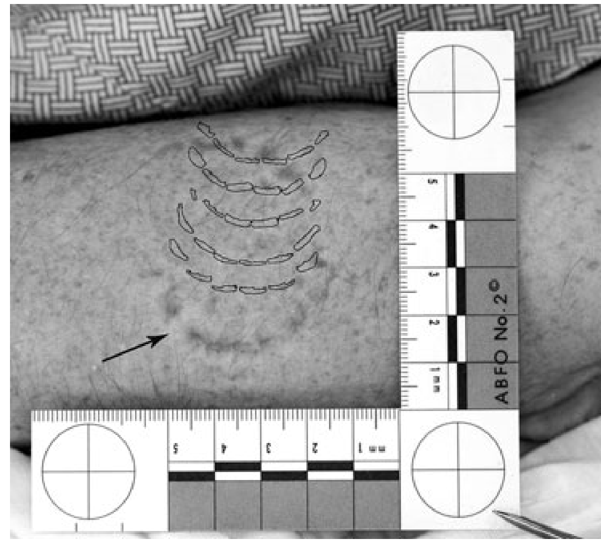

FIG. 7—*Five overlays are placed above the bite. A diastema, tooth out of the occlusal plane, or a missing tooth is suggested on the left in the area of tooth #23 (arrow).*

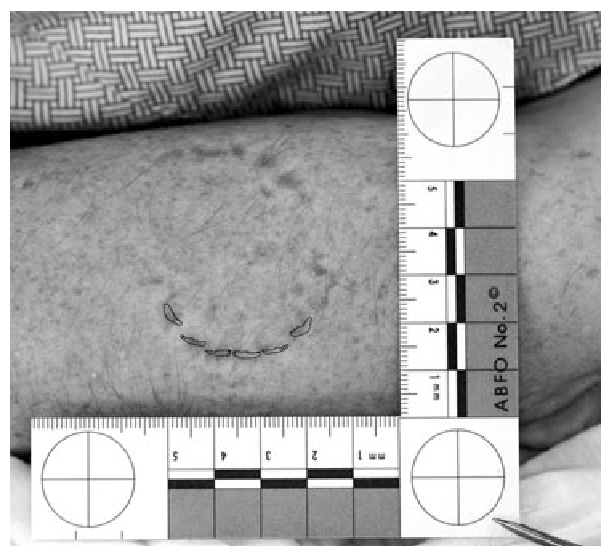

FIG. 8—*An overlay with a diastema between tooth #22 and #23 is placed on the bite. This is not the biter.*

Discussion

The dentition can be measured with certain accuracy; however, the uniqueness of the dentition cannot be perfectly transferred to skin. Thus, distortional effects as well as other factors ultimately contribute to a reduction of resolution in the transference of dental details. This article demonstrates how human skin affects the ability to recognize unique dental features in a bitemark.

The experimental results indicate that similarly aligned dentitions cannot be ruled out as the biter in all cases. In addition, when comparing the entire 100-sample population of nonsimilar mal-alignments, certain dentitions could be included as the biter, thus allowing for the possibility of exclusion of the biter and inclusion of an innocent person. Indeed, some dentitions appear to "fit" better than the biter's dentition with a resultant false positive. It should

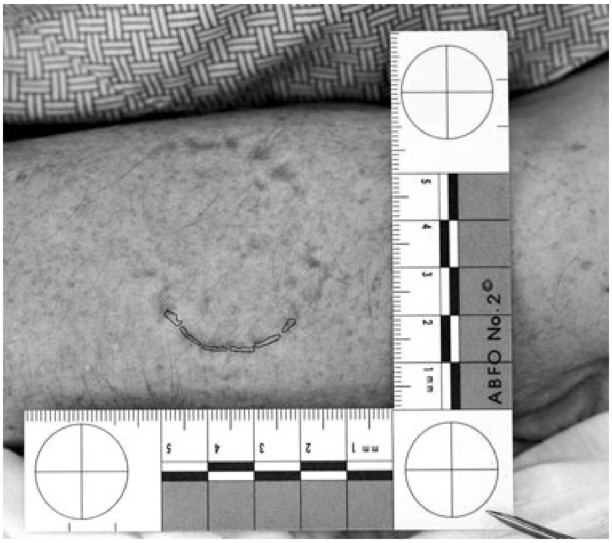

FIG. 9—*Overlay of the biter is placed on the bite. There is no diastema between #22 and #23. Also note the discrepancy for the placement of the canines.*

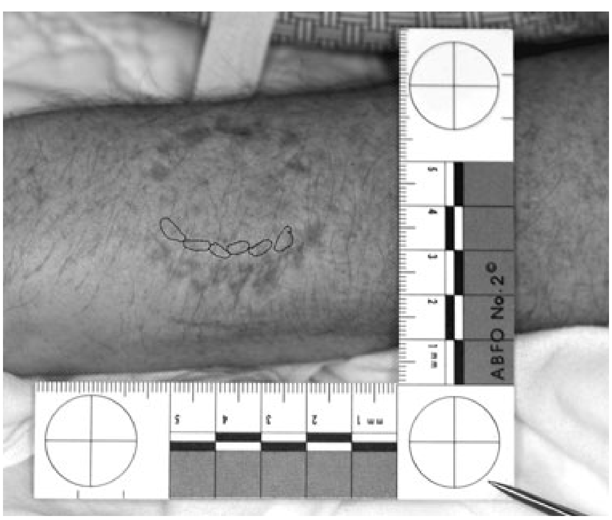

FIG. 10—*Nondistinct bitemark. It is difficult to clearly delineate the outline of specific teeth. The overlay of the biter is placed above the bite.*

be noted that this research was not designed as a proficiency test among forensic odontologists. Thus intra- and inter-observer effects were not studied. The experiment described represents one of the first steps in providing a basic understanding of loss of resolution due to distortion in a bitemark when impressed in human skin.

It is acknowledged that cadaver skin differs from living tissue with its lack of inflammatory response and potential subcutaneous bleeding (17–20). These additional parameters could provide supplementary information for perpetrator identification. However, the use of cadavers has a benefit in that clear indentations were produced in most cases that could be used for measurement and comparison purposes.

Also, this was a single arch study. There could be additional perpetrator information had it included the upper arch. The authors further understand that this open population study may differ from an actual closed population bitemark case such as in child/spousal/elderly abuse.

The analysis was two-dimensional, without benefit of other photographic techniques, excision, trans-illumination, three-dimensional dental, and bitemark impression analysis. Although two-dimensional analysis does provide measurable and therefore comparative metric/angular analysis, the teeth and substrate have three dimensions. Evaluation of a photograph, scan, or overlay solely, may cause important information to be overlooked. Valuable information that might be related to discrepancies in pattern development can be found through three-dimensional evaluations of the models, such as height discrepancy in teeth. As the longer teeth engage the tissue first, they not only create a pattern, but also begin to further pull or distort the medium before the next teeth engage. This will leave a patterned injury less consistent with the two-dimensional overlay pattern. It is the authors' intention to emphasize that all aspects of evidence collection and analysis must be considered to render an opinion in a bitemark case.

It is important to stress that two of the 10 experimental dentitions did not produce clear bitemark indentations for measurement purposes. This suggests that there may be situations in which a dentition may produce a poor representation of itself, not so much because of distortion of the skin, but rather the specific alignment and tooth configuration of the dental arch.

Bitemark analysis has recently come under scrutiny resulting from well-publicized DNA exonerations. Critics point to the lack of scientific studies that test its fundamental precepts. Although studies have addressed dentition uniqueness, more are needed on skin and underlying tissue effect.

In conclusion, the result of this study suggests that an open population postmortem bitemark should be carefully and cautiously evaluated particularly if limited exclusively to two-dimensional overlay comparison. This is due in part to distortion and loss of resolution in the transference of arch and dental characteristics to skin.

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Biomechanical Factors in Human Dermal Bitemarks in a Cadaver Model*

ABSTRACT: In bitemark analysis, the forensic odontologist must consider how the biomechanical properties of the skin contribute to distortion of the bitemark. In addition, one must consider how the bitemark can be distorted by postural movement of the victim after the bite has occurred. A fundamental review of the architecture and biomechanical properties of the dermis is described and evaluated through bites made on cadavers. In order to assess distortion, 23 bites from a single characterized dentition were made on un-embalmed cadaver skin. Bite indentations were photographed. Following various body manipulations they were re-photographed in different positions. Hollow volume overlays of the biting dentition were constructed, and metric analysis of the dentition and all bitemarks was completed. The overall intercanine, mesial to distal, and angle of rotation distortion was calculated. Of the 23 bites made, none were measurably identical, and in some cases, dramatic distortion was noted.

KEYWORDS: forensic science, forensic odontology, bitemarks, bitemark research, human skin, distortion

Bitemarks may be inflicted during violent situations such as sexual attacks, child or domestic partner abuse, and during offensive or defensive combat altercations. In these circumstances the bitemark may be the only evidence linking the biter to victim (1). The ability to properly interpret bitemark evidence can be critical. However, bitemark interpretation remains a complex subject in forensic science. Scientific studies are needed to address fundamental aspects of bitemark analysis, specifically analysis of distortion of a bite in human skin.

The premise of bitemark interpretation is based on two assumptions. The first is that each human dentition is unique. The second is that human skin records this individuality with sufficient fidelity that the biter can be identified, included, or excluded as a suspect. Few scientific studies support or corroborate these assumptions (2). Despite this, bitemark testimony has been admissible in the judicial system (3).

Even with the advent of the Daubert ruling, bitemark testimony has been accepted, although it may be questioned whether sufficient empirical testing, peer review, or error rates have been established (2,3). A number of individuals, convicted on bitemark evidence, have spent years incarcerated only to have the convictions overturned (4,5).

Although there have been studies that address the individuality of the human dentition (6–11), few have tested the transfer to a bitten substrate. Those that make a comparison to a bitten substrate have used media such as wax (12,13) or styrofoam (14–16). Wax and styrofoam behave quite differently from human skin, as they undergo permanent plastic deformation under stress, unlike skin, which exhibits a visco-elastic response to applied stress. A number of recent studies have used nonhuman subjects that closely mimic human skin to evaluate this transfer (17–23).

Only a few studies have examined distortional factors with regard to skin (24–29). The authors of these studies urged further investigation and acknowledged potential for discrepancies. Indeed, one study found a linear expansion of an inked concentric circle on the lateral thoracic wall to be as great as 60% as the arm was flexed and then raised (27).

A bitemark can be distorted because of the biomechanical properties of skin and underlying tissue. The degree of deformation can be influenced by anatomic location, thus affecting tooth relationships within an arch, arch size, and shape. Movement of the victim can also cause postural distortion. Postural distortion occurs when a bitemark is photographed with the victim in a different position than that in which the bite occurred.

Skin behaves in a heterogeneous, nonlinear, visco-elastic, anisotropic manner (30). It also exhibits hysteresis, which affects how long an indentation remains. The issue is compounded by variability between and within individuals and from site to site on the body. These properties also differ with age, weight, and physiologic condition (31,32). Biomechanical properties dictate how a material deforms in response to applied force. When teeth engage skin, a complex interaction takes place. The skin may be pulled and compressed. Although the overall bite may be considered as being a compression injury, locally, where the tooth contacts the skin there is tension. As a bite force is applied, skin strains under tension until either tissue is released or lacerating rupture occurs.

Applied stress (force per unit area) can be measured. The ability of skin to absorb force and deform in a given location is dependent on the underlying tissue structure. The biomechanical property of skin is largely determined by the architecture of the dermis (31). The dermis consists mainly of collagen fiber bundles, elastin fibers, and ground substance which have specific properties that contribute to visco-elasticity, nonlinearity, anisotropy, and hysteresis of skin.

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Visco-Elasticity

At low stress, skin is fairly extensible, but as stress increases, skin becomes more rigid. Therefore, during normal activity under low stress, the skin behaves elastically (31–33). It is this property that causes a light push in the skin by a finger to rebound immediately. However, with increasing stress, skin exhibits elastic and viscous properties, hence the term visco-elastic. For visco-elastic materials, rebounding does not occur immediately. Bite-related tooth indentations will remain in skin before rebounding. Visco-elastic materials must first go through an elastic phase, which occurs at low forces. They then enter the viscous phase as force is increased or maintained. It is the interaction between elastin, collagen, and ground substance that contributes to the visco-elastic properties of skin.

Elastin fibers range from 0.5–0.8 um in width and up to 50 μ in length, are interwoven among the collagen fibers, and compose 4% of fat-free dry weight (30). They possess a rubber-like nature for high extensibility. As skin is pulled by a light force, elastin restores the normal fibrous array, thus quickly restoring skin to its original position (31). As force and extension increases, collagen fibers begin to stretch.

The collagen fiber network comprises 75–77% of the fat-free dry weight of skin. Each fiber varies from 1 um to 40 um and is separate from others along its length (32). They possess high tensile strength and low extensibility rupturing at strains in the order of 5–6% (30,31).

The ground substance is an amorphous gel that fills the spaces between fibers. Its main constituents are mucopolysaccharides. As collagen and elastin fibers are extended under high stress, ground substance is squeezed between the collagen bundles into surrounding tissue. It is movement of the ground substance that results in the viscous behavior of skin (31–35). After stress is released, time permits the ground substance to slowly regain its original position, restoring the original skin topography (31–33). This is the hysteresis effect.

In summary, the properties of the elastin, collagen, and ground substance determine the physical response to applied stress in the skin. These properties dictate how an indentation can be formed and why it subsequently disappears.

Nonlinearity

The mechanical properties of visco-elastic materials alter with the rate of loading or straining, thus load deformation relationship for skin is nonlinear (31,32,34–36). This nonlinearity is described by a "J" shaped stress–strain curve (Fig. 1). The *Y*-axis represents stress, expressed in Pascal units (force per unit area). The *X*-axis is strain expressed as a fraction derived from the change in length divided by the original length. This axis can also be expressed as a percentage elongation. Figure 1 shows the typical curve shape. This is a generic curve and no units are specified, as actual values are dependent on tissue type.

The curve is divided into three phases. Phase I represents the rapid extension of skin under low stress, the elastic phase. The elastin fibers reorient and straighten in the direction of the force. The stress required to do this is low, as it is mainly the elastin fibers that are stretched and the majority of the collagen fibers themselves are not extended.

Phase II represents stiffening of the skin to a point at which further stretch is very limited. As the elastin fibers have already been stretched, the collagen fibers begin to orient in the direction of the stress, straighten, and the skin stiffens (30). Thus skin rigidity is attributed to the fibers progressively becoming aligned and resisting tension along their length. By the end of phase II most of the collagen fibers are straight and oriented in the direction of stress. This makes any further stretch of the skin difficult.

The viscous effects of skin occur in stage II of the stress–strain curve (30,31). Damage to blood capillaries also occurs late in stage II (32). Initially, blanching occurs, as blood flow through the capillaries is restricted. Under increased pressure, capillaries rupture and blood flows into surrounding tissues (in the living) (32). This results in a subcutaneous hemorrhage that, following rebound, may be all that remains to indicate that a bite has occurred.

In the third phase, all of the collagen fibers are fully extended and have straightened. This accounts for the almost linear appearance to the curve in phase III (32). The slope in phase III increases as a logarithm of strain rate. Thus skin appears to resist fracture at very high strain rates (31,32). However, skin exhibits a rate-dependent resistance to stress, and if a load is applied rapidly it may rupture at lower stress levels (34). Rupture, and hence laceration, occur in phase III.

Stiffness of the underlying substrate affects the shape of the stress/strain curve. When substrates of differing stiffness are encountered such as muscle, cartilage, and bone, the curve progressively shifts to the left (Fig. 2). For example, in thin skin overlying the forehead, the skin undergoes very limited elongation and thus phases II and III occur at lower stress levels.

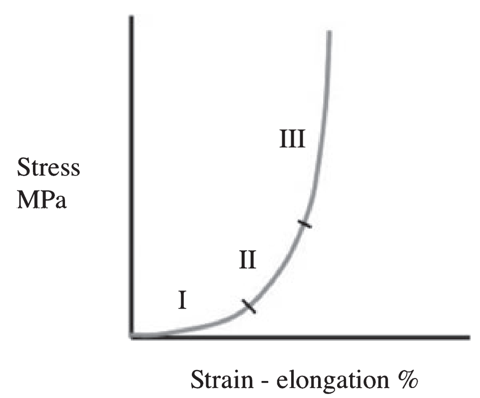

FIG. 1—*Stress/strain curve for skin. The curve may be divided into three phases. In Phase I, most of the elongation takes place under low applied stress. In Phase II, indentation occurs followed by contusion and crushing of capillaries. At some point in Phase III, laceration results.*

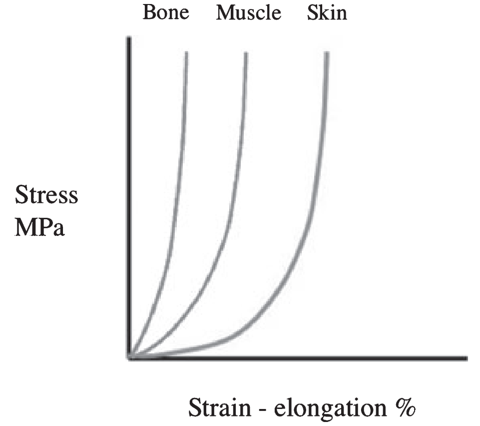

FIG. 2—*The effect of substrate stiffness on the stress/strain curve. As the substrate becomes stiffer, elongation of the skin is limited and the curve becomes more linear.*

Thus, knowledge of the local skin anatomy and consideration of the stress/strain curve are critical to an understanding of how applied stress affects skin during biting.

Anisotropy and Movement

The skin is normally in a constant state of pretension, and this tension is greater in one direction than another. As this tension varies with movement, skin is said to be anisotropic (32,37–39). Anisotropy means that skin possesses different properties in different directions. Thus, properties defined by the stress/strain curve are dependent on preexisting normal tension (31).

Dermal architecture exhibits preferential extensibility that is characterized by the skin tension lines (32). Tension is always greater parallel to tension lines and more relaxed perpendicular to them. Elastin and collagen fibers are under tension along tension lines, so skin extensibility is lower along the direction of these lines. Conversely skin stretches further across tension lines (30–32). This tension pattern, originally described by Karl Langer in 1861, is known as Langer lines (40,41).

Tension lines not only vary between regions of the body, but also with movement (32,41). Borges describes the movement variation as relaxed tension lines (42). Site to site variation of skin extension is dictated by mechanical demands of each part of the body, such as muscle movement and joint articulation (32). Descriptions of skin tension lines have appeared in the literature since the mid-1800s with 36 tension line descriptions, the most widely acknowledged being Langer lines (43).

Thus anatomic location, skin tension, and movement are linked, and play a role in bitemark distortion. Knowledge of skin response to the movement and the areas susceptible to distortion may help the forensic odontologist to better predict and even anticipate bitemark distortion.

The goals of this project were twofold:

1. To determine the degree of distortion (if present) between bites made parallel to skin tension lines compared with those oriented perpendicular to them.
2. To determine the degree of distortion (if any) resulting from movement of the bitemark recipient site subsequent to the making of the bite.

Materials and Methods

Polyvinylsiloxane impressions of the upper and lower dentition were collected from an individual whose casts served as the only biter. The casts were poured into a low viscosity metallographic epoxy resin (Buehler Epo-Thin, Lake Bluff, IL) according to manufacturer's directions. This material has a Shore D hardness value of 78 and is comparable with the teeth that have a Shore D hardness of 70 (the Shore D scale is a measurement of hardness). Thus, epoxy casts are capable of creating indentations and detail reproduction, highly similar to that of natural teeth.

The casts were articulated and mounted to a hand held vice grip. The opening diameter was set at 40 mm corresponding to the biter's dimension. The force produced by the apparatus was tested with a bite force transducer and determined to be within a human bite range of 175–215 N (N = Newton, a unit of force, where force = mass times acceleration). This range was previously established by *in-vivo* volunteer's test bites on the transducer.

Human Subject Review Board (HSRB) exemption was granted for cadaver use. Bites were inflicted on three un-embalmed human cadavers. The use of cadavers to test biomechanical properties of skin is well established. (30–41). Although wound response is not seen in cadavers (edema, inflammation, bruising, and healing), the biomechanical features of the skin are retained for a period of time with properly refrigerated cadavers. Therefore, transfer of indentations and distortion can be studied.

The cadavers were acquired following *rigor mortis,* and were stored at 4°C. The cadavers were allowed to warm to room temperature. Each cadaver received bites on naked skin both perpendicular and parallel to skin tension lines and in various initial biting positions. For example, cadaver No. 1's initial shoulder bite was produced with the arm flexed, medially rotated and supinated, whereas cadaver No. 3 received the initial shoulder bite with the arm straight.

The bite sites included the arm, forearm, lateral thoracic wall, and upper and lower legs. Three photographs were taken immediately after each bitemark. The bitten limb was then moved and rephotographed (Tables 1–3). All photography took place within 10 min of bite marks as many indentations showed signs of rebound.

All bitemark photographs were taken with a Canon Rebel XTi 10.1 Mp digital camera with an ABFO No. 2 reference scale. Using Adobe Photoshop, images were sized 1:1 and metric/angular corrections were done utilizing the Johansen and Bowers method (44).

Bitemark measurements included mesial-distal width of each indentation, intercanine distance for each arch, and relative angle of rotation between teeth. The angle was measured by taking the difference in rotation of the mesial-distal axis between teeth, allowing a comparative measurement. Buccal to lingual incisal measurement was not performed.

A second set of casts was poured under vacuum in Jadestone (Whipmix, Louisville, KY), thus creating models of the biter's dentition for comparison to the photographs of the bitemark. These models were scanned on a flatbed scanner (Hewlett Packard 6100/CT) at 300 dpi resolution. Using Adobe Photoshop, hollow volume overlays were constructed (44–46) and metric/angular measurements were performed using the Johansen and Bowers method (44). Teeth No. 6–11 and No. 22–27 were measured mesio-distally, as was the intercanine distance for each arch and the angle of rotation between each pair of teeth. These measurements were compared with those taken from the bites and the percentage change of each parameter was noted. Similarly, percentage change was calculated through a series of bodily movements. From the measurements made, no two bites were identical, nor did they match the biting dentition.

The experimental intraoperator measurement error of the mesial-distal width and intercanine distance was ± 0.2 mm. The measurement error for the rotation angle was determined to be ± 2 degrees. These calculations were made from measurements of the scanned photographs.

In order to assess the location of the skin tension lines, diagrams from Langer's publications were consulted as well as employing the Borges "pinch" test (40–42). Pinching the skin between the thumb and forefinger highlights tension lines; it is easy to gather the skin perpendicular to tension lines and difficult along them. Repeating the pinch test after limb movement indicated whether the skin tension relaxed.

Results

While the visco-elastic and nonlinear properties influence indentation, anisotropy is the principal determinant of the degree of distortion. Skin tension, direction, and movement played the

TABLE 1—*Anatomic locations of bites, movements, and changes in measurements for cadaver No. 1.*

Location of Bite	Skin Tension Direction	Tension Lines Altered	Movement Difference	Intercanine Difference (%)	M-D* Difference (%)	Angulation (%)
Shoulder	Perpendicular	Yes—tighter	Initial bite—arm flexed, medially rotated, supinated	+6.2	−6.25	0.5 flatter
			Arm flexed	+3.7	−5.5	10 flatter
			Arm straight at side	+4.1	−3	8.6 flatter
Shoulder	Parallel	No	Initial bite—arm straight at side	+10.7	−14.4	26 steeper
			Arm abducted	+14	−4.2	18.5 flatter
			Arm flexed, medially rotated	+5	+2.4	3.2 flatter
Upper arm	Perpendicular	Yes—tighter	Initial bite—arm flexed, medially rotated, supinated	+3.5	−1	18 flatter
			Arm flexed	+10.3	+3.5	12.2 flatter
			Arm straight at side	+1.8	+6.25	12.4 flatter
Lower arm	Parallel	No	Initial bite—arm straight at side	+6.6	+3.75	32 steeper
			Arm flexed, medially rotated	+9.5	+11	7.5 flatter
Lateral thoracic wall	Perpendicular	No	Initial bite—arm straight at side	+4.5	+11	11 flatter
			Arm extended above head	+7.4	+5.2	14.2 flatter
			Arm flexed and medially rotated	+2.9	−8.3	11 flatter
Lateral thoracic wall	Parallel	No	Initial bite—arm straight at side	−12.4	−14	12 steeper
			Arm raised above head	+7.9	+1.8	39 flatter
			Arm abducted	−4.9	−6	13 steeper

*Mesial-distal.

TABLE 2—*Anatomic locations of bites, movements, and changes in measurements for cadaver No. 2.*

Location of Bite	Skin Tension Direction	Tension Lines Altered	Movement Difference	Intercanine Difference (%)	M-D* Difference (%)	Angulation (%)
Shoulder	Perpendicular	Yes—tighter	Initial bite—arm flexed, medially rotated, supinated	+5.4	−2.6	43.7 flatter
			Arm flexed	+4.1	−6.3	28 flatter
			Arm straight at side	+7.8	+17	3.1 flatter
Upper arm	Perpendicular	Yes—tighter	Initial bite—arm flexed, medially rotated, supinated	+8.7	−3	36.7 flatter
			Arm flexed	+6.6	−8.9	25 flatter
			Arm straight at side	+10	+0.3	16 flatter
Upper arm	Parallel	Yes—relaxed	Initial bite—arm flexed	−3.7	+2 max. −2.5 mand.	20.4 steeper
			Arm flexed	−0.5	+0.4 max. −2.8 mand.	16 steeper
			Arm straight at side	+2.1 max. −0.8 mand.	−6.75	7.7 steeper
Lateral thoracic wall	Parallel	No	Initial bite—arm straight at side	+4.5	−2.1	35 flatter
			Arm extended above head	+15	+9.6	38 flatter
			Arm flexed and medially rotated	+7.7	+7.5	42 flatter
Lateral thoracic wall	Perpendicular	No	Initial bite—arm straight at side	−1.5	−9.1	9.5 flatter
			Arm raised above head	−7.3 max. +6.6 mand.	−10.2	12.4 flatter
			Arm flexed medially rotated	+3.7	−14.5	8.5 flatter
Upper leg	Parallel	Yes—tighter	Initial bite—leg flexed, laterally rotated	+5	−3.5	41.7 steeper
			Leg allowed to fall off table	+4.9	−5.9	84 steeper
Upper leg	Perpendicular	Yes—tighter	Initial bite—leg flexed and laterally rotated	−1.7	−5.6	27.9 steeper
			Leg allowed to fall off table	−8.7	−9.7	81 steeper
Lower leg	Perpendicular	Yes—tighter	Initial bite—leg flexed and laterally rotated	+4.6	−5.6	13 flatter
Lower leg	Parallel	Yes—tighter	Initial bite—leg flexed and laterally rotated	+6.8	−6.2	3.1 steeper

*Mesial-distal.

greatest roles in distortion. Figures 3 and 4 depict the approximate location of the bites made and the direction in which Langer lines follow.

Of the 23 bites made in this study, no two bites were visually or measurably identical. Indeed, the variation in appearance of the bitemarks was considerable. Using one individual as the biter allowed for controlled comparison of measurements to a single characterized dentition.

As no two bites were the same, each was considered as a unique event and statistical treatment was not found to be appropriate. However, consistent distortional trends emerged considering bitemark production and subsequent bodily movement. Tables 1–3 show the conditions of each bite and the percentage change of the measured parameters with respect to the original dentition for each cadaver.

Perpendicular to Tension Lines

Bites placed perpendicular to tension lines in firm, relaxed, or stretched muscle showed the least distortion. All showed a widening of the arches, thus flattening the angle of rotation between teeth marks (Fig. 5). Mesio-distal dimensions of each tooth mark were smaller for most of these bites. In situations where skin could be

TABLE 3—*Anatomic locations of bites, movements, and changes in measurements for cadaver No. 3.*

Location of Bite	Skin Tension Direction	Tension Lines Altered	Movement Difference	Intercanine Difference (%)	M-D* Difference (%)	Angulation (%)
Shoulder	Perpendicular	No	Initial bite—arm straight at side	+5.1	−7.3	13 flatter
			Arm flexed and medially rotated	+17.5	−14	8 flatter
Upper arm	Perpendicular	No	Initial bite—arm straight at side	+11.2	−5.7	5 flatter max. 70 flatter mand.
			Arm flexed	+13.6	−5.5 max. +5.2 mand.	20 flatter max. 63 flatter mand.
			Arm flexed and medially rotated	+10	−9.7	13 flatter max. 3 flatter mand.
Upper arm	Parallel	No	Initial bite—arm straight at side	−4	−16.2	66 steeper
			Arm flexed and medially rotated	+5.8	−8.9	88 steeper
Lower arm	Perpendicular	No	Initial bite—arm straight at side	+24	−0.3	81 flatter
			Arm flexed and medially rotated	+17	+3.3	72 flatter
Lateral thoracic wall	Parallel	No	Initial bite—arm above head	+4.1	−13.5	21.6 flatter
			Arm straight at side	−8	−15	13 flatter
			Arm flexed and medially rotated	−19.7	−23.6	11 steeper max. 46 steeper mand.
Lateral thoracic wall	Perpendicular	Yes—tighter	Initial bite—arm above head	+8.7	−12.45	23 flatter
			Arm straight at side	+12.8	−23.5	37 flatter
			Arm flexed and medially rotated	+17.7	−9.8	41 flatter
Upper leg	Perpendicular	No	Initial bite—leg straight	−5.3	−15	37 flatter
			Leg allowed to fall off table	−20	−29.9	76 steeper
			Leg flexed at knee	+9.9	−12.9	43 flatter
Upper leg	Perpendicular	No	Initial bite—leg straight	+13.9	−7.4	52.5 flatter
			Leg allowed to fall off table	−27.9	−29	25 steeper

*Mesial-distal.

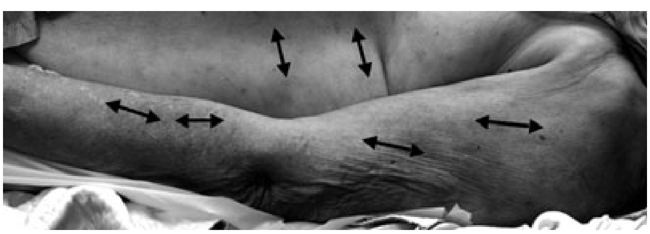

FIG. 3—*Approximate location of the bites made and the direction in which Langer's lines follow on the arm, forearm, and lateral thoracic wall.*

FIG. 4—*Approximate location of the bites made and the direction in which Langer's lines follow on the thigh and calf.*

FIG. 5—*The bite was created perpendicular to the tension lines in firm muscle while the arm was flexed, medially rotated, and supinated. This bite showed the least amount of distortion of all bites in this study.*

gathered because of looseness of the tissue, there was an apparent lengthening of the arches and an extreme flattening of the angle of rotation (Figs. 6 and 7).

Bites that were inflicted in very thin skin showed considerable lingual detail of the upper arch (Fig. 8). Although this was the extreme case for the display of lingual detail, it should be noted that this varied and depended on the degree of firmness of the tissue that was bitten.

Bites in very firm tissue due to initial placement of the body part showed an appearance similar to, though not as extreme as, the bites that were made parallel to tension lines.

Parallel to Tension Lines

Bites that were oriented parallel to tension lines showed greater "dragged" appearance of the upper arch, and marked constriction of both arches which resulted in the angle of rotation between teeth becoming very steep. Figures 9 and 10 show a typical bite made parallel to tension lines. When a bite was attempted in this direction, the upper arch could not maintain hold of the skin and slid until a smaller opening diameter was achieved that could pinch the tissue. Bites placed parallel to the tension lines with the tension relaxed because of flexure of the body part displayed an

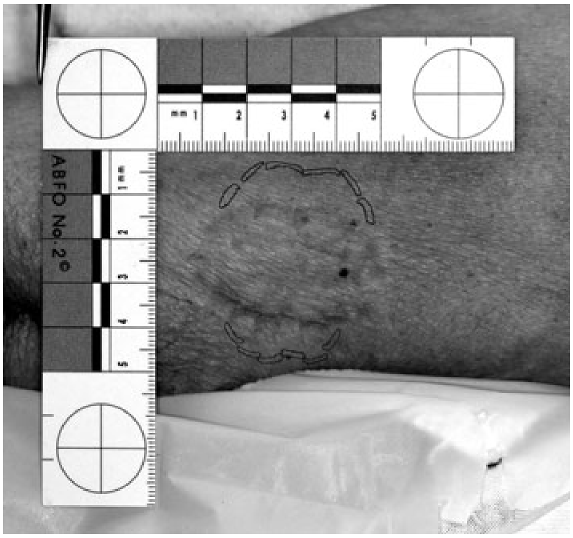

FIG. 6—*A bite created perpendicular to tension lines in loose tissue. The arm was straight and at the side of the body. There is a flattening of the angles of rotation between teeth and apparent widening of the arches.*

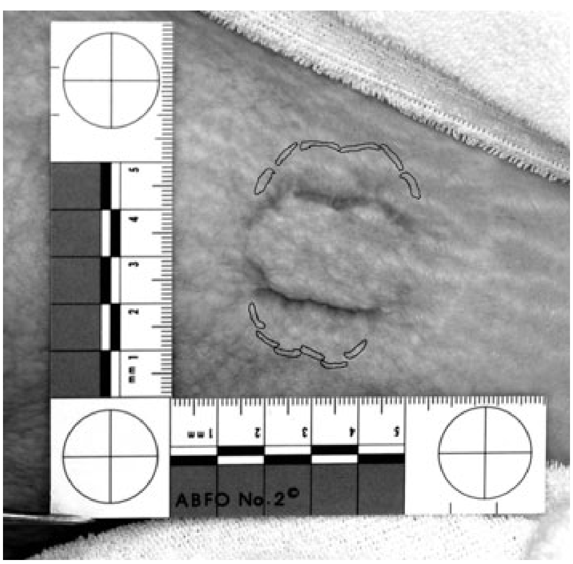

FIG. 7—*A bite created perpendicular to tension lines in loose tissue. This bite was made on the upper portion of the thigh. Note the flattening of the angles of rotation between teeth and a widening of the arches.*

appearance characterized by constriction of the arches, but the "dragged" appearance of the upper arch was absent (Fig. 11). Bites parallel to skin tension lines in areas that had extensive subcutaneous fat had an appearance similar to the bitemarks made perpendicular to the tension lines in loose tissue as there was a flattening of the arch (Figs. 12–14). Bites in fatty tissue made perpendicular to tension lines had a similar appearance as those in muscle perpendicular to tension lines.

Movement

Body movement distorts a bitemark by pulling it in the direction of movement. Figure 15 demonstrates the result of arm extension. The degree of distortion upon movement is dependent upon the range of motion of the body part. Indeed, some bitemarks changed little when the body part was moved, while greater distortion was observed with movement in other areas.

FIG. 8—*The bite on the left was made in very thin skin perpendicular to tension lines. Considerable lingual detail of the upper arch can be seen. The bite on the right was inflicted parallel to tension lines. Note the difference in appearance.*

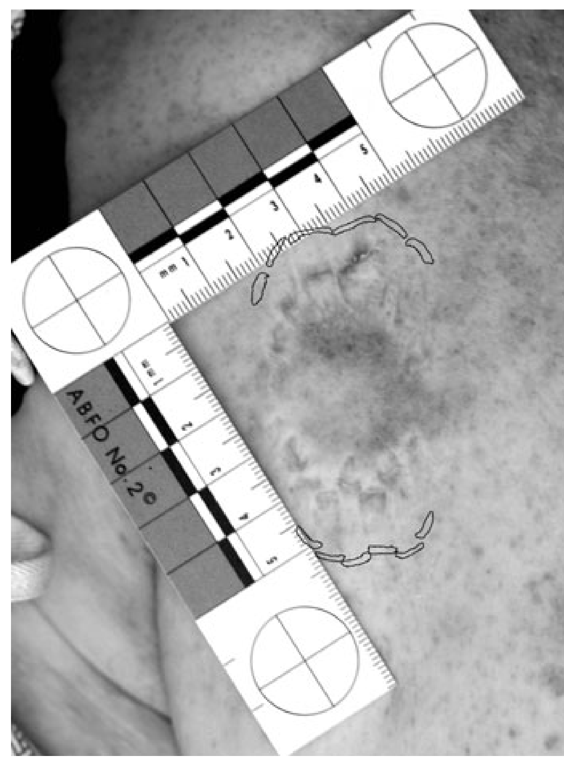

FIG. 9—*A bite made parallel to tension lines. The upper arch shows a "dragged" and constricted appearance while the lower arch shows steepening of the angles of rotation between teeth as well as a constriction of the arch.*

Generally extension led to more distortion (Fig. 16). The lateral thoracic wall for example, was highly extensible when the arm was raised above the head, but this only occurred when the bite was close to the axilla or breast. If the bite occurred caudally, little movement was seen. Thus, in Tables 1–3, lateral thoracic wall bites exhibit variable amounts of distortion.

Body movement usually distorted part of or the entire bitemark. Movement never affected a single tooth alone (Figs. 17 and 18). There are areas of the body that were not as susceptible to postural distortion. Differences are listed in the adjoining tables. Although the original intent was to duplicate the bitten area in each cadaver,

FIG. 10—*A bite made parallel to tension lines. Note the similar appearance to Fig. 9.*

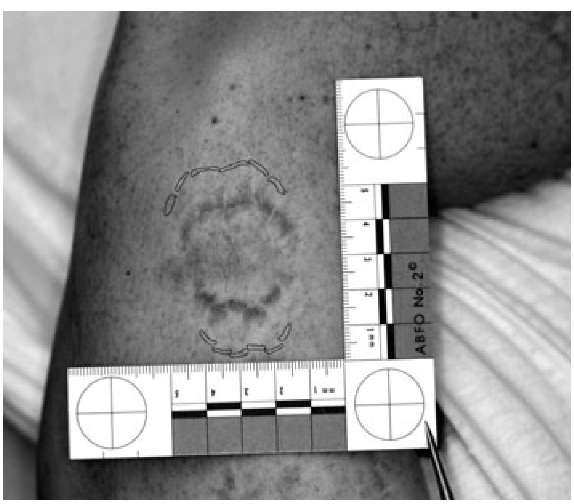

FIG. 11—*A bite made parallel to tension lines while the arm was flexed. Note the constriction of the arches, but the absence of lingual surfaces from upper teeth.*

slight variations occurred as a result of individual body characteristics.

In summary, the range of distortion seen from the single dentition can be described. Values of maximum positive and negative percent change in intercanine measurements were −27% to +24%, giving a range of 51%. For mesial to distal measurements the excursion was −29% to +5%, for a range of 34%. For angulation between teeth the difference was −81% to +80% resulting in a range of 161%. These ranges were the maxima reported in this study. Actual values differed between individuals and bite circumstance. Nonetheless these results suggest that distortion can be a major issue in bitemark production rendering dental comparison complex.

Discussion

A bitemark can be distorted by the biomechanical properties of skin, its underlying tissue, and by subsequent movement of the bite site or the adjacent area. Explanations for these distortions can

FIG. 12—*Two bites created side by side on the lateral thoracic wall. The arm was parallel to the body when the bites were inflicted. Note the differences in appearance.*

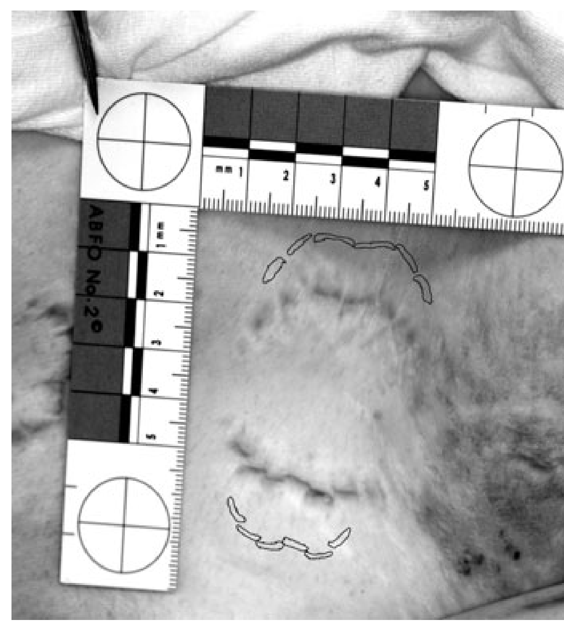

FIG. 13—*Closer view of the bite on the right in Fig. 12. This bite was made parallel to the tension lines in highly fatty tissue, thus mimicking the appearance of bites perpendicular to tension lines in loose tissue as in Fig. 6.*

partially be found in the properties of skin, namely visco-elasticity, hysteresis, nonlinearity, and anisotropy. Consideration of the stress/strain curve for skin provides insight into how the sequence of events that constitutes a bite progresses from elastic deformation through visco-elastic extension.

The use of cadavers excluded the effects of edema, hemorrhage, and inflammation in bitemark production observed in living tissue. This was considered an advantage as it allowed a controlled situation where indentations could be studied as opposed to swollen tissues with bruise patterns. The authors understand that the use of cadaver skin may not replicate living tissue.

The shape of the dentition as transferred to skin in the form of a bitemark is altered at the moment of engagement. The principal

FIG. 14—*Close up of bite on the left depicted in Fig. 12. This bite was made perpendicular to tension lines in fatty tissue.*

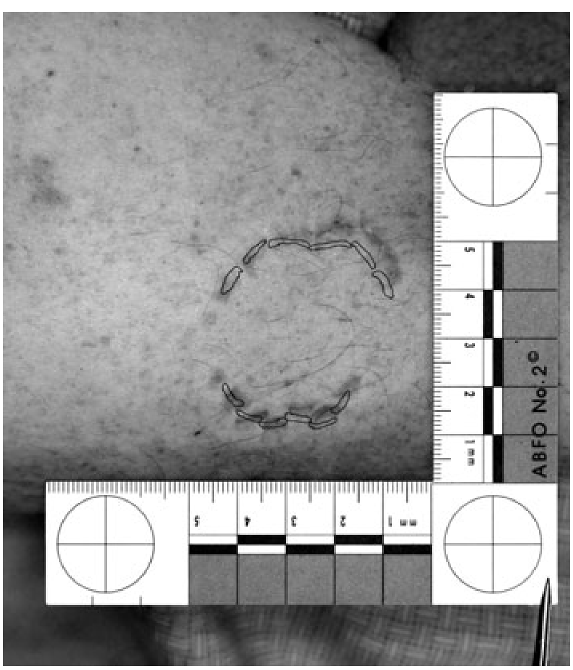

FIG. 15—*Postural distortion of the bite depicted in Fig. 5. The arm is no longer medially rotated and supinated but flexed. Note distention of half of the bite in the direction of movement.*

distortion occurs at this precise moment and the degree of distortion is affected by several factors including teeth gathering skin, stiffness of the substrate, anatomic location, skin tension, and others.

As may be expected, the extensibility of an anatomic location affects the degree of distortion. Distortion due to movement varied depending on anatomic location. In some cases the bitemark appeared completely different depending on the anatomic site relative to tension lines.

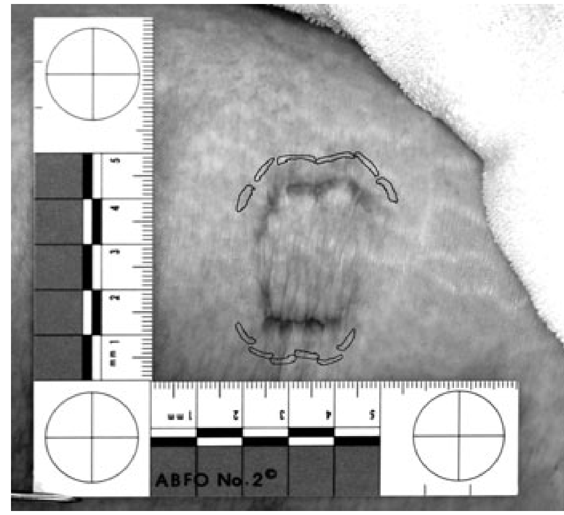

FIG. 16—*Alteration of the appearance of the bite depicted in Fig. 7 with the leg moved from a straight to an abducted position.*

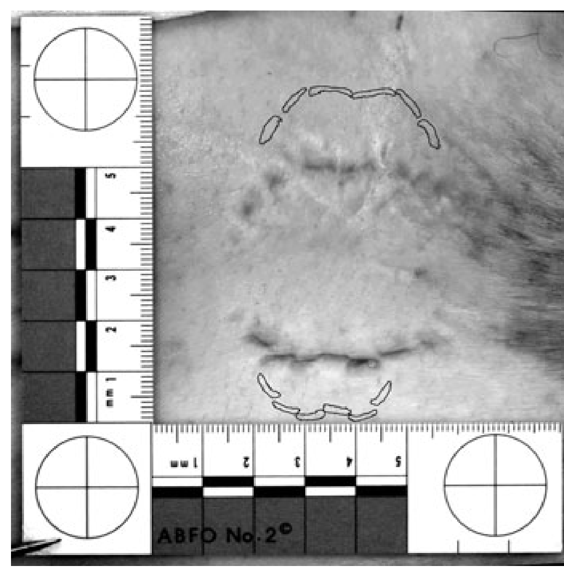

FIG. 17—*Postural distortion resulting from raising the arm above the head. See Fig. 13.*

The bites made on the cadavers exhibited clear indentations. In both living and cadaver skin, indentations do not persist and typically disappear after 30 min. Thus the conditions in this experiment represented the optimum situation pertaining to indentation-type bitemarks. With distortion of up to 80% in clear indentations, interpretation of a bitemark in a live individual in which indentations have faded and only a diffuse bruise remains should be approached with caution.

Because of the dramatic differences seen between bitemarks from the same dentition, each bite had to be considered as a unique event because of the morphologic difference encountered between bites and bitemark location. Definite trends of distortion pattern were observed. This is an important observation from a legal perspective as it can be inferred that each bitemark should be evaluated on an individual basis.

The authors understand the limitations of this study and acknowledge that individual conditions such as pathology, age of the victim, and numerous other factors will alter the

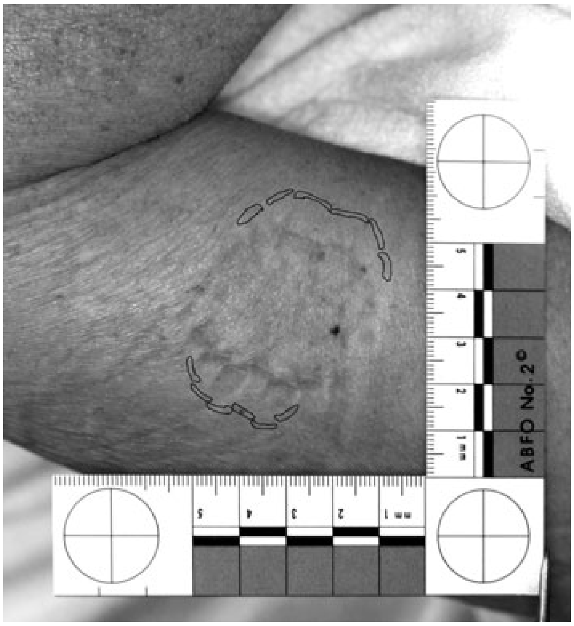

FIG. 18—*Postural distortion resulting from arm movement. The arm was originally straight at the body's side then flexed and medially rotated. See Fig. 6.*

mechanical properties of the skin. In addition, only limited anatomic sites were studied which did not include locations in which the substrate has different properties such as the breast, skull, and ear.

However, the study illustrates that understanding the properties of skin and how it responds to applied stress can be a valuable adjunct to bitemark analysis.

Although the dentition can be accurately measured and described mathematically, its imprint on skin has inherent distortion that a prudent examiner might need to analyze before tendering an opinion. For example, if the uniqueness of a dentition is defined by a five-degree rotation of an anterior tooth in relation to its adjacent dental units and a 20-degree distortion is observed in the bite, then the defining measurement of its uniqueness is insignificant when compared with the effect of distortion. This explainable discrepancy might be difficult to justify without the knowledge of skin biomechanics.

Acknowledgment

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Exhibit

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CASE NO. S223651
(PRIOR SUPREME COURT CASE NO. S189275)

IN THE SUPREME COURT
OF THE STATE OF CALIFORNIA

William Joseph Richards,
Petitioner,

vs.

Robert A. Fox, Warden, California Medical Facility, and
California Department of Corrections and Rehabilitation,
Respondents.

ON PETITION FOR WRIT OF HABEAS CORPUS
APPEAL FROM THE DECISION OF THE COURT OF APPEAL,
FOURTH APPELLATE DISTRICT, DIVISION TWO,
HABEAS CASE NO. E049135
(PRIOR COURT OF APPEAL CASE NO. E024365)
ON APPEAL FROM THE SUPERIOR COURT, COUNTY OF SAN BERNARDINO,
HABEAS CASE NO. SWHSS700444
(PRIOR TRIAL CASE NO. FVI00826)

HONORABLE MARGARET POWERS (RET.)

APPLICATION FOR LEAVE TO FILE *AMICI CURIAE* BRIEF OF MICHAEL J. SAKS, THOMAS ALBRIGHT, THOMAS L. BOHAN, BARBARA E. BIERER AND 34 OTHER SCIENTISTS, STATISTICIANS AND LAW-AND-SCIENCE SCHOLARS AND PRACTITIONERS IN SUPPORT OF THE PETITION FOR WRIT OF HABEAS CORPUS BY WILLIAM JOSEPH RICHARDS

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TO THE HONORABLE CHIEF JUSTICE TANI G. CANTIL-SAKAUYE, AND ASSOCIATE JUSTICES OF THE SUPREME COURT OF CALIFORNIA:

Pursuant to California Rule of Court 8.520(f), the following scientists, statisticians, and law-and-science scholars or practitioners seek leave to appear as *amici curiae* in this matter: Thomas Albright, Thomas L. Bohan, Barbara E. Bierer, Michael Bowers, Mary A. Bush, Peter J. Bush, Arturo Casadevall, Simon A. Cole, M. Bonner Denton, Shari Seidman Diamond, Rachel Dioso-Villa, Jules Epstein, David Faigman, Lisa Faigman, Stephen E. Fienberg, Brandon L. Garrett, Paul C. Giannelli, Henry T. Greely, Edward Imwinkelried, Allan Jamieson, Karen Kafadar, Jerome P. Kassirer, Jonathan "Jay" Koehler, David Korn, Jennifer Mnookin, Alan B. Morrison, Erin Murphy, Nizam Peerwani, Joseph L. Peterson, D. Michael Risinger, Michael J. Saks, George F. Sensabaugh, Jr., Clifford Spiegelman, Hal Stern, William C. Thompson, James L. Wayman, Sandy Zabell and Ross E. Zumwalt (collectively, "*amici*"). *Amici* respectfully request leave to file the attached *amicus* brief in support of the petition for writ of habeas corpus by William Joseph Richards.

In accordance with California Rule of Court 8.250(f)(4), no party or counsel for any party, other than counsel for *amici*, have authored the proposed brief in whole or in part or funded the preparation of the brief. This brief is timely, as it is filed within 30 days after the last reply brief was filed.

STATEMENT OF INTEREST

Amici are a diverse group of scientists, statisticians, and law-and-science scholars or practitioners who value and encourage the thoughtful use of sound science by the courts. We write in the interest of helping the Court to gain a clearer and more complete understanding of the scientific issues at the heart of the case at bar. No overall characterization can adequately summarize our wide-ranging backgrounds; provided below is biographical information about each of the brief's authors. The views expressed in the attached Brief represent those of the individual authors/cosigners and not necessarily of the institutions with which they are associated.

Petitioner was convicted on the basis of the now-recanted testimony of Dr. Norman Sperber, who claimed that an impression "on the victim's hand was a bite mark matching [P]etitioner's unusual dentition." (Pet. at 33) However, forensic analysis of bitemark evidence is generally riddled with a number of unresolved questions regarding accuracy, reliability, bias, proper technique and application, and others. *Amici*'s proposed brief provides much-needed context and history to explain the reliability and scientific underpinning, or lack thereof, of claims that bitemarks can be used to reliably identify a suspected biter. The brief of *Amici* will provide critical, focused assistance to the Court in understanding: that the history, research, and practice of forensic odontology has been misunderstood by the courts for years; the difficulties inherent in identifying whether an injury is a bitemark in the first instance; the difficulties inherent in linking bitemarks on the skin of crime victims to their source; that the available empirical research suggests that, except in the most unusual circumstances, forensic odontology currently does not possess the ability to offer reliable and valid bitemark identifications to the courts; and that the latent uncertainty in the current state of forensic odontology undermines the probative value of any individual identification of the source of a bitemark.

Amici's proposed brief incorporates a broad array of insight, experience, and expertise in odontology, forensic certainty, evidentiary sufficiency, and other related specialties, which *Amici* submit will assist the Court in understanding the fundamental uncertainty underlying the use of bitemark evidence to reliably identify a suspect. A brief description of the background and work of each of the *amici* is as follows:

Amicus **Thomas Albright,** Ph.D. (psychology and neuroscience), trained at Princeton University, is professor and director of the Vision Center Laboratory at the Salk Institute. He is a researcher whose lab focuses on the neural structures and events underlying perception of motion, form, and color. His recent studies have uncovered the existence of multiple brain areas devoted to the detection, analysis, and interpretation of specific types of visual information. Albright is a member of the National Academy of Sciences, chaired the NAS committee on eyewitness identification, and has been a consultant to the National Commission on Forensic Science.

Amicus **Thomas L. Bohan**, Ph.D., J.D., President of the American Academy of Forensic Sciences, 2009-2010, and currently President of the Forensic Specialties Accreditation Board, holds his physics Ph.D. from the University of Illinois-Urbana/Champagne and his law degree from the University of New Hampshire School of Law. He has authored books and peer-reviewed papers in the scientific and legal professional literature. Reflecting his interest in forensic science and its admission into evidence, these publications include early commentary on the *Daubert* decision and an extensive review of the 2009 National Academy of Science report *Strengthening Forensic Science in the United States*. He resides on Peaks Island in the State of Maine.

Amicus **Barbara E. Bierer**, M.D., is a Professor of Medicine at Harvard Medical School and the Brigham and Women's Hospital. She is the Program Director of the Regulatory Foundations, Law and Ethics Program. Dr. Bierer directs the Multi-Regional Clinical Trials Center at Harvard, a University-wide effort to improve standards for the planning and conduct of clinical trials. She has served as Senior Vice President, Research, at the BWH. Bierer also served as the Chair of the Secretary's Advisory Committee for Human Research Protections, DHHS, and is currently a member of the National Academies of Sciences Committee on Science, Technology and the Law. She has authored or co-authored over 180 publications and is on the editorial boards of a number of journals, including *Current Protocols of Immunology*. Bierer received a B.S. from Yale University and an M.D. from Harvard Medical School.

Amicus **Michael Bowers** is a practicing dentist and an Associate Clinical Professor at The Ostrow School of Dentistry of USC. Over many years he has collaborated with notable legal and forensic dental colleagues to improve the methods and results in forensic identification. His accompanying intent has been to inform the Criminal Justice system about bitemark identifiers' scientifically unsubstantiated and dangerous claims of certainty and reliability. Some of his empirical studies and reporting in published peer reviewed books and articles on this subject were cited in the 2009 NAS report as a partial basis for its bitemark findings contained in that document.

Amicus **Mary A. Bush,** DDS, is an Associate Professor at SUNY at Buffalo School of Dental Medicine. She is Past President of the American Society of Forensic Odontology, is a Fellow of the American Academy of Forensic Sciences, and is Director for the Laboratory for Forensic Odontology Research, University at Buffalo. She is on the Editorial Board for the *Journal of Forensic Science*, has published numerous articles, has contributed to various textbooks, and lectures widely on the topic of forensic odontology including an invited presentation at a congressional hearing on Capitol Hill. She serves on the Odontology Subcommittee of the Organization of Scientific Area Committees ("OSAC") of the National Institute of Standards and Technology ("NIST").

Amicus **Peter J. Bush** is Director of the South Campus Instrument Center at the State University of New York School of Dental Medicine and Adjunct Professor of Art Conservation at Buffalo State College. He is a co-founder of the

Laboratory for Forensic Odontology Research and a Fellow of the American Academy of Forensic Sciences. He is a member of the Research Committee for the American Society of Forensic Odontology. Mr. Bush has worked in many scientific areas, including Forensic Odontology. He has published over 60 articles and his work is referenced in numerous sources including the NASA website.

Amicus **Arturo Casadevall** is the Bloomberg Distinguished Professor and chair of the Molecular Microbiology and Immunology department at Johns Hopkins School of Public Health. He received his M.D. and Ph.D. from New York University. Subsequently, he completed internship and residency in internal medicine at Bellevue Hospital. Casadevall has authored over 630 scientific papers. He was elected to membership in the American Society for Clinical Investigation, the American Academy of Physicians, the American Academy of Microbiology and the Institute of Medicine (of the National Academy of Sciences).

Amicus **Simon A. Cole** is Professor of Criminology, Law & Society at the University of California, Irvine and Director of The Newkirk Center for Science & Society. He holds a Ph.D. in Science & Technology Studies from Cornell University. He is the author of Suspect Identities: A History of Fingerprinting and Criminal Identification (Harvard University Press, 2001) and more than 20 scholarly articles and book chapters about forensic evidence. He is a member of the Human Factors Subcommittee of the National Commission on Forensic Science, and he is Co-Editor of the journal *Theoretical Criminology*.

Amicus **M. Bonner Denton** is recognized as a world leader in scientific optical imaging and development of new analytical instrumentation. His work has been recognized through numerous awards and today he is a Fellow of the American Association for the Advancement of Science, the Royal Society of Chemistry; the American Chemical Society, and the Society for Applied Spectroscopy. He received his Ph.D. in Chemistry in 1972 from the University of Illinois and is currently a Galileo Professor of Chemistry and Professor of Geological Sciences at the University of Arizona. He served as co-author of the National Research Council Report, *Strengthening Forensic Science in the United States*, and is a Member of the National Commission on Forensic Science.

Amicus **Shari Seidman Diamond** is the Howard J. Trienens Professor of Law and Professor of Psychology at Northwestern University, where she directs the J.D./Ph.D. program, and a research professor at the American Bar Foundation. Professor Diamond has published more than a hundred articles on legal decision-making in law reviews and behavioral science journals. She was elected to the American Academy of Arts and Sciences. She has been on advisory boards of the National Science Foundation, National Academy of Sciences (Panel on the Evaluation of Forensic DNA Evidence), National Center for State Courts, Federal Judicial Center, American Bar Association, and American Judicature Society. Her publications have been cited by federal and state courts, including the U.S. Supreme Court.

Amicus **Rachel Dioso-Villa**, Ph.D., is a Lecturer in the School of Criminology and Criminal Justice at Griffith University, Australia. Her research investigates the admissibility of the forensic sciences, the validation of forensic science techniques, specifically fire investigation expertise, and the causes and correlates of wrongful conviction. Her work has appeared in the Stanford Law Review, Canadian Journal of Criminology, Law Probability and Risk and the Wall Street Journal. She has received grants and fellowships from the Social Science and Humanities Research Council of Canada, the American Society of Criminology and the Canadian Foundation of University Women.

Amicus **Jules Epstein** is a Professor of Law at Widener University School of Law, where he teaches Evidence, Criminal Procedure and Criminal Law and is Director of the Taishoff Advocacy, Technology and Public Service Institute. He is faculty for the National Judicial College, teaching Evidence and Capital Case courses. Professor Epstein has worked on two DNA workgroups for NIJ, and on a working group on latent print issues for the NIST. He is co-editor of *Scientific Evidence Review: Admissibility and the Use of Expert Evidence in the Courtroom, Monograph NO. 9* (ABA, 2013) and *The Future of Evidence* (ABA, 2011) and served as section editor for the *Encyclopedia of Forensic Sciences*, 2nd Edition (2013). Professor Epstein has lectured on forensics to judges and attorneys.

Amicus **David Faigman** is the John F. Digardi Distinguished Professor of Law at the University of California, Hastings, and a Professor in the School of Medicine (Department of Psychiatry) at UCSF. He is the author of numerous books and articles on the use of scientific research in legal decision making. He is also a co-author/co-editor of the five-volume treatise *Modern Scientific Evidence: The Law and Science of Expert Testimony* (with Blumenthal, Cheng, Mnookin, Murphy & Sanders). Professor Faigman was a member of the National Academies Committee that studied the validity of polygraphs and is a member of the MacArthur Law and Neuroscience Network.

Amicus **Lisa Faigman** is a Visiting Professor at the University of California, Hastings College of Law. Her teaching and research areas include forensic evidence, wrongful conviction, evidence, criminal procedure, and the general intersection of science and law.

Amicus **Stephen E. Fienberg** is Maurice Falk University Professor of Statistics and Social Science at Carnegie Mellon University, and co-director of the Living Analytics Research Centre with appointments in the Department of Statistics, the Machine Learning Department, the Heinz College, Cylab and the Human Rights Science Center. He is the author or editor of over 25 books and 500 papers and related publications, several of which deal with forensic statistics topics. He is a member of the National Academy of Sciences, and a fellow of the Royal Society of Canada, the American Academy of Arts and Sciences, and the American Academy of Political and Social Science. In January 2014 he was appointed as a member of the National Commission on Forensic Science.

Amicus **Brandon L. Garrett** is a Professor of Law at the University of Virginia, where he has taught since 2005. His research and teaching interests include criminal procedure, wrongful convictions, habeas corpus, corporate crime, scientific evidence, and constitutional law. Garrett's recent research includes studies of DNA exonerations and organizational prosecutions. Garrett's book examining corporate prosecutions, titled *Too Big to Jail: How Prosecutors Compromise with Corporations*, was published by Harvard University Press in 2014. In 2011, Harvard University Press published Garrett's book, *Convicting the Innocent: Where Criminal Prosecutions Go Wrong*, examining the cases of the first 250 people to be exonerated by DNA testing. Garrett attended Columbia Law School, where he was an articles editor of the Columbia Law Review. He clerked for the Honorable Pierre N. Leval of the U.S. Court of Appeals for the Second Circuit. He then worked as an associate at Neufeld, Scheck & Brustin LLP in New York City.

Amicus **Paul C. Giannelli** is a Distinguished University Professor and the Albert J. Weatherhead III & Richard W. Weatherhead Professor of Law at Case Western Reserve University. He received his J.D. degree from the University of Virginia, where he served as Articles Editor of the Virginia Law Review. His other degrees include an LL.M. from the University of Virginia, an M.S. in Forensic Science from George Washington University, and a B.A. from Providence College. He served as both a prosecutor and defense counsel in the military. Giannelli has written extensively in the field of evidence and criminal procedure, especially on the topic of scientific evidence. He has authored or co-authored twelve books, including *Scientific Evidence* (5th ed. 2012), and has written over 200 articles and other works, mostly on scientific evidence and the law. He is co-author of the chapter on forensic science in *Federal Judicial Center, Reference Manual on Scientific Evidence* (3d ed. 2011). Giannelli's work has been cited in nearly 700 judicial opinions throughout this country (including seven decisions of the U.S. Supreme Court), as well as in foreign courts. Among other service, he is a commissioner, National Commission on Forensic Science and a member, National Academy of Sciences, Bullet Lead Elemental Composition Comparison Committee.

Amicus **Henry T. Greely** is Deane F. and Kate Edelman Johnson Professor of Law and Professor, by courtesy, of Genetics at Stanford University. He specializes in ethical, legal, and social issues arising from the biosciences. He chairs the California Advisory Committee on Human Stem Cell Research and directs the Stanford Center for Law and the Biosciences and the Stanford Program in Neuroscience and Society. He is a member of the Committee on Science, Technology, and Law of the National Academy of Sciences and the Institute of Medicine's Neuroscience Forum. In 2007, he was elected a fellow of the American Association for the Advancement of Science.

Amicus **Edward Imwinkelried** is the Edward L. Barrett, Jr. Professor of Law Emeritus at the University of California, Davis. He is the coauthor of *Scientific Evidence* (5th ed. 2012) and "Reference Guide on Forensic Identification Expertise," *Reference Manual on Scientific Evidence* (3d ed. 2011). He was a member of the NIST expert working group that released *Latent Print*

Examination and Human Factors: Improving the Practice Through a Systems Approach (2012). He served as the Legal Consultant to the Surgeon General's Commission on Urinalysis Testing in the Armed Forces. He is a contributing editor on scientific evidence to *Criminal Law Bulletin* and was formerly the expert testimony columnist for *National Law Journal.*

Amicus **Allan Jamieson** is a forensic scientist in the U.K. He holds a Ph.D. in forensic science from Strathclyde University. He is a Visiting Professor of Forensic Sciences at Staffordshire University, Editor in Chief of *Wiley's Encyclopaedia of Forensic Sciences* and has published in peer-reviewed and other journals. He was external examiner for forensic sciences at Edinburgh University and the University of Kent at Canterbury; Visiting Professor of Forensic Biology at Napier University, Edinburgh; head of Lothian & Borders Police Forensic Science laboratory; a director of Forensic Alliance; chair of the United Kingdom Forensic Toxicology Forum; chair of the Standards Committee and the Academic and Education Committee of the Forensic Science Society; and a member of the editorial board of Clarke's Analysis of Drugs & Poisons. He has testified in criminal cases in Scotland, Northern Ireland, England and Wales, the U.S., Australia, New Zealand, and Cyprus, and has been involved in thousands of criminal cases as an expert.

Amicus **Karen Kafadar** is Commonwealth Professor & Chair of Statistics at University of Virginia. She received her Ph.D. in Statistics from Princeton University, and previously held positions at NIST, Hewlett Packard, NCI, University of Colorado-Denver, and Indiana University. Her research focuses on robust methods, exploratory data analysis, and characterization of uncertainty in the physical, chemical, biological, and engineering sciences. She has been editor of several journals including, currently, Biology & Genetics Editor for *The Annals for Applied Statistics*. She has served on several National Academy of Sciences committees, including those that led to the reports, *Weighing Bullet Lead Evidence* (2004), *Strenghening Forensic Science in the United States* (2009), *Evaluating Testing, Costs, and Benefits of Advanced Spectroscopic Portals* (2011), and *Identifying the Culprit: Assessing Eyewitness Identification* (2014). She is a member of the Forensic Science Standards Board.

Amicus **Jerome P. Kassirer**, M.D., Distinguished Professor of Medicine at Tufts University School of Medicine and Editor-in-Chief of the New England Journal of Medicine between 1991-1999, has studied the process of diagnosis for 37 years. He is author of numerous scientific papers and review articles on diagnostic reasoning and diagnostic testing and is co-author of "Learning Clinical Reasoning" (Lippincott, 2010). He is coeditor of the most recent issue of the Manual of Scientific Information, the data source for federal judges, and has published on the way information is assessed by the courts. He teaches diagnosis weekly at Tufts Medical Center in Boston and monthly at Stanford University.

Amicus **Jonathan "Jay" Koehler** is the Beatrice Kuhn Professor of Law at Northwestern University School of Law. Koehler has a Ph.D. in Behavioral Sciences from the University of Chicago. He conducts research in how people reason with forensic and quantitative evidence in legal cases. He teaches classes in statistics and probability, forensic science, decision making, and evidence. He has published dozens of peer-reviewed journal articles, and is an editor of Law, Probability & Risk, and a consulting editor of Judgment and Decision Making.

Amicus **David Korn**, M.D., was Stanford University Vice-President and Dean of Medicine, and Professor and Founding Chair of Pathology. Korn served for 11 years as Senior Vice President and Chief Scienti• c Officer of the Association of American Medical Colleges (AAMC), and then Vice-Provost for Research at Harvard University. He is currently Consultant in Pathology at the Massachusetts General Hospital and Professor of Pathology at Harvard Medical School. He is a member of the Institute of Medicine of the National Academies of Science (NAS). He was a founding member and served as co-chair of the NAS Committee on Science, Technology and Law, which initiated and oversaw the Reports, *Strengthening Forensic Science in the United States*, and *Review of the Scientific Approaches Used During the FBI's Investigation of the 2001 Anthrax Letters*.

Amicus **Jennifer Mnookin** has been named the Dean of UCLA Law School, and is currently the David G. Price and Dallas P. Price Professor of Law and the Faculty Director of the Program on Understanding Law, Science and Evidence at UCLA Law School. Her scholarship and teaching focus on evidence, especially expert evidence and issues in forensic science. She is a co-author of two evidence treatises, *The New Wigmore: Expert Evidence, and Modern*

Scientific Evidence (where her editorial responsibilities include the chapter on bitemark identification), and she has written numerous academic articles focusing on a variety of forensic identification disciplines, among other topics. She is currently a member of the National Academy of Science's Committee on Science, Technology and Law. In addition to a J.D. from Yale, Mnookin holds an A.B. from Harvard and a Ph.D. from M.I.T.

Amicus **Alan B. Morrison** is the Associate Dean for Public Interest & Public Service Law at George Washington University Law School. He has served for • fteen years as a member of the Committee on Science, Technology & Law of the National Academy of Sciences, which sponsored the report, *Strengthening Forensic Science in the United States.*

Amicus **Erin Murphy** is a Professor of Law at New York University School of Law. Murphy's research focuses on forensic evidence and the use of new technologies in the criminal justice system. She is the author of the forthcoming book, *Inside the Cell,* which addresses scientific, legal, and ethical questions raised by forensic DNA testing methods.

Amicus **Nizam Peerwani,** M.D. is the chief medical examiner for Tarrant County, Texas, and chair of the Texas Forensic Science Commission. His work has included the evaluation of genocide and human rights violations in Rwanda and Bosnia-Herzegovina. Peerwani was honored by Physicians for Human Rights for his human rights work. Peerwani is a graduate of the American University of Beirut (MD '76). He completed his residency in pathology at Baylor University

Medical Center in Dallas, and is board certified in clinical, anatomic and forensic pathology.

Amicus **Joseph L. Peterson**, D.Crim. recently retired as Professor in the School of Criminal Justice and Criminalistics at California State University, Los Angeles. Over the past forty years, Peterson's research has monitored the evolution of the forensic sciences, documenting their growing potential as well as their shortcomings. His research has focused on the uses and effects of scientific evidence at key decision points in the criminal justice system. His work has also explored the quality of crime laboratory results via proficiency testing of examiners, problems associated with the placement of crime laboratories within law enforcement agencies, and ethical dilemmas faced by forensic scientists practicing in an adversarial justice system. Peterson's 2002 and 2005 Census(es) of Publicly Funded Forensic Crime Laboratories for the Bureau of Justice Statistics have documented high caseloads, lengthy backlogs, and severe budgetary and personnel needs. He recently completed two NIJ studies examining the role and impact of scientific evidence in the criminal justice process. Peterson received the Distinguished Fellow Award from the American Academy of Forensic Sciences in 2008.

Amicus **D. Michael Risinger** is a graduate of Yale College and Harvard Law School. He is a life member of the American Law Institute, and a past chair of the Association of American Law Schools' Evidence Section. He was for 25 years a member of the New Jersey Supreme Court Committee on Evidence, and is currently a member of the Human Factors Subcommittee of the National Commission on Forensic Science. He is the author of two chapters in West's *Modern Scientific Evidence* ("Handwriting Identification" and "A Proposed Taxonomy of Expertise"), and also of articles on a range of subjects, including many articles on expert evidence issues, and on the convicted innocent.

Amicus **Michael J. Saks** is Regents Professor at the Arizona State University where he is on the faculty of the Sandra Day O'Connor College of Law and the Department of Psychology, and is a fellow in the Center for Law, Science, and Innovation. Previously, he was the Edward F. Howrey Professor of Law and Professor of Psychology at the University of Iowa. He has taught courses in scientific evidence to appellate judges in the University of Virginia Law School's LL.M. program and Duke's "Judging Science" program, as well as to law faculty at Georgetown University and Ohio State University. His research interests include forensic science and the law. Saks's is the most-cited research in the NAS report, *Strengthening Forensic Science in the United States*. Among over 200 other publications, he has been co-editor/co-author of *Modern Scientific Evidence* (five volumes) and the *Annotated Reference Manual on Scientific Evidence, Second*. His work has earned a number of awards and has been cited in various judicial opinions, including several by the United States Supreme Court. In addition to his Ph.D., Saks earned an M.S.L. from the Yale Law School.

Amicus **George F. Sensabaugh, Jr.** is Professor Emeritus of Biomedical and Forensic Sciences in the School of Public Health at the University of

California, Berkeley; he also teaches at UC Davis where he is a member of the Graduate Group in Forensic Science. His research interests include the application of the biosciences in forensic science, particularly as applied in sexual assault investigation. He is also engaged in research on the comparative population genetics of staphylococci. Sensabaugh served on the two NAS Committees on DNA Technology in Forensic Science (1988-1992 & 1994-1996) and on the NAS Committee on Assessing the Research Program of the National Institute of Justice (2006-2010). He has served on the editorial boards of several forensic science journals. His professional memberships include the California Association of Criminalists, the American Academy of Forensic Sciences (Paul L. Kirk Award, 1987), and the International Society for Forensic Genetics (President, 18th International Congress, 1999). He holds a B.A. from Princeton University and a Doctor of Criminology from UC Berkeley.

Amicus **Clifford Spiegelman** is Distinguished Professor of Statistics, Texas A&M University. He holds a Ph.D. in statistics and applied mathematics from Northwestern University. Spiegelman's major research interests include applications of statistics to chemistry, proteomics, the environment, transportation, and the forensic sciences. He was a member of the National Academy of Sciences panel that evaluated the validity of comparative bullet lead analysis and published its findings as, *Forensic Analysis: Weighing Bullet Lead Evidence* (2004). He is the head organizer of the National Science Foundation's Statistics and Applied Mathematics Institute's 2015-2016 program on Forensic Science.

Amicus **Hal Stern** is Ted and Janice Smith Family Foundation Dean and Professor of Statistics in the Donald Bren School of Information and Computer Sciences at the University of California, Irvine. He received a B.S. degree in mathematics from MIT and an M.S. and Ph.D. in statistics from Stanford University. His research focuses on Bayesian statistical methods and on applications of statistics in the physical, biological and social sciences. He is a Fellow of the American Statistical Association and the Institute of Mathematical Statistics. He recently finished a term as Applications and Case Studies and Coordination Editor for the Journal of the American Statistical Association. He is a member of the Physics/Pattern Interpretation Scientific Area Committee, part of the Organization of Scientific Area Committees run by the NIST. He served on the NIST-NIJ expert working group that produced the report *Latent Print Examination and Human Factors: Improving the Practice through a Systems Approach.*

Amicus **William C. Thompson**, J.D., Ph.D. is a professor at the University of California, Irvine, where he has academic appointments in criminology, psychology and law. He has published extensively on the use and misuse of scientific and statistical evidence in the courtroom and on jurors' reactions to such evidence. His research has been funded by the National Science Foundation and the National Institute of Justice. He is a member of the Human Factors Subcommittee of the National Commission on Forensic Science and is vice-Chair of the Human Factors Committee of the Organization of Scientific Advisory

Committees (OSAC), a federal standards-setting organization for forensic science that is jointly sponsored by the U.S. Department of Justice and the NIST.

Amicus **James L. Wayman** received a Ph.D. in Engineering from the University of California, Santa Barbara in 1980 and has worked continuously in the field of automated human recognition since 1984. From 1997-2000, he was Director of the U.S. National Biometric Test Center. He has served on three National Research Council committees and is currently the Vice-Chair of the Forensic Speaker Recognition Subcommittee within the DOJ/NIST OSAC. He is a Fellow of the IEEE and the IET and has 34 peer-reviewed publications.

Amicus **Sandy Zabell** is a Professor of Mathematics and Statistics at Northwestern University. He received his A.B. from Columbia University, and both an A.M. in Biochemistry and Molecular Biology, and a Ph.D. in Mathematics from Harvard University. He is a Fellow of the American Statistical Association and the Institute of Mathematical Statistics. He is currently a member of the Subcommittee on DNA Analysis 2 (interpretation) of the NIST OSAC; the Scientific Advisory Board of the Washington, DC, Department of Forensic Sciences; and is a member of the American Statistical Association's Ad Hoc Committee on Forensic Science.

Amicus **Ross E. Zumwalt,** M.D., is a Medical Investigator and Professor of Pathology. He received his B.A. from Wabash College, Crawfordsville, Indiana and his M.D. from University of Illinois College of Medicine. He had a pathology residency at the Southwestern Medical School, Dallas and forensic fellowship training at the Dallas County Medical Examiner's Office. He served in the military as director of laboratories at the Navy Regional Medical Center in Camp Lejeune, North Carolina. Dr. Zumwalt has also served as a Deputy Coroner in Cleveland, Ohio (2 years); Deputy Coroner in Cincinnati, Ohio (6 years); Medical Examiner for the State of New Mexico (1987-present); and Chief Medical Examiner for the State of New Mexico (1990-2014). Dr. Zumwalt is certified in anatomic and forensic pathology by the American Board of Pathology; was a Trustee of the American Board of Pathology (1993 to 2004); was President of the American Board of Pathology (2000); was President of the National Association of Medical Examiners (1995-1996); and was a Member of the Committee on Identifying the Needs of the Forensic Science Community, National Academy of Sciences (2006-2009).

CONCLUSION

For all of the foregoing reasons, *amici* respectfully request that the Court grant *amici*'s application and accept the enclosed brief for filing and consideration.

CASE NO. S223651
(PRIOR SUPREME COURT CASE NO. S189275)

**IN THE SUPREME COURT
OF THE STATE OF CALIFORNIA**

William Joseph Richards,
Petitioner,

VS.

Robert A. Fox, Warden, California Medical Facility, and
California Department of Corrections and Rehabilitation,
Respondents.

ON PETITION FOR WRIT OF HABEAS CORPUS
APPEAL FROM THE DECISION OF THE COURT OF APPEAL,
FOURTH APPELLATE DISTRICT, DIVISION TWO,
HABEAS CASE NO. E049135
(PRIOR COURT OF APPEAL CASE NO. E024365)
ON APPEAL FROM THE SUPERIOR COURT, COUNTY OF SAN BERNARDINO,
HABEAS CASE NO. SWHSS700444
(PRIOR TRIAL CASE NO. FVI00826)

HONORABLE MARGARET POWERS (RET.)

***AMICI CURIAE* BRIEF OF MICHAEL J. SAKS, THOMAS ALBRIGHT, THOMAS L. BOHAN, BARBARA E. BIERER AND 34 OTHER SCIENTISTS, STATISTICIANS AND LAW-AND-SCIENCE SCHOLARS AND PRACTITIONERS IN SUPPORT OF THE PETITION FOR WRIT OF HABEAS CORPUS BY WILLIAM JOSEPH RICHARDS**

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OVERVIEW

This Brief begins by explaining that beliefs about the capacity of bitemark comparisons to accurately identify the source of a questioned bitemark have moved from a period of widespread skepticism (before the mid-1970s) through one of widespread credulity to the current growing return to doubt. It explains that those doubts are based on an emerging recognition that the field stands on a foundation of very thin scientific support – if any at all. A growing body of scientific research and analysis concerning the unsupported claims of bitemark identification are cited, as well as the conclusions of a committee of the National Academy of Sciences regarding bitemark identification.

Part I of the Brief explains the general logic of forensic identification. Part II discusses the claims of bitemark identification against that background of general principles. Part III focuses on studies assessing the accuracy of bitemark identification.

The numerous scientific issues discussed in the course of the Brief are encapsulated immediately following this Overview, in a section titled Summary of Scientific Issues.

SUMMARY OF SCIENTIFIC ISSUES

As detailed in this Brief, the following issues are central to the ability to accurately associate an injury on human skin to the dentition of a specific individual. Yet they have not been validated. Some have been refuted by existing research. Others remain matters of speculation by forensic dentists attempting bitemark identifications.

Recognizing a bitemark. Is an injury on skin a bitemark or some other type of injury? Objective criteria for making such determinations have not yet been developed, so each examiner makes his or her best judgment. With how much agreement do forensic dentists make this basic determination? Recent research indicates a high disagreement rate. How accurate any such determinations are remains unknown.

Qualities of skin as a substrate. The underlying claim of bitemark identification is not only that all dentitions are unique; it is that every bitemark in skin produced by those dentitions can be associated only with themselves and not be confused with any other dentition. Yet both research and casework observations have confirmed that a single set of teeth creates a range of different markings from one bite to the next. The image of dentition that is recorded also changes owing to stretching or twisting of skin at the time a bite is imposed, reactions of flesh to injury, influences of the environment, the position of the body part as a bitemark is observed, and other factors.

Methods for visualizing and comparing. Assuming the problems already described can be solved, which methods of visualizing and comparing bitemarks with dentition are most reliable and valid and under what circumstances? Are some methods currently in use so undependable that they ought not to be continued in use?

Evaluating similarity between a bitemark and dentition. No criteria exist to guide forensic dentists regarding the inclusion/exclusion of a person's dentition as one that could have made the bite markings observed. As criteria are proposed, the reliability and validity of the inclusion/exclusion judgments they foster need to be empirically tested.

Observer effects. The limited information in, and ambiguity of, bitemarks in skin make the task of bitemark identification vulnerable to well-established "observer" (or "context") effects. What that means is that, below the level of their own awareness, observers tend to resolve ambiguities in the direction of confirming what they are expecting or hoping to see. Forensic dentists have not adopted procedures for protecting their work from errors resulting from such cognitive distortions.

Evaluating the meaning of an inclusion. When a suspect's dentition is similar enough to a bitemark to be judged an "inclusion," how probative is that opinion of an inference that the suspect's dentition actually created the bitemark? Conventionally, forensic dentists relied "on the theory that each person's dentition is unique." It now is recognized that evidence does not support the speculation that dentitions are unique from each other and not confusingly similar. It is now understood that speculations about uniqueness are unsupported by research or any known theory. An alternative, and scientifically sound, basis for evaluating an observation of similarity between a bitemark and suspected biters needs to be developed, but work on the problem has not begun. Though no scientific basis exists for asserting that any particular person is "the only person in the world" who could have made the bitemark at issue, such unwarranted assertions have been common in the testimony of forensic dentists.

Reliability and validity of odontological decisions regarding bitemark source. Finally, how reliable and valid are the decisions of forensic dentists when they opine that a given suspect dentition is the source of a bitemark? Very little research exists on this essential question, but what does exist produces results that can only be regarded as worrisome.

INTRODUCTION

Amici submit this Brief not to suggest how the Court should apply its jurisdiction's law to the case at bar. Rather, the Brief's purpose is to provide the Court with relevant background knowledge regarding the nature, history, and current scientific status of bitemark identification.

Beliefs about the capacity of bitemark comparisons to accurately identify the source of a questioned bitemark have followed a trajectory from widespread skepticism through widespread credulity to a growing return to doubt. That growing doubt is based on the emerging realization that the field stands on a quite limited foundation of scientific fact,[1] that there is "a lack of valid evidence to

1 Committee on Identifying the Needs of the Forensic Science Community National Research Council, *Strengthening Forensic Science in the United States: A Path Forward* (2009) (hereinafter, NAS Report). The original, and parent, organization, created by Congress in 1863, during the administration of

support many of the assumptions and assertions made by forensic dentists during bite-mark comparisons,"[2] and that error rates by forensic dentists are perhaps the highest of any forensic identification specialty still being practiced.[3] In sum, bitemark testimony has been "introduced in criminal trials without any meaningful scientific validation, determination of error rates, or reliability testing…."[4]

Abraham Lincoln, is the National Academy of Sciences. One of its major sub-units is the National Research Council, through which "the NAS provides objective, science-based advice on critical issues affecting the nation." http://www.nasonline.org (last visited June 9, 2015).

2 Iain Pretty & David Sweet, *The Scientific Basis for Human Bite Mark Analyses – A Critical Review,* 41 Science & Justice 85, 85 (2001). *See also* Mary A. Bush & Peter J. Bush, *Current Context of Bitemark Analysis and Research, in* Bitemark Evidence: A Color Atlas and Text § 6-303 (Robert B.J. Dorion ed., 2010) (2d ed. 2010); Ademir Ranco et al., *The Uniqueness of the Human Dentition as Forensic Evidence: A Systematic Review on the Technological Methodology*, Int'l J. Legal Med. (Nov. 15, 2010); Iain A. Pretty & David J. Sweet, *Digital Bitemark Overlays—An Analysis of Effectiveness,* 46 J. Forensic Sci. 1385 (2001); NAS Report, at 176; Paul Gianelli, Edward J. Imwinkelried and Joseph L. Peterson, Reference Guide on Forensic Identification Expertise, Federal Judicial Center, *Reference Manual on Scientific Evidence* (3d ed. 2011) (hereinafter, FJC Reference Manual); C. Michael Bowers, *Identification from Bitemarks, in* Modern Scientific Evidence: The Law and Science of Expert Testimony (David L. Faigman et al. eds, 2014) (hereinafter, Modern Scientific Evidence Chapter).

3 The findings of studies testing bitemark examiners' ability to correctly identify the source of bitemarks are reviewed, *infra*. The text's allusion to forensic techniques "still being practiced" refers to several forms of forensic science (voiceprint identification, comparative bullet lead analysis, and a large number of arson "indicators") that have ceased to be offered to courts following reviews by scientific bodies finding them to lack validity, though prior to those reviews they had frequently been admitted into evidence by courts.

4 NAS Report, at 108.

Those realizations have been taken up most prominently in the work of a committee of the National Academy of Sciences, which reviewed the scientific support for the claims of bitemark identification, among others, and found serious deficiencies.[5] The Committee on Identifying the Needs of the Forensic Science Community was co-chaired by Judge Harry Edwards, of the U.S. Court of Appeals for the D.C. Circuit, who described the Committee's work:

> [The Committee spent] more than two years... listening to testimony from and reviewing materials published by countless experts, including forensic science practitioners, heads of public and private laboratories, directors of medical examiner and coroner offices, scientists, scholars, educators, government officials, members of the legal profession, and law enforcement officials. Not only were we trying to understand how the forensic science disciplines operate, we were also trying to determine the extent to which there is any... scientific research to support the validity and reliability of existing forensic disciplines; in particular, we were looking for scientific studies that address the level of accuracy of forensic disciplines that rely on subjective assessments of matching characteristics. We invited experts in each discipline to refer us to any such research....[6]

The Committee completed its work and issued its Report in 2009. Several observations and conclusions can be drawn from the Report relevant to evaluating asserted bitemark identification expertise, including the following.

Bitemark identification was seen as a field in which "forensic science professionals have yet to establish either the validity of their approach or the

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[5] NAS Report.

[6] Harry T. Edwards, *Solving the Problems that Plague the Forensic Science Community*, 50 Jurimetrics J. 5 (2009)

accuracy of their conclusions, and the courts have been utterly ineffective in addressing this problem."[7]

"Although the majority of forensic odontologists are satisfied that bite marks can demonstrate sufficient detail for positive identification [of a perpetrator], no scientific studies support this assessment...."[8] "[T]he scientific basis is insufficient to conclude that bite mark comparisons can result in a conclusive match."[9]

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7 NAS Report, at 53.

8 NAS Report, at 176.

9 NAS Report, at 175. Though no scientific basis exists for identifying any particular person as the one and only possible source of a bitemark, such unwarranted assertions have been common in the testimony of forensic dentists. Illustrative of many other case are the following.

In the capital rape-murder trial of Ray Krone in Arizona, two forensic dentists testified: "The teeth of Ray Krone did cause the injuries on the body of [the victim] to a reasonable degree of medical certainty. This represents the highest order of confidence that no other person caused the bite mark injuries." "I'm certain [of the identification]." (Figure 1 shows one of the evidence photographs from that case, comparing a mold of Krone's dentition to a bitemark on the murder victim. Ten years after being sentenced to death, Krone was exonerated by DNA.)

At the Wisconsin trial of Robert Lee Stinson, a board-certified, ABFO diplomate concluded that the bitemarks "had to have been made by teeth identical" to Stinson's, and that there was "no margin for error" in his conclusion. (After 23 years in prison, Stinson was exonerated by DNA.)

At a preliminary hearing in Michigan, the forensic dentist testified that Anthony Otero was "the only person in the world" who could have caused the bitemarks on the victim's body. (A month later, DNA testing excluded Otero as the perpetrator.)

One reason for doubts about "the value and scientific validity of comparing and identifying bite marks"[10] is the unsatisfactory nature of skin as a substrate for registration of tooth impressions: "Unfortunately, bite marks on the skin will change over time and can be distorted by the elasticity of the skin, the unevenness of the bite surface, and swelling and healing. These features may severely limit the validity of forensic odontology."[11] This aspect of bitemark identification sets it apart from other types of forensic pattern-comparison techniques.

"There is no science on the reproducibility of the different methods of analysis that lead to conclusions about the probability of a match. This includes reproducibility between experts and with the same expert over time. Even when using the guidelines, different experts provide widely differing results and a high percentage of false positive matches of bite marks using controlled comparison studies."[12]

The NAS Committee recognized the work of cognitive scientists whereby, when viewing ambiguous information, the observer's mind tends to see what the observer expects or hopes to see.[13] Ambiguities are resolved as being consistent

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[10] NAS Report, at 173.

[11] NAS Report, at 174.

[12] NAS Report, at 174.

[13] *See*, D. Michael Risinger et al., *The* Daubert/Kumho *Implications of Observer Effects in Forensic Science: Hidden Problems of Expectation and Suggestion*, 90 Cal. L. Rev. 1 (2002); Itiel Dror et al., *Contextual Information Renders Experts Vulnerable to Make Erroneous Identifications*, 156 Forensic Sci. Int'l 74 (2006). The NAS Report called for further research regarding this problem.

with expectations, and bitemark experts do not generally employ procedures for preventing such errors: "[F]orensic odontology suffers from the potential for large bias among bite mark experts in evaluating a specific bite mark in cases in which police agencies provide the suspects for comparison and a limited number of models from which to choose from in comparing the evidence. Bite marks often are associated with highly sensationalized and prejudicial cases, and there can be a great deal of pressure on the examining expert to match a bite mark to a suspect. Blind comparisons and the use of a second expert are not widely used."[14]

In concluding that "[m]ore research is needed to confirm the fundamental basis for the science of bite mark comparison," the NAS Report summarized "[s]ome of the basic problems inherent in bite mark analysis and interpretation" as follows:

> (1) The uniqueness of the human dentition has not been scientifically established.
>
> (2) The ability of the dentition, if unique, to transfer a unique pattern to human skin and the ability of the skin to maintain that uniqueness has not been scientifically established.
>
>> i. The ability to analyze and interpret the scope or extent of distortion of bite mark patterns on human skin has not been demonstrated.
>>
>> ii. The effect of distortion on different comparison techniques is not fully understood and therefore has not been quantified.

[14] NAS Report, at 175.

(3) A standard for the type, quality, and number of individual characteristics required to indicate that a bite mark has reached a threshold of evidentiary value has not been established.[15]

I. THE LOGIC OF FORENSIC IDENTIFICATION - GENERALLY

Forensic identification, including bitemark identification, involves two indispensable steps.[16] The first step is to compare the crime scene markings to the possible sources of that mark.[17] The examiner compares images of the questioned markings to those from the known and makes a judgment about whether they differ to an extent that the suspect should be excluded as the source, or that the similarities seem so great that the suspect should be included in the pool of possible contributors. In the case of crime scene markings created by one object leaving markings of itself on another object – such as a fingerprint onto a surface, a firearm barrel onto a bullet, or teeth onto skin – the faithfulness of the transfer from the original to the receiving surface, and the ability of the receiving surface to retain the impression unchanged, are essential to the probativeness of the comparison of the mark on the receiving surface to a suspected source.

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15 NAS Report, at 175-76.

16 Allan Jamieson, *The Philosophy of Forensic Scientific Identification*, 59 Hastings L.J. 1031 (2008).

17 In regard to DNA, what we refer to as "markings" or "marks" would be equivalent to the visualizations of the DNA – at one time in the form of autorads, now as electropherograms.

A. Problems with Declaring a "Match"

In comparing the images of the questioned and the known, if examiners are left to their own subjective judgment of how similar two images need to be in order to declare them similar enough to be included in the pool, then inconsistencies will occur when different examiners look at the same evidence. The less well the criteria are defined and held in common among examiners, the more rife with inconsistency their work will be.[18]

The description in the preceding paragraph is careful to avoid using the term "match." Though employed with decreasing frequency, that word is still in wide use and is unexpectedly troublesome. The term has multiple meanings in the forensic context, which are easily conflated. The term risks misleading factfinders into believing the expert's conclusion is more certain than pattern-matching conclusions can be.

One meaning has to do with observation. It says that the questioned and the known images share many similar features. This observation is almost never (and perhaps literally never) that the two images are identical, or indistinguishably alike. Differences are always present in all forensic pattern matching. Part of the examiner's task is to try to decide which differences can safely be disregarded as unimportant and which similarities are of significance. Here, one might say, "they

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[18] Research, described *infra*, suggests a high degree of inter-examiner inconsistency among bitemark examiners.

match" – if that statement simply means that the questioned and the known are highly similar in appearance.

A second meaning has to do with inference. The examiner's ultimate goal is to try to infer whether the questioned and the known "share a common source." Did the finger that made the file print make the latent print? Did the gun that fired the crime scene bullet fire the test bullet? In line with this meaning, one would like to say, "it's a match" – that is, the one and only source of the crime scene evidence has been identified.

Such a conclusion can never be reached in more than a probabilistic sense, and for that reason the assertion of a "match" to mean a definite inference of common source is misleading. It is impossible to know how many other sources could have made marks as similar to the crime scene mark as the one under examination. The most that can justifiably be said is that the known image belongs to a pool containing an unknown number of other objects that can produce images with very similar characteristics. This is precisely why DNA typing produces "random match *probabilities*" (RMPs) rather than assertions that "the" source of the crime scene DNA has been found. The RMPs provide the best available sense of the probability that a randomly selected person's DNA would "match" the crime scene DNA (in addition to that of a suspect whose DNA profile has been found to "match").[19]

Upon hearing an expert witness state that an assertedly scientific process has determined that the questioned and the known are "a match," factfinders can be forgiven for mistakenly thinking the identification is more certain than it is capable of being.[20]

A third meaning of the word "match" had been used until recently by forensic dentists. The American Board of Forensic Odontology's[21] official guidelines for testifying to bitemark comparison opinions approved use of the term "match" to mean: "Some concordance, some similarity, but no expression of specificity intended; generally similar but true for large percentage of population."[22]

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19 To say that every object of forensic interest is unique (that they can always be distinguished from each other, or that one can never be mistaken for another), are statements of speculation, not of empirical science. As a prominent population geneticist explained, "It is impossible to prove any human characteristic to be distinct in each individual without checking every individual, which has not been done." David J. Balding, *Weight-of-Evidence for Forensic DNA Profiles* 54 (2005).

20 At the same time, when one knows enough about the distribution of object attributes in the population, and the relevant probabilities in the case at hand are known (or believed on good grounds) to be sufficiently small, it is not irrational for a decision-maker to conclude that the known and the questioned probably do share a common source.

21 American Board of Forensic Odontology, Diplomates Reference Manual (January 2013), hereinafter referred to as the ABFO.

22 Modern Scientific Evidence Chapter.

Upon hearing that a suspected source and a crime scene object "matched," laypersons in one study interpreted that term to indicate the strongest linkage (even though it was intended to be the weakest linkage) of any of the terms then available to forensic dentists for expressing their sense of the association between a bitemark and a suspect's dentition.[23] In the current ABFO Diplomates Reference Manual (2013), the term "match" has been eliminated as an acceptable term for expressing opinions about bitemark source attribution.[24]

To avoid the misunderstandings from which the term "match" suffers, this brief tries to avoid its use as much as possible. When that is not possible, we try to use it carefully.

B. Evaluation of an Inclusion

If the decision reached by the examination process is inclusion of the suspected source, the next step is to evaluate the meaning of that inclusion. Its probativeness depends upon how many other members of the population could also have produced markings with a very similar appearance to the crime scene marks.

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23 Dawn McQuiston & Michael J. Saks, *Communicating Opinion Evidence in the Forensic Identification Sciences: Accuracy and Impact*, 59 Hastings L.J. 1159 (2008).

24 In the current ABFO Diplomates Reference Manual (January 2013), the term "match" has been eliminated as an acceptable term for expressing an opinion about bitemark source attribution.

This evaluation is done most transparently in the methods of DNA comparison for single-source crime stains, where sampling of the relevant population has been conducted and informs examiners about the frequency of occurrence of the alleles being compared. That information allows calculation of the "random match probability" ("RMP"), that is, the probability that a random member of the population has the same DNA profile as that collected at the crime scene. The more people in the population with the same profile (the larger the RMP), the less probative is the fact of the suspected source having the same profile. The fewer people in the population who share the profile (the smaller the RMP), the more probative is the fact of the suspected source having the same profile as the crime scene DNA.

Thus, some estimate of the size of the sub-population that shares a profile with the crime scene mark is necessary to evaluate the meaning of a "match." That is not to say it must be done just as DNA typing does it. But without some method for evaluating the meaning of a suspected source having similar appearance to the crime scene evidence, a factfinder has no way to gauge how probative that fact is, and might be misled by testimony saying only that a suspected source has been judged to "match" the crime scene mark – in whatever terms that fact might be expressed.

Because the forensic identification process is fundamentally probabilistic, absolute statements of identification are insupportable. "[T]he scientific basis is insufficient to conclude that bite mark comparisons can result in a conclusive match."[25] Thus, any opinions expressed in terms suggesting pinpoint identification – such as "identification to the exclusion of all others," "indeed and without doubt," "certainty," "perfect match" – have been properly criticized by numerous authorities as exceeding what the forensic identification process is capable of.[26] Such extreme opinions are (now) disapproved by the ABFO as well: "Terms assuring unconditional identification of a perpetrator, or without doubt, are not sanctioned as a final conclusion."[27] At the same time, in contradiction, the ABFO currently permits a conclusion that a suspect is "The Biter," which is an expression of unconditional identification. And, prefatory to all of the currently approved conclusions,[28] the ABFO requires: "*All opinions stated to a reasonable degree of dental certainty.*"[29]

Recently, a subcommittee of the National Commission on Forensic Science has proposed that the Commission issue a caution against the use of the expression,

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[25] NAS Report , at 175.

[26] NAS Report (at numerous points in the Report).

[27] ABFO Diplomates Reference Manual (2013), at 119.

[28] ABFO Diplomates Reference Manual (2013), at 119.

[29] ABFO Diplomates Reference Manual (2013), at 119 (emphasis in original). *See also* Brandon L. Garrett & Peter J. Neufeld, *Invalid Forensic Science Testimony and Wrongful Convictions*, 95 Va. L. Rev. 1, 68 (2009) (pointing out that, despite forswearing insupportable extreme opinions, the ABFO guidelines allow "members to give conclusions expressing near certainty. Examples of the conclusions they may draw include that a bite mark matches a criminal defendant to a 'reasonable medical certainty,' 'high degree of certainty,' and 'visual certainty with no reasonable possibility that someone else did it.'").

"to a reasonable scientific certainty," or its discipline-specific variants, to characterize an expert opinion: "It is the view of the National Commission on Forensic Science that the scientific community should not promote or promulgate the use of this terminology." The National Commission on Forensic Science subcommittee explained that the expression has no scientific meaning and tends to be misleading to factfinders because it asserts certainty.[30]

Exaggerated testimony expressing conclusions about pattern-comparison evidence – that is, testimony that exceeds what a field's knowledge and techniques can support – led the FBI to agree to review approximately 2500 cases worked from 1972-1999 by its own microscopic hair examiners. With about half the cases reviewed, "by the FBI's count examiners made statements exceeding the limits of science in about 90 percent of testimonies, including 34 death-penalty cases."[31]

II. BITEMARK IDENTIFICATION IN LIGHT OF THE LOGIC OF FORENSIC IDENTIFICATION

Against the background of forensic identification more generally, the special difficulties of bitemark identification can be more readily appreciated.

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[30] National Commission on Forensic Science, *Testimony Using the Term "Reasonable Scientific Certainty"*, U.S. Dep't of Justice (Apr. 2013). The proposed admonition apparently is aimed at witnesses and not courts because: "The Commission recognizes the right of each court to determine admissibility standards, but expresses this view as part of its mandate to 'develop proposed guidance concerning the intersection of forensic science and the courtroom.'"

[31] Spencer S. Hsu, *FBI Admits Flaws in Hair Analysis Over Decades*, Wash. Post, Apr. 18, 2015.

A. The Source of the Bitemark

When trying to identify a decedent who has a full mouth of teeth by comparing those to dental records, a great deal of information is available:

> The human adult dentition consists of 32 teeth, each with 5 anatomic surfaces. Thus, there are 160 dental surfaces that can contain identifying characteristics. Restorations, with varying shapes, sizes, and restorative materials, may offer numerous additional points of individuality. Moreover, the number of teeth, prostheses, decay, malposition, malrotation, peculiar shapes, root canal therapy, bone patterns, bite relationship, and oral pathology may also provide identifying characteristics.[32]

But when trying to identify the source of a bitemark, only a fraction of that information is available: "[I]n the typical bite mark case, all 32 teeth cannot be compared; often only 4 to 8 are biting teeth that can be compared. See Figure 2, which presents molds of the dentition from two different people (drawn from a sample of 500) whose six front teeth are indistinguishably alike. Similarly, all five anatomic surfaces are not engaged in biting; only the edges of the front teeth come into play."[33] Moreover, the amount of information contained in the dentition involved in creating a bitemark is far less than that contained in fingerprints, DNA, and most other forms of forensic identification. Thus, the process of bitemark identification begins with a serious disadvantage relative to other types of forensic evidence: less information from the unknown specimen with which to work.

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[32] FJC Reference Manual, at 104-105.

[33] FJC Reference Manual, at 106.

B. The Substrate onto Which a Bite Pattern is Transferred

The potentially identifying information contained in the teeth that create a bitemark has to be captured by the material (the substrate) into which the bite is impressed. If the image of the bitemark in skin is undependable and unstable, then examiners cannot know whether they are looking at a true picture of the dentition that created the bitemark, or a distorted picture.[34]

In the crime context where bitemarks are found, that substrate usually is skin. Skin is a poor substrate for recording the pattern of teeth. It is far less able than the modern dental materials used in dental offices to capture and dependably retain the features of, say, a tooth being replaced by a crown. Skin is a visco-elastic material. The elastic property means that indentations left by teeth will rebound, leaving potentially no record of the three dimensional structure of the biting edges of teeth. This reduces the information that may be used for comparison. The analysis then might typically consist of comparison of a bruise to a dental model. Because a bruise consists of diffusion of blood from crushed capillaries, no precise measurements can be made for comparison.

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[34] Under most circumstances, this distortion should lead to more false negative errors than to false positives. On the other hand, if the bitemark has not been accurately recorded in the flesh, and will not match the actual biter, it sometimes can match, or be made to match (through manipulations used to "correct" distortions), the dentition of other persons. R.G. Miller et al., *Uniqueness of the Dentition as Impressed in Human Skin: A Cadaver Model*, 54 J. Forensic Sci. 909 (2009).

To further complicate the situation, biting in the criminal context typically occurs during struggles, during which skin is stretched and contorted at the time the bitemark is created. When the skin returns to its normal shape, the resulting image of the biter's dentition can be distorted to an unknown extent. Figure 3 of this Brief illustrates what can happen when a marking is placed on skin that has been stretched and the skin then returns to its normal shape. Similarly, the position in which body parts are positioned post-mortem can change the shape of the bitemark. Figure 4 illustrates this problem with an actual bitemark on the skin of a human cadaver.

In addition, live flesh reacts to injury, becomes inflamed, changes shape, and swells as healing begins. After death, changes in the skin and flesh occur due to decomposition, animal predation, insect activity, embalming, and environmental factors as well as other processes.

The pliability, elasticity and reactivity of skin and flesh all create a major challenge for bitemark identification and set it apart from other kinds of pattern-comparison forensic identification. As the NAS Report concluded in regard to these substrate problems: "These features may severely limit the validity of forensic odontology."[35]

[35] NAS Report, at 174.

C. Methods of Comparison

When a forensic dentist undertakes to compare a questioned bitemark with a suspect's dentition, numerous techniques exist and are recognized by the ABFO Guidelines, including drawing bitemark images by hand. "The issue of the multiple methods of bitemark analysis continues to thwart any attempts to standardize procedures to any sort of 'gold standard.' The use of digital methods in the superimposition of bitemark evidence appears to be increasing, although the older, more experienced forensic dentists still seem to resist the use of two dimensional computer methods."[36]

Although there has been some research comparing techniques, finding some to be significantly better than others at facilitating the visualization of bitemark-to-dentition similarities and differences,[37] the Guidelines do not specify criteria under which one method might be preferred to another. And, in any event, there is no oversight, so forensic dentists are free to use whichever method they happen to be familiar with or prefer.

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36 Modern Scientific Evidence Chapter; *see also* NAS Report, at 174-175; ABFO Diplomates Reference Manual (2013).

37 E.g., David Sweet & C. Michael Bowers, *Accuracy of Bitemark Overlays: A Comparison of Five Common Methods to Produce Exemplars from a Suspect's Dentition*, 43 J. Forensic Sci. 362 (1998) (finding differences in accuracy as a function of method and recommending that forensic dentists cease using hand drawings of a suspect's teeth and increased use of digital images of dental characteristics).

Nor has the field of forensic odontology developed inclusion/exclusion criteria. Each examiner is left to form his or her own judgment about which features of the bitemark to compare and whether to declare a (suspected) bitemark and a suspect's dentition to be so similar that the examiner should declare an inclusion. Absent from bitemark analysis are "precise and objective criteria for declaring matches," considered to be essential elements of any field of forensic identification.[38]

D. Lack of Data on Population Frequencies

To this point, we have addressed potentially insurmountable difficulties in bitemark identification that involve nothing more than the seemingly straightforward task of comparing a questioned bitemark to a suspect's dentition. Assume, however, an optimal case: sufficient information from source dentition exists and has been impressed upon a stable substrate on a victim's body; that sound methods have been employed to visualize and compare the bitemark on the victim and a suspect's dentition; that valid criteria have been developed for deciding when to include and when to exclude dentition as a possible source; and that a forensic dentist has reached a justifiable conclusion that the images were sufficiently similar to include. The next step would be to assess what that decision

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[38] Eric S. Lander, *Fix the Flaws in Forensic Science*, N.Y. Times, Apr. 21, 2015 (arguing "[n]o expert should be permitted to testify without showing three things: a public database of patterns from many representative samples; precise and objective criteria for declaring matches; and peer-reviewed published studies that validate the methods").

can tell a factfinder about the likelihood that the suspected person's dentition did in fact produce the bitemark. As discussed earlier, such an evaluation depends upon estimating the frequency of similar patterns in the relevant population.

Unfortunately, forensic dentists have very little information of the kind needed to make an informed assessment. "If a bite mark is compared to a dental cast using the guidelines of the ABFO, and the suspect providing the dental cast cannot be eliminated as a person who could have made the bite, there is no established science indicating what percentage of the population or subgroup of the population could also have produced the bite."[39] Actual probabilities are not known because no population studies have been carried out to determine what features to consider, much less the actual degree of variation in teeth shapes, sizes, positions, etc., that exist in the population.[40] Work to remedy this shortcoming is at an early stage.[41]

Recent studies, however, have cast light on the risk of erroneously calling similar dentitions a "match" by establishing "match" rates among dental populations using methods of measurement resolution that are better than can

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[39] NAS Report, at 174.

[40] *Id.*

[41] L. Thomas Johnson et al., *Quantification of the Individual Characteristics of the Human Dentition*, 59 J. Forensic Identification 609 (2009) (reporting one original study, observing that, "Very few studies have been published on the quantification of dental characteristics," and noting that, "Expansion of the sample size through collaboration with other academic researchers will be necessary to be able to quantify the occurrence of these characteristics in the general population.").

possibly be achieved with marks on skin. In these studies, a "match" was defined as specimens that could not be determined as distinguishable within measurement error.[42] A fundamental conclusion from these studies was that as any database of dental arrangement increases in size, the probability of one dental arrangement matching another one increases. This was especially true in analysis of orthodontically treated dentitions, in which dental arrangements are purposely made homologous.[43] The latest of these studies (n=1099) documented the most common patterns of dental mal-alignment three-dimensionally in a large population. This study also found that the effect of increasing distortion (reducing measurement resolution) was that dramatically larger numbers of dentitions "matched."[44] In short, these recent studies indicate that, given relatively large numbers of people with seemingly unusual mis-alignments of teeth, compared

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[42] Mary A. Bush et al., *Statistical Evidence for the Similarity of the Human Dentition*, 56 J. Forensic Sci. 118 (2011); H.D. Sheets et al., *Dental Shape Match Rates in Selected and Orthodontically Treated Populations in New York State: A Two Dimensional Study*, 56 J. Forensic Sci. 621 (2011); Mary A. Bush et al., *Similarity and Match Rates of the Human Dentition In 3 Dimensions: Relevance to Bitemark Analysis*, 125 Int'l J. Leg. Med. 779 (2011); H.D. Sheets et al., *Patterns of Variation and Match Rates of the Anterior Biting Dentition: Characteristics of a Database of 3D Scanned Dentitions*, 58 J. Forensic Sci. 60 (2013). Measurement error, and thus the resolution of measurement of the dental arrangement, was quantified by repeated measurements of the same specimen, followed by analysis of the scatter of the measurement points. Resolution was determined to be 120 microns, or slightly more than one tenth of a millimeter.

[43] Sheets et al., *Dental Shape Match Rates*, *supra* note 42.

[44] Sheets et al., *Patterns of Variation*, *supra* note 42.

using the relatively poor resolution of teethmarks on skin, the risk of false positive errors is quite real.

In the absence of data concerning population frequencies of dental characteristics, how have forensic dentists assessed the value of an inclusion? One way has been to speculate or guesstimate about the population frequencies of the characteristics of biting teeth. A forensic dentist might judge a bitemark to have been made by a pattern of teeth that seems unusual in his or her experience. On occasion, a source's teeth are so unusual that they are obvious outliers; then, when a suspect's teeth are deemed closely similar (a well-defined bitemark, impressed into a stable substrate), the probability is smaller that a different person will have produced the bitemark.[45] Nevertheless, a forensic dentist's placing too much faith in the apparent unusualness of a source dentition has led to known erroneous convictions. There is no escaping the fact that forensic identification is an essentially probabilistic endeavor. For the great majority of bitemarks, however, population frequencies will necessarily be higher than in the very unusual cases, and the risk of erroneous identification greater.[46]

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45 *See* Gerald L. Vale et al., *Unusual Three-Dimensional Bite Mark Evidence in a Homicide Case*, 21 J. Forensic Sci. 642 (1976).

46 The high error rates for bitemark identification, described *infra*, likely are in part caused by a tendency toward under-guesstimation by forensic dentists of the probability that multiple members of a population will match a questioned bitemark.

E. Uniqueness

The conventional solution to the problem of assessing the meaning of a "match" has been to assume uniqueness. "Identification of a suspect by matching his or her dentition with a bite mark found on the victim of a crime rests on the theory that each person's dentition is unique."[47] But as the uniqueness assumption has increasingly come to be recognized as unproved and unsound, it also has ceased to serve as a viable solution to the problem of how to evaluate the meaning of a high degree of similarity between a bitemark and a suspect's dentition.

Two different concepts are expressed by the notion of bitemark "uniqueness."[48] One is the claim that no two dentitions duplicate one another in absolutely every respect. This has been termed "mere uniqueness." An even stronger claim is being made by forensic dentistry: not only that all dentitions are unique, but also that every bitemark produced by those dentitions can be associated only with themselves and not with any other dentition. If this claim were true, it would indeed be possible to conclude that a dentition found consistent with a mark is the source of that mark. But we know from the substrate problems described, above, and from systematic empirical research as well as observations

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[47] FJC Reference Manual, at 104.

[48] Simon A. Cole, *Forensics without Uniqueness, Conclusions without Individualization: The New Epistemology of Forensic Identification*, 8 Law, Probability and Risk 233 (2009).

by practicing forensic dentists, that repeated bites by the a single set of dentition produces very different bite markings.

The advantage of adopting and asserting the assumption of uniqueness is that it obviates the need to collect, analyze, and employ information about the population distribution of dentitions and bitemark characteristics. Much of the hard work of empirical research can be dispensed with. If no two dentitions belonging to different persons can possibly produce bitemarks that are indistinguishably alike or confusingly similar, then a judgment that a questioned bitemark looks much like a suspect's dentition is assumed to mean that the suspect is *the* source of the bitemark, not merely a member of a pool containing some unknown number of possible contributors.

The problem with the assumption of uniqueness is that it is nothing more than *ipse dixit.* The NAS Report on forensic science stated: "No thorough study has been conducted of large populations to establish the uniqueness of bite marks; theoretical studies promoting the uniqueness theory include more teeth than are seen in most bite marks submitted for comparison. There is no central repository of bite marks and patterns. Most comparisons are made between the bite mark and dental casts of an individual or individuals of interest. Rarely are comparisons made between the bite mark and a number of models from other individuals in addition to those of the individual in question."[49] In sum, "The committee received

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[49] NAS Report, at 174.

no evidence of an existing scientific basis for identifying an individual to the exclusion of all others."[50]

A recent review sought to examine all empirical research aimed at determining whether all human dentition is unique.[51] Following an extensive bibliographic database search, 13 studies were found and each was reviewed in detail. None was able to support a conclusion of dental uniqueness. Nine of the studies explicitly failed to find uniqueness. Four claimed to have succeeded, but were found to be methodologically incapable of supporting the asserted conclusions. Four additional studies[52] found specimens in the study populations that were indistinguishable within measurement resolution – that is, their differences did not exceed the margin of error for the study population.

These findings bring the notion of dental uniqueness, central to bitemark analysis, into considerable doubt. As the assumption of uniqueness fades away, so does the claim that bitemark comparison can dependably link a bitemark to its source.

In light of these developments, the ABFO has recently backed away from the theory of uniqueness and the associated notion of identification-to-the-

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[50] NAS Report, at 176.

[51] Franco et al., *supra* note 2.

[52] *See supra*, note 42.

exclusion-of-all-others.[53] The ABFO has gone so far as to suggest that any attempt to narrow identification to a single individual has to be limited to cases involving "closed populations" – that is, cases in which only a small number of known persons could have been in a position to inflict the questioned bite. Forensic dentists then need only distinguish among the dentition of a handful of known people, not speculate about tens of millions of unknown dentitions.[54]

III. HOW ACCURATE ARE BITEMARK IDENTIFICATIONS?

The empirical research described in this section is noteworthy, first, for how little of it there is and, second, for how much of what does exist refutes the claims of forensic dentists regarding their ability to identify the source of a bitemark.

A. Measuring Error - Generally

In the context under discussion, decision error consists of two distinct types: a *false positive*, which is a decision that a bitemark came from a specific set of teeth when in fact it was made by other teeth. And a *false negative*, a decision that

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53 The most recent editions of the ABFO Diplomates Reference Manual state that the identification of a single biter from an open population of possible biters is no longer sanctioned.

54 Even here, the rhetoric has again gotten ahead of any empirical research on the issues involved. Moreover, if investigators are mistaken about access being limited to all but the identified suspects, then we are back to an open population, only we don't know it. Furthermore, even the "closed population" approach does not preclude errors of erroneously identifying an innocent suspect as the perpetrator. See the Gordon Hay case in Scotland. Case review presented at the 2000 meeting of the Forensic Science Society by Dr. Allan Jamieson.

a bitemark did not come from a specific set of teeth, when in fact it did. However the forensic comparisons are reported – "match," "consistent with," "cannot exclude" – the opinions would all be classified as false positives if the "ground truth" is that the bitemark did not actually come from the teeth of the suspect.[55]

False negative errors could occur for many reasons – some pertaining to the circumstances of the bite and the substrate receiving the bite, some pertaining to the medium the examiner is using to visualize the questioned and known patterns (e.g., photographs under different lighting conditions), others pertaining to the decision-making machinery of the examiners. Careful research would need to be designed in order to isolate the various possible causes of the errors and to try to develop ways to reduce errors stemming from those causes. Similarly, false positive errors could occur for a variety of reasons, pertaining to different aspects of the bite sources, tools for and conditions of visualizing the bitemarks, or the perceptual and decision characteristics of examiners.

Although the terms *reliability* and *validity* often are used interchangeably by laypersons, it is useful to maintain the distinction used by scientists and statisticians.[56] Scientists and statisticians distinguish between and separately

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[55] This approach to "accuracy" comes from the field of signal detection theory. Propounded in the 1960s in such works as D.M. Green and John A. Swets, *Signal Detection Theory and Psychophysics*, Vol. 1 (1966).

[56] *See Daubert v. Merrell Dow Pharms., Inc.*, 509 U.S. 579, 590 n.9 (1993) (discussing the distinction and stating, "In a case involving scientific evidence,

measure reliability and validity. *Reliability* is the extent to which a measuring instrument (including human examiners) produces the same results again and again when it measures the same thing repeatedly. Intra-examiner (or within-examiner) unreliability refers to the same examiner giving different answers on different occasions when examining the very same evidence. Inter-examiner (or between-examiner) unreliability refers to different examiners examining the same evidence and reaching different conclusions about it.

Reliability concerns only consistency of measurement. It does not address whether a measurement is correct. *Validity* is concerned with the question of whether a measuring instrument (including the judgments, decisions, and opinions of humans) is generating correct answers. Five forensic dentists might all agree on whether or not a suspect's dentition made a bitemark (high reliability), but they might all be incorrect (low validity).[57]

B. Recent Research on Reliability

The ABFO recently sponsored and conducted a reliability study of the judgments of experienced, board-certified forensic dentists making very basic

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evidentiary reliability will be based upon *scientific validity*.") (emphasis in original).

[57] This is not a fanciful illustration. In the 1984 Forensic Sciences Foundation handwriting proficiency test of handwriting experts, all of the examiners taking the test independently reached the same conclusion that a particular writer was not the author of a particular questioned document (100% reliability), but they were all incorrect (0% validity). Summarized in D. Michael Risinger, *Handwriting Identification, in* Modern Scientific Evidence: The Law and Science of Expert Testimony (David L. Faigman et al. eds. 2013).

decisions about bitemarks.[58] The researchers selected 100 photographs of suspect bitemark injuries from actual cases. These were examined by 38 ABFO-certified forensic odontologists having an average of 20 years' experience in bitemark identification.

The 38 examiners were asked to review the injuries in each of the 100 photographs and respond to three very basic questions. As will become apparent, the greater the degree of agreement among the examiners, the more reliability is indicated (that is, repeatability of judgments by different examiners), and the lower the rate of agreement, the less reliable their judgments are. No one can know which answers were right or wrong (that is, this was not a test of validity). We can know only the extent to which they agreed or disagreed with each other.

Question 1: Is there sufficient evidence in the presented materials to render an opinion on whether the patterned injury is a human bite mark? Findings: For only four of the 100 cases did all examiners agree on whether an opinion could be reached on whether an injury was a bitemark or not. For half of the cases there

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58 These results were presented at the annual meeting of the 2015 American Academy of Forensic Sciences, held in Orlando, Florida, in February. ABFO officials have indicated that they do not wish the results published until further research has been conducted. However, the researchers supplied the raw data to a number of people, and we draw from their descriptions of it. The one published description is found in Radley Balko's *A Bite Mark Matching Advocacy Group Just Conducted a Study that Discredits Bite Mark Evidence*, Wash. Post, Apr. 8, 2015.

was less than 71% agreement. For one quarter of the cases there was less than 47% agreement.

Question 2. Is it a human bite mark, not a human bite mark, or suggestive of a human bite mark? Findings: In about a quarter of the cases, fewer than half of the examiners agreed on whether the injury was or was not a bitemark. In 71 of the 100 cases, fewer than 70% agreed on whether the injury was a bitemark.

Question 3. Does the bite mark have distinct, identifiable arches and individual tooth marks?

By the time they reached Question 3, the examiners were already widely divided from each other in their opinions. Those who did not think the injury photograph contained enough information to make a decision did not opine on whether it was or was not a bitemark. Those who did not think the injury was a human bitemark would not be addressing whether individual tooth marks were identifiable.

Taking all three questions together, for just under half of the cases, half or fewer of the examiners agreed on the same trio of responses. For only 14 of the 100 cases did at least 80% of the examiners agree on the trio of responses.

Although no one knows which answers of which examiners were correct or not (the validity question), one can be sure that many answers were incorrect since contradictory answers cannot all be correct. The reliability of a measuring instrument sets an upper limit on its possible validity.

The study just described suggests that on this earliest threshold issue – before any of the other difficulties of bitemark *comparison* have to be confronted – bitemark analysis has not been shown to be reliable (let alone valid). Put simply, if dental examiners cannot agree on whether or not there is enough information in an injury to determine whether it is a bitemark, and cannot agree on whether or not a wound is a bitemark, then there is nothing more they can be relied upon to say. Unless and until they can do this threshold task dependably, there is no other aspect of bitemark identification that can be counted upon to produce dependable conclusions.

C. Studies of Forensic Dentists' Accuracy in Simulated Bitemark Lineups

Over the approximately four decades in which forensic dentists have been testifying in courts claiming the ability to accurately identify the individuals who were the sources of bitemarks, remarkably few tests have been carried out to assess their accuracy. While there have been hundreds of studies of eyewitness accuracy, and many dozens of proficiency tests of forensic examiners in other fields, forensic dentists have been tested only a handful of times.

Such tests as exist present practitioners with bitemarks to compare under circumstances where those conducting the study know which answers are correct and which are incorrect.

The earliest of these tests were conducted in the mid-1970s by forensic dentist David Whittaker.[59] Exemplar bites were made on pigskin. Note that pigskin is a more stable material for recording and retaining a bitemark than living human skin, so that tests using pigskin as the substrate would likely overstate the accuracy obtained by bitemark examiners. Incorrect identifications of the bites made in the Whittaker study ranged from 24% under ideal conditions to 91% when identifications were made from photographs taken 24 hours after the bites were made (which is more typical of how bitemark comparisons are done). Whittaker commented that, "the inability of examiners to correctly identify bitemarks in skin … under *ideal* laboratory conditions and when examined immediately after biting suggests that under sometimes adverse conditions found in an actual forensic investigation it is unlikely that a greater degree of accuracy will be achieved."

The ABFO conducted several "workshops" in which forensic dentists could test their identification skills. Only the 1999 workshop results have been made public. In that test, "All 95 board certified diplomates of the American Board of Forensic Odontology were eligible to participate in the study. Of the 60 diplomates who requested and were sent the study material, 26 returned the

[59] David K. Whittaker, *Some Laboratory Studies on the Accuracy of Bite Mark Comparison*, 25 Int'l Dent. J. 166 (1975).

necessary data by athe deadline [six months after receiving the test materials] and were included in the data results."[60]

All four of the "questioned" bites were made by biters whose identity was known. Three consisted of materials from actual cases (in which the biter's identity was established by independent means), and the fourth was a bite into cheese. Each of those bitemarks was compared to what in effect was a lineup of seven bites. Overall, examiners were in error on nearly half of their responses, more of those being false positive errors (identifying a non-biter as being the biter) than false negatives (failing to identify the actual biter).[61]

In 2001, in the course of evaluating digital overlays as a technique for comparing known and questioned bitemarks, forensic dentists Iain Pretty and David Sweet observed levels of error by examiners that troubled them: "While the

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60 Our description of the study and its findings is taken from the Modern Scientific Evidence Chapter on bitemark identification.

61 Out of a possible maximum error rate of 27%, examiners had a median overall error rate of 12.5%, for an error rate that in effect was 46%. Forensic dentist Michael Bowers, in Modern Scientific Evidence Chapter, explains why caution is needed in counting errors in such tests:

> Once one set of dentition is linked (correctly or incorrectly) to a bitemark, the others are not linked, and therefore are scored as "correct." In other words, given the test design, an examiner could never make more than two mistakes, and all remaining dentitions are scored as "correct." If instead of providing a set of seven dentitions from which to choose, there had been 100, then the overall accuracy rate, using this seemingly straightforward method of counting, could never be lower than 98% correct—one false positive inculpation of an innocent suspect, one overlooked guilty suspect, and 98 remaining dentitions that get scored as "correct." And, thus, the poorest possible performance would be "2% error."

overall effectiveness of overlays has been established, the variation in individual performance of odontologists is of concern."[62] Using board-certified forensic dentists to evaluate the test bitemarks (made in pigskin), the study found that intra-examiner agreement (agreement with one's own prior judgments given three months earlier) ranged as low as 65%. False positive responses (affirmatively linking a bite to a person who had not made the bite) averaged 15.9% (and ran as high as 45.5%) while false negatives (failing to link a bite to the person who actually made it) averaged 25.0% (and ran as high as 71.4%).

Blackwell and colleagues in 2007 examined forensic dentists' analyses of bitemarks using 3D imaging and quantitative comparisons between human dentitions and simulated bitemarks, with the bitemarks recorded in acrylic dental wax – a far better substrate for bitemark comparisons than human skin – and false positive error rates still ran as high as 15%.[63]

D. Studies of Bitemarks in a Cadaver Model

Another line of simulation research sought to understand the "accuracy" of skin as a substrate for recording bitemarks. Mary and Peter Bush of the School of Dental Medicine at the State University of New York at Buffalo, along with

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[62] Iain A. Pretty & David J. Sweet, *Digital Bitemark Overlays—An Analysis of Effectiveness*, 46 J. Forensic Sci. 1385 (2001) (cautioning that the "[p]oor performance" is a cause of concern because of its "very serious implications for the accused, the discipline, and society," at 1390).

[63] S. Blackwell et al., *3-D Imaging and Quantitative Comparison of Human Dentitions and Simulated Bite Marks*, 121 Int'l J. Legal Med. 9 (2007).

statistician David Sheets, have produced an extensive body of research.[64] They obtained access to a reliable supply of fresh cadavers. They designed a biting machine to inflict bites that could be fitted with various cast dentitions from their reference collection, and proceeded to apply multiple bites from the same and different dentitions to different areas of cadaveric skin. They then analyzed the resulting bitemarks and compared them to the dentitions in their collection, using digitized modeling and various statistical techniques.

The first major finding was that, due to the anisotropic[65] properties of skin, no two bitemarks inflicted by the same dentition appeared the same.[66] If bitemarks

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64 Mary A. Bush et al., *Biomechanical Factors in Human Dermal Bitemarks in a Cadaver Model*, 54 J. Forensic Sci. 167 (2009); R.G. Miller et al., *Uniqueness of the Dentition as Impressed in Human Skin: A Cadaver Model*, 54 J. Forensic Sci. 909 (2009); Mary A. Bush et al., *The Response of Skin to Applied Stress: Investigation of Bitemark Distortion in a Cadaver Model*, 55 J. Forensic Sci. 71 (2010); Mary A. Bush et al., *Inquiry into the Scientific Basis For Bitemark Profiling and Arbitrary Distortion Compensation*, 55 J. Forensic Sci. 976 (2010); H.D. Sheets & Mary A. Bush, *Mathematical Matching of a Dentition to Bitemarks: Use and Evaluation of Affine Methods*, 207 Forensic Sci. Int'l 111 (2011); Mary A. Bush et al., *A Study of Multiple Bitemarks Inflicted in Human Skin by a Single Dentition Using Geometric Morphometric Analysis*, 211 Forensic Sci. Int'l 1 (2011); H. Holtkoetter et al., *Transfer of Dental Patterns to Human Skin*, 228 Forensic Sci. Int'l 61 (2013). These were the first studies in the bitemark field to investigate and summarize the biomechanical and structural properties of skin, including the J-shaped curve that describes the stress-strain relationship.

65 To have physical properties that are different in different directions.

66 The same conclusion was expressed recently by two prominent bitemark practitioners testifying about their casework: Frank Wright, testifying in *State v. Prade*, No. CR 1998-02-0463, 2013 WL 658266 (Ohio Com. Pl. Jan. 29, 2013), *rev'd* 2014-Ohio-1035, 9 N.E.3d 1072 ("No two bitemarks that I've ever seen from the same biter on the same victim look the same.") David Senn, testifying

are not reproducible, then doubt increases about the evidentiary reliability of bitemark analysis. Both the biomechanical properties of human skin and the way it reacts to biting result in marks that often can be seen and characterized as fitting multiple different sets of dentition even within the researchers' rather small reference sample (measured in the hundreds). The *apparently* "matching" dentitions frequently did not include the dentition that actually did the biting, and the *actually* "matching" dentitions frequently were not similar to each other.

These findings suggest that accurate source attributions (that is, determining which dentition made which bite), is likely to require the bites to have been in more stable substrates (such as wax or cheese). The degree of distortion found in the marks on skin was such that even large variations in tooth arrangements did not faithfully transfer, making profiling (prediction of dental characteristics) unreliable. In addition, the level of distortion was often far above the measurement resolution of dental shapes (discussed above), allowing a potential "match" of numerous dentitions in any given population.

To better understand the implications of this line of work, it is helpful to keep in mind the range of possible substrates. At one extreme is the kind of material used in dental offices to create molds of patients' dentition. That material is designed to receive and hold impressions of teeth with a high degree of accuracy

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in *New York v. Dean*, 04555 CR2007 (N.Y. Sup.Ct., June 12, 2012) ("They are surprised… when the same teeth make bitemarks and they all look different, well we've known that forever."). (Transcripts on file with author.)

and stability. There is nothing better for the purpose. At the other extreme are elastic and unstable substances that cannot capture details and that subsequently change shape, distorting the tooth impression as they do. Skin, as a substrate, is closer to the latter extreme. The research described above used cadavers. Because the skin of cadavers lacks the vital response, and does not undergo the changes caused by inflammatory reactions – while most bitemarks encountered by courts have been imposed on living victims – it is important to appreciate that the substrate used in the research is more stable, closer to the dental office material end of the spectrum than living flesh is. Consequently, the research is more conservative in that by employing a more stable substrate it obtained *more accurate* impressions than can be found in criminally inflicted bites. Moreover, it did so under more controlled conditions, preventing the distortion and slippage due to movement that occurs in a criminal struggle. Put simply, if the research found worrisome levels of variability in bitemarks and erroneous "matches," then bites from actual criminal cases will suffer from more extreme imperfections and be that much more prone to error.

E. Conclusion and Implications

For many years, concerns about the difficulty of linking bitemarks on the skin of crime victims to their source prevented forensic dentists from offering such identification opinions to courts. The research described above underscores the wisdom of that earlier caution.

Before 1974, forensic dentists limited their work to identifying victims of mass disasters. They refrained from trying to identify the source of bitemarks on the skin of crime victims because the challenges of identifying the source a bitemark seemed to them prohibitively daunting. "The two tasks differ in important ways. In the disaster situation, there is a finite number of candidates to identify, and full dentition often is available from the victims as well as from the dental charts. In forensic bitemark cases, the number of potential suspects is huge, the bitemarks include only a limited portion of the dentition, and flesh is a far less clear medium than having the teeth (of the disaster victim) themselves."[67] Crime scene bitemarks contain only a fraction of the information available from the full dentition of mass disaster victims, and the limited dental information that is available is neither clear (because flesh is a poor medium for recording bitemarks) nor dependably accurate (because of the elasticity of flesh and the distortion to which it is subject at the time of and after receiving the bite).

A single case became the exception that swallowed the rule. In *People v. Marx*[68] three forensic dentists saw what they regarded as a rare exception to the

[67] Modern Scientific Evidence Chapter, Sec. 37:1, note 2.

[68] 54 Cal. App. 3d 100 (1975). *Marx* was decided under California's version of *Frye v. United States*, 293 F. 1013, 1014 (D.C. Cir. 1923), which remains California law. Recently, however, the California Supreme Court incorporated a *Daubert*-style analysis into California jurisprudence in *Sargon v. University of Southern California*, 55 Cal. 4th 747 (2012). *See also* David L. Faigman & Edward J. Imwinkelried, *Wading into the Daubert Tide: Sargon Enterprises, Inc. v. University of Southern California*, 64 Hastings L.J. 1665 (2013).

then generally accepted rule among forensic dentists that crime scene bitemarks could not be trusted to yield accurate source identifications. The three dentists took pains to note that in many other cases they had refused to opine on the source of crime scene bitemarks (for the reasons described above). But this case, they felt, was a rare exception to the general rule. The teeth that made the bitemark were highly unusual. The bitemark was exceptionally well defined and three-dimensional because it was in cartilage, not the soft tissue of other body areas where bitemarks usually are found. The forensic dentists characterized these bite impressions as the clearest they had ever seen, either personally or in the literature.[69]

Marx became the paradoxical seed from which most, and perhaps all, subsequent decisions about admissibility of bitemark expert testimony grew. Although the experts in *Marx* agreed to testify only because they regarded its facts as a rare exception to the field's general belief that accurate source identification was not possible using bitemarks in flesh – and the court of appeals in *Marx* affirmed admission because of that rarity – subsequent cases ignored that critical distinction. *Marx* was used to support the far more general proposition that typical bitemarks in typical flesh could typically be associated with their sources with a high degree of accuracy. *Marx* came to stand for the very empirical proposition

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[69] Gerald L. Vale et al., *Unusual Three-Dimensional Bite Mark Evidence in a Homicide Case*, 21 J. Forensic Sci. 642 (1976).

that the experts in the case, and in their field, had up to that point in time rejected.[70]

In short, the *Marx* decision transformed forensic dentistry's view of its own value to the courts. Forensic dentists had not persuaded the courts of their ability to identify the source of a bitemark; indeed, they had not even tried to do so. Rather, by expanding *Marx* far beyond the borders of its facts, and by admitting bitemark expert testimony "wholesale" and without serious scrutiny, the courts persuaded forensic dentists that what they had to offer was better than the dentists themselves had believed it to be. The wisdom of the field prior to *Marx* was wiped away.

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[70] A prominent treatise on forensic scientific evidence and the law, the lead author of which was himself a former forensic scientist turned legal scholar, summarized those developments in these terms:

> The wholesale acceptance, by the courts, of testimony on bite mark identification has transformed the profession. Whereas prior to 1974 the main thrust of forensic dentistry was to prove identity of persons by means of a comparison of postmortem and antemortem dental records in mass disasters, the profession has changed direction and is now heavily involved in assisting prosecutors in homicide and sex offense cases. Having received judicial approval of bite mark comparisons, there seems to be no more limit on the extent of forensic odontological conclusions.

Andre Moenssens et al., *Scientific Evidence in Civil and Criminal Cases* (4th ed. 1995), at 985.

Another commentator observed: "After *Marx* and [an Illinois case] there was little serious consideration given to bite mark foundational dependability by subsequent courts...." D. Michael Risinger, *Navigating Expert Reliability: Are Criminal Standards of Certainty Being Left on the Dock*, 64 Alb. L. Rev. 99, 138 (2000).

Today, however, the empirical research that does exist confirms the field's earlier judgment that, except in the most unusual circumstances, it lacked the ability to offer reliable and valid bitemark identifications to the courts.

IV. SUMMARY

The scientific community, and society generally, expect that before being offered to courts, and before courts grant broad and unqualified admission, the claims for a field's techniques will have been validated.[71] This validation has not happened for bitemark identification. Moreover, recent reviews of the field's claims, as well as recent empirical findings, have underscored the lack of reliability and validity of the most fundamental claims about the ability of forensic dentists to identify the source of bitemarks on human skin.

A committee of the National Academy of Sciences concluded that bitemark identification testimony has been "introduced in criminal trials without any meaningful scientific validation, determination of error rates, or reliability testing…."[72] Two leading forensic dental researchers noted that there is "a lack of

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[71] The scientific perspective is that a field's claims are considered valid only to the extent that they have been empirically tested, using soundly designed research, yielding results that support the claims. That is also the perspective advanced by *Daubert*, supra note 56, as well by *Frye*, supra note 68 (though less explicitly than in *Daubert*).

[72] *Supra* note 4.

valid evidence to support many of the assumptions and assertions made by forensic dentists during bite-mark comparisons."[73]

The claims of forensic dentistry have for decades outrun empirical testing of those claims. Rather than confirming the field's claims, recent research, described in this brief, has confirmed that the foundations of bitemark identification are unsound. Perhaps, in the future, research will be conducted to solve the problems that have been identified, or find that they are not susceptible of solution, or find that the problems are less serious than they appear to be. At present, however, asserted bitemark experts "have yet to establish either the validity of their approach or the accuracy of their conclusions, and the courts have been utterly ineffective in addressing this problem."[74]

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[73] *See* Pretty & Sweet, *Critical Review*, *supra* note 2, at 85.

[74] NAS Report, at 53.

Figure 1. Bitemark Evidence from Trial of Arizona v. Krone.

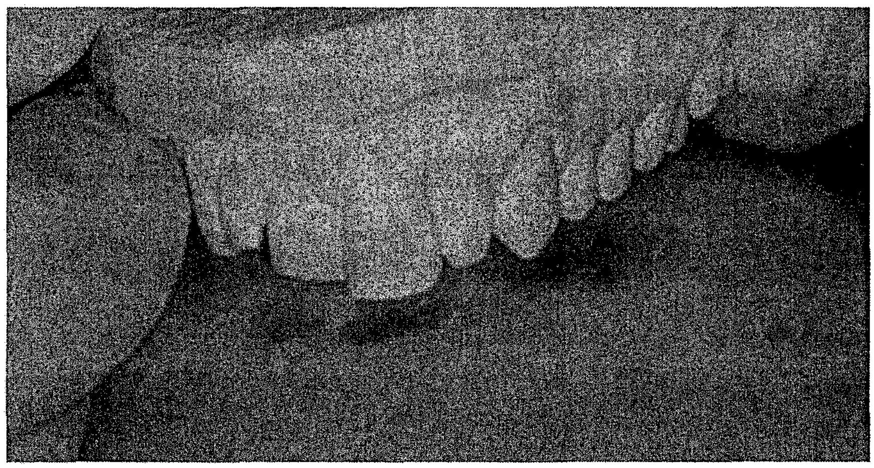


Figure 2. Indistinguishably Similar Dentition. Three-dimensional models of two different people's dentitions in which the six anterior (front) teeth were found to have the same three-dimensional shape, based on measurement error determined by repeated measurement. [From Mary A. Bush & Peter J. Bush, Current Context of Bitemark Analysis and Research, in R.B.J. Dorion (ed.), Bitemark Evidence (2d ed) (2010)]

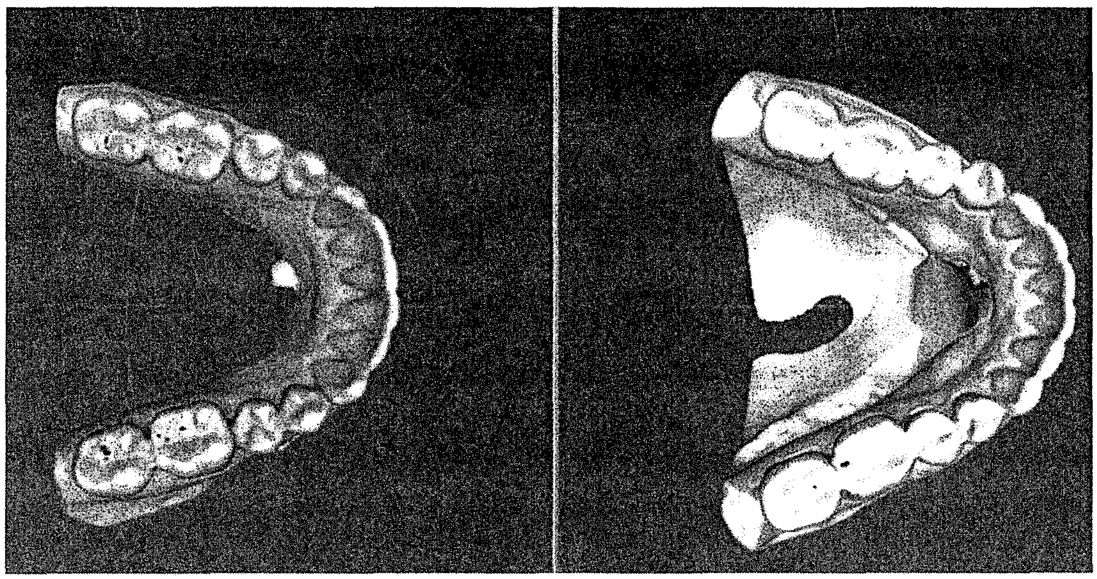


Figure 3. Two Identical Marks on Human Skin. The lower mark has been distorted by applying pressure to the area (duplicating Devore's Test). [From Bite mark Identification, Modern Scientific Evidence, Chapter 37]

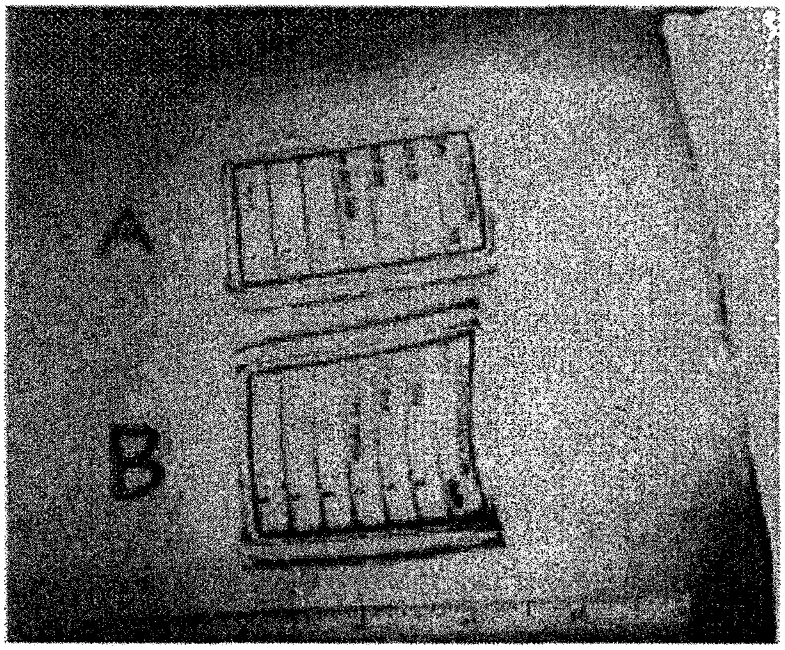
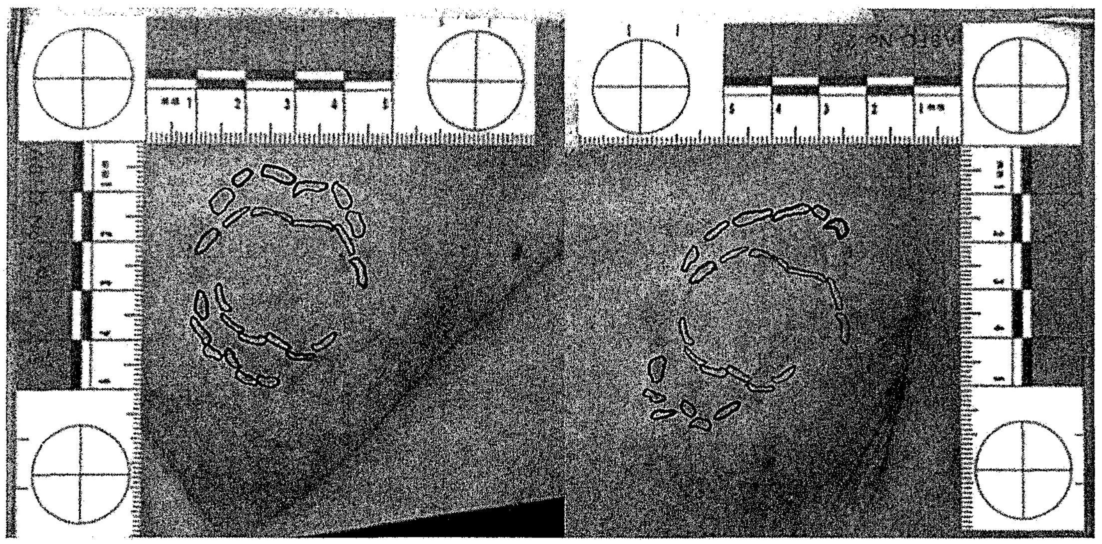


Figure 4. Changes in Bitemark Appearance Depending Upon How the Body Part is Positioned. The bite was inflicted with the arm straight at the side (left). The bitemark is outlined in black for ease of viewing; biter's overlay is in blue. Notice the alteration to the bite pattern when the arm is positioned over the head (right). [Both photos from Bush et al., 54 Journal of Forensic Sciences 167 (2009).]



CERTIFICATE OF WORD COUNT

I, the undersigned, certify that the application consists of 5,058 words and the brief consists of 11,584 words exclusive of those portions of the brief specified in California Rule of Court 8.204(c)(3), relying on the word count of the Microsoft Word computer program used to prepare the application and brief.

Dated: June 16, 2015

Respectfully submitted,

David L. Faigman

PROOF OF SERVICE

I, the undersigned, declare as follows: I am employed in the City of San Francisco and County of San Francisco, State of California; I am over the age of eighteen years and not a party to the above entitled action; my business address is: 200 McAllister Street, San Francisco, CA 94102.

On the date indicated below, I caused the following document(s) to be served:

APPLICATION FOR LEAVE TO FILE *AMICI CURIAE* BRIEF AND *AMICI CURIAE* BRIEF OF MICHAEL J. SAKS, THOMAS ALBRIGHT, THOMAS L. BOHAN, BARBARA E. BIERER AND 33 OTHER SCIENTISTS, STATISTICIANS AND LAW-AND-SCIENCE SCHOLARS AND PRACTITIONERS IN SUPPORT OF THE PETITION FOR WRIT OF HABEAS CORPUS BY WILLIAM JOSEPH RICHARDS

on the following courts and parties, through their attorneys of record, named below, and addressed as follows:

The Honorable Tani Cantil Sakauye, Chief Justice and Honorable Associate Justices Supreme Court of California 350 McAllister Street San Francisco, CA 94102-4797	**California Supreme Court** (13 Copies)
California Court of Appeal Fourth Appellate District, Div. 2 3389 Twelfth Street Riverside, CA 92501 Telephone: (951) 782-2500	**California Court of Appeal** (1 Copy)
The Hon. Margaret A. Powers (Ret.) c/o Clerk of the Court San Bernardino County Superior Court 235 East Mountain View Avenue Barstow, CA 92311	**Trial Court** (1 Copy)
The Hon. Brian S. McCarville c/o Clerk of the Court San Bernardino Superior Court 303 West Third Street San Bernardino, CA 92415	**Trial Court** (1 Copy)

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Robert W. Fox, Warden California Medical Facility 1600 California Drive Vacaville, CA 95696 Telephone: (707) 448-6841	**Respondent** (1 Copy)
California Department of Corrections and Rehabilitation 1515 S Street Sacramento, CA 95811 Telephone: (916) 445-7682	**Respondent** (1 Copy)

( ) BY HAND DELIVERY: I instructed Ace Attorney Service, Inc. to deposit the said documents to the California Supreme Court at the addresses listed above.

( ) BY MAIL: I placed said documents in a sealed envelope to all other parties and the trial and appellate court listed above, with said postage thereon fully prepaid for first class mail, for collection and mailing at a metered depository in San Francisco, California.

( ) BY EMAIL: I emailed the said documents.

( ) BY FACSIMILE: I caused the said document(s) to be transmitted by facsimile machine to the number indicated after the address noted above.

(X) BY FEDERAL EXPRESS: I placed a true and correct copy thereof in a Federal Express (overnight) envelope addressed to the individual named above at the address shown, and by sealing and delivering the aforementioned documents to the Federal Express Drop Box at 100 Montgomery Street, San Francisco, California to be delivered by next day, on this date.

( ) BY PERSONAL SERVICE: I caused the said document(s) to be personally served on the attorneys identified above at the above address on this date.

I declare under penalty of perjury under the laws of the State of California that the foregoing is true and correct.

Executed on June 16, 2015, in San Francisco, CA

David L. Faigman

Exhibit

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The Washington Post

The Watch

A bite mark matching advocacy group just conducted a study that discredits bite mark evidence

By Radley Balko April 8

In February, I posted a four-part series on the forensic speciality of bite mark analysis. The series looked at the history of the field, how it came to be accepted by the courts as scientific evidence despite the lack of any real scientific research to support its basic assumptions, the innocent people who have been convicted based on bite mark analysis and how the bite mark matchers, advocacy groups like the American Board of Forensic Odontology and their supporters have waged aggressive, sometimes highly personal campaigns to undermine the credibility of people who have raised concerns about all of this.

The series ran during the annual American Academy of Forensic Sciences convention in Orlando, Florida. That conference included a presentation by Adam Freeman, who sits on the executive board of the ABFO, and Iain Pretty, who is not a member of the ABFO, has been critical of bite mark analysis and chairs the AAFS committee on forensic odontology.* Freeman and Pretty were to present the results of a study they had designed with David Senn, another ABFO member and a proponent of bite mark analysis.**

Senn in fact was the main witness for New York County Assistant District Attorney Melissa Mourges during a 2013 evidentiary hearing on the scientific validity of bite mark analysis in *State v. Dean*. That hearing was the first to assess the science behind bite mark matching since the field came under fire in a landmark 2009 report by the National Academy of Sciences. Ultimately, Senn and Mourges prevailed. Judge Maxwell Wiley ruled that the evidence could be admitted at Clarence Dean's trial. In fact, to date, every court to rule on the admissibility of bite mark analysis has allowed it to be used as evidence. This, despite an ever increasing number of wrongful convictions, wrongful arrests, and lack of scientific research to support the field, and a new body of research suggesting that its core assumptions are false.

The study

All of this makes the presentation by Pretty and Freeman particularly interesting. In response to mounting criticism, last year the ABFO released a "decision tree" for bite mark specialists to follow when performing their analysis. The "tree" is basically a flow chart. It begins by asking if there is sufficient evidence to know whether or not a suspicious mark is a human bite. It then asks whether it is in fact a bite, then what distinguish characteristics are noticeable in the bite, and so on.

But the problem with bite mark analysis was never the lack of a flow chart. The problem is that there has never been any real scientific research to support its two main underlying premises — that human dentition is unique, and that human skin is capable of registering and recording that uniqueness in a useful way. And the research that *has* been done strongly suggests those two premises are not true. The flow chart was just adding a series of procedures to a method of analysis that is entirely subjective, and that lacks basic scientific quantifiers like probability and margin for error.

Yet the ABFO wanted to show that its flow chart worked. So last year, the organization put together an exam to prove its effectiveness. Pretty and Freeman, with consultation from Senn and others within the organization, gave 39 ABFO-certified bite mark analysts photos of 100 bite marks, then asked them to answer three preliminary questions, all based on the decision tree chart. The average analyst who participated in the study had 20 years experience as a forensic odontologist. Here are the three questions they were asked:

- Is there sufficient evidence in the presented materials to render an opinion on whether the patterned injury is a human bite mark?
- Is it a human bite mark, not a human bite mark, or suggestive of a human bite mark?
- Does the bite mark have distinct, identifiable arches and individual tooth marks?

That last question is asking if, once the analyst has determine that the mark is a human bite, the mark contains enough distinguishing features to be of value as evidence.

Interestingly, the intent of this study was to measure consensus, not whether the analysts were actually correct in their conclusions. Consensus is important, particularly in a field that relies so much on pattern matching and subjective analysis instead of quantifiable data. Consensus also shows predictability, which is also an important characteristic when assessing whether a field is legitimately based in science. There will of course occasionally be cases in which the evidence is ambiguous, but if a cross section of experts from a particular field consistently fail to reach consensus conclusions after looking at the same pieces of evidence, you have to start asking if the field is much more than guesswork.

But it's also notable that there was no effort here to determine the rightness or wrongness of the answers. For example, if 10 out of 10 analysts agree that a mark on human skin is a human bite, that would suggest that the decision tree succeeded at fostering consensus. If only 7 out of 10 agree, that's more troubling. But it would be even *more* troubling if the seven in the majority were also wrong.

The study didn't measure for accuracy in part because the photos were taken from actual cases, so for many of them, whether or not the bite is actually human has never been definitively determined. But as I pointed out in my original series, it's also keeping the field's tendency to be more concerned about methodology than veracity. ABFO conducts its certification exams in a similar manner. The candidates are evaluated only on their method of analysis, not on on whether or not they're actually correct in matching a bite mark to the correct dental mold.

This reflects an ugly reality about the pattern-matching fields of forensics: Because they're so subjective, it isn't difficult for attorneys on either side of a case to find an expert who will testify to the conclusion they're looking for. In these fields then, the most important attribute in a witness is not that they be accurate, but that they *sound* accurate — that they be more convincing to a jury than the expert on the other side. Juries don't like wishy-washy witnesses. They like witnesses who seem sure of themselves, who speak with authority. But in forensic specialties as subjective as pattern matching, certainty is a red flag. Most of the time, an honest witness *should* hedge, speak in probabilities, and avoid definitive conclusions. But this means that the least honest experts can often be the most persuasive, and there's a clear incentive for prosecutors and defense attorneys to seek them out.

Finally, note that this study also did not ask the examinees to actually match a mark to the teeth of an individual human being the way this sort of evidence would be presented in court. (A previous competency test administered by bite mark critic Michael Bowers in 1999 found a 60 percent error rate among the analyst test takers.) It only asked the three preliminary questions above.

So in sum, this study only measured the ability of ABFO-certified experts to come to a consensus, and only on the most basic, preliminary questions about a piece of evidence.

The results

Even within these limited parameters, and even when designed and administered by the field's biggest advocates, this study shows that bite mark analysis fails.

The first question — again, whether the test provided sufficient evidence to determine whether or not the photographed mark was a human bite — isthe most basic question a bite mark specialist should answer before performing an analysis. Yet the 39 analysts came to unanimous agreement on just 4 of the 100 case studies. In only 20 of the 100 was there agreement of 90 percent or more on this question. By the time the analysts finished question two — whether the photographed mark is indeed a human bite — there remained only 16 of 100 cases in which 90 percent or more of the analysts were still in agreement. And there were only 38 cases in which at least 75 percent were still in agreement. (These figure come from my own examination of the raw data, as well as processing of the data done by the Innocence Project.)

By the time the analysts finished question three, they were significantly fractionalized on nearly all the cases. Of the initial 100, there remained just 8 case studies in which at least 90 percent of the analysts were still in agreement.

“These results are really disturbing,” says Paul Giannelli, a law professor at Cast Western Reserve University who specializes in scientific evidence. Giannelli also serves on the National Commission on Forensic Science, started by President Obama to address and remedy the shortcomings in forensic evidence outlined in that 2009 NAS report. “But they aren’t all that surprising. There have been a number of cases over the years in which one bite mark analyst testified that a mark was a human mark, while another testified it was something entirely different, for example a bug bite, or an indentation from a belt buckle.”

Peter Bush, who with his wife Mary heads up the University of Buffalo research team that has cast doubt on the integrity of bite mark analysis (and who has been attacked by the community of bite mark analysts and their supporters for that research), agrees: “When there have been exonerations of people convicted with bite mark evidence, the forensic odontologists have said that the problem is with the analysts — that they’re rogue or incompetent experts who didn’t do the analysis properly. This is just another piece of evidence that’s it’s both of these things. It’s the improper analysis, but it’s also the very nature of the evidence itself.”

To put these results in perspective, it might help to ask what might have happened if a similar exam had been given to specialists from a more science-based field of forensics, such as DNA analysis.

“It would be difficult to set up a DNA test that was exactly the same, but if you could, you’d see overwhelming agreement,” Giannelli says. “I’d expect it to be unanimous. And on the questions where it wasn’t unanimous, you’d be able to go back and find the source of the problem — whether it was tainted evidence, or some glitch in the exam. With bite mark analysis, you can’t really even go back, because it’s just a subjective disagreement over what the analysts are seeing.”

Chris Fabricant, the director of strategic litigation for the Innocence Project who is challenging bite mark evidence in several cases across the country, points to a similar study of fingerprint analysts published in 2011 that found 99 percent agreement. “Contrast that to some of the questions in this study, in which the level of agreement among the analysts was only slightly better than randomness,” Fabricant says.

The reaction

The bite mark community reacted with shock, disappointment, and ultimately an effort to suppress the results of the study. According to reliable sources within the ABFO, David Senn initially wanted to cancel the panel at the AAFS conference in which Freeman and Pretty were to present the results. These sources say Senn was astonished at the results, and told other members of the ABFO that he was "reeling" from them. He also apologized to the organization for his role in the study.

In the end, the organization did proceed with the presentation of the results, but then played down their significance. Newly-elected ABFO president Gary Berman briefly mentioned the study in his quarterly message to the organization's members.

> In order to improve the study of bitemarks the ABFO developed a decision tree to assist practitioners in the proper selection and pathways of analysis in bitemark analysis. The ABFO has conducted preliminary research, presented in Orlando, designed to evaluate the first step of a revised decision tree; statistical analysis of the study showed inconsistent overall agreement among the individuals who participated in the project. The ABFO in reaffirming its commitment to ensure accuracy in bitemark analysis is revising the decision tree to ensure reliable results by forensic dentists and will be conducting additional studies this year.

While it's commendable that the ABFO is attempting to create guidelines that will "ensure reliable results," it's far more troubling that the current guidelines *don't,* that the unreliable results those guidelines produce have for years been used and continue to be used in court, and that rather than running to courtrooms across the country to halt the convictions, imprisonments and pending executions based on the results, the organization continues to fight for its members' ability to testify using the very analysis it now concedes is flawed.

In an email in response to my query, Berman blamed the poor design of the study for the results. "Post analyses of the results indicate that the design of the survey and the design of Step 1 of the decision tree may be flawed, and that an ABFO guideline term may be the root cause," Berman wrote. "The troublesome term, 'suggestive of a human bitemark', is one of the currently recommended terms for confidence that a pattern is or is not a bitemark."

Berman writes that some of the test-takers may have answered the first question in the affirmative (that there was sufficient evidence to show that the mark was a human bite), but then changed their mind as they answered the other questions. He writes, "they were loathe to go back and change the answer to the negative . . . Instead they selected the hedged, and available third choice, 'suggestive of a human bitemark.'"

Berman's explanation raises another common criticism made by skeptics of bite mark evidence, although perhaps he raised it inadvertently: Because so much of their value as expert witnesses relies on their credibility, there's a strong disincentive to change their minds about their conclusions once they've made them, even when new evidence suggests they should. If an analyst is loathe to admit a mistake in an anonymous proficiency study, it doesn't bode well for his ability to admit to a mistake after putting his name and reputation behind court testimony, or in an affidavit leading to an arrest.

Indeed, bite mark analysts have concocted some fantastic theories of culpability even after a suspect convicted based on their testimony was found not to be a match to the semen taken from a victim who was raped, or even to the saliva taken from the bite mark itself. On more than one occasion, for example, a bite mark analyst has confronted a DNA mismatch on semen taken from a rape victim by arguing that someone else must have raped the victim while the suspect implicated by their testimony must have held the suspect down and bit her.

But even more concerning than the results of the study itself, the ABFO has since decided to hold off on publishing those results until the organization can tweak the design of the study and conduct it again, a process that's expected to take at least a year.

"If this were truly a science-based organization, I would not only expect them to be extremely troubled by the results of this study, I would expect them to want to publish the results," says Paul Giannelli. "And sooner rather than later, so that they could be considered in any pending criminal cases in which bite mark evidence is a factor."

The ABFO did release the raw data from the study in spreadsheet form to a few people, but won't release the presentation given at the AAFS meeting, nor will they publish the data in a journal or another publicly assessable format, at least until the completion of the second study. "We are in the process of modifying the decision tree, the language, and then we will be running the study again," Adam Freeman wrote in response to an email query. "The results of both studies will then be sent to the [Journal of Forensic Sciences] for publication.The release of the presentation at this point would be premature. "

Critics like Fabricant are skeptical. "If the results had been more to their liking, I can't imagine that they'd be objecting over the language in their own study, then taking another year or so to rerun the study to get more favorable results before releasing the data. In the meantime, people are suffering in prison. Some are fighting a death sentence."

One of the pending criminal cases is the one mentioned at the start of this post: that of Clarence Dean, which is expected to go to trial sometime this year. As noted above, that case included an important evidentiary hearing in which a New York judge ruled that bite mark evidence is admissible and scientifically valid. Many other judges have made that ruling in the past, but this was the first such ruling since the publication of the NAS report in 2009. The prosecutor in Dean's case is Melissa Mourges, a fierce advocate for bite mark matching who, as I explained in the series in February, has not only advocated for bite mark analysis as a field, but has waged nasty, often highly personal attacks on those who have raised concerns about its legitimacy.

Mourges included a reproduction of the ABFO's "decision tree" in her brief for the bite mark hearing in the Dean case. She cited the tree as another example of the bite mark community's dedication to accuracy:

> An important Guideline revision was added in February 2013 when the ABFO voted to include a bitemark flow chart or decision tree, included below. Properly used, the decision tree will guide forensic odontologists' investigatory paths leading to proper conclusions based on the quality of the bitemark and the teeth of the suspected biters. This new guideline offers specific recommendations for forming degrees of linkage conclusions based on the quality of both injury features and suspected biter dentitions.

Mourges attended the presentation by Pretty and Freeman at the AAFS conference in February. I reached out to the Manhattan DA's office where Mourges works to ask for her official reaction to the study. She didn't respond, but the office did issue a statement from Chief Assistant District Attorney Karen Friedman Agnifilo:

> This study reinforces the importance of basing decisions on the best possible evidence available. The use of forensic odontology, properly performed, has been and continues to be a valuable tool to aid in the identification of assailants and can also be used to help place victims, many of whom are children, out of harm's way. Equally important, forensic odontology is used to exclude and exonerate suspects. Each time an injury is recognized as a bitemark and swabbed, investigators gain both DNA evidence and potential bitemark identification. Forensic odontology differs from DNA evidence in that it may not be dispositive, but it is probative. Undeniably, bitemarks have significant evidentiary value, which is why this type of evidence is admissible in all 50 states.

Agnifilo's statement conflates a lot of issues, and I examined several of the points she makes in the February series. But briefly, few would object to swabbing potential bite marks for DNA. Rather, critics of bite mark evidence fault the attempt to match marks on human skin to human teeth. The fact that bite mark evidence is admissible in all 50 states is convincing only if you believe the courts have done an adequate job of keep bad science out of criminal cases. Part two of the February series argues that they haven't. Agnifilo's point about the quality of the evidence is a good one. But it remains true that even with the most pristine bite mark evidence, there's no scientific research to support the contention that the marks we make with our teeth are individually, or to what extent they're unique, or that, even if they were unique, that human skin is capable of preserving that uniqueness in a way that allows it to be analyzed.

The Manhattan DA's office insistence on standing behind bite mark evidence is interesting in and of itself. Current Manhattan DA Cyrus Vance, Jr., was elected in 2009 on a platform of "community justice," and won endorsements from criminal justice reform advocates — including, interestingly, Peter Neufeld and Barry Scheck, co-founders of the same Innocence Project that is now feuding with Mourges in court. On its website, Vance's office stresses the importance of fairness and sound evidence in preventing wrongful convictions:

> The Manhattan District Attorney's Office spares no effort in seeking justice in every case that comes before it. Through the years and around the country, innocent men and women have been convicted of crimes they did not commit. This not only robs an innocent person of his or her freedom, it leaves a criminal on the street, free to commit more crimes.
>
> To protect New Yorkers and ensure justice, District Attorney Vance created the Conviction Integrity Program in March 2010. The Program is comprehensive in scope, and is unique in purpose: not only does it address claims of actual innocence, it also seeks to prevent wrongful convictions from occurring . . .
>
> The Conviction Integrity Policy Advisory Panel is comprised of leading criminal justice experts, including legal scholars and former prosecutors, who advise the Office on national best practices and evolving issues in the area of wrongful convictions.
>
> The work of the Conviction Integrity Program, combined with the Office's commitment to using the most advanced scientific and investigative tools available, has made the cases brought by the Office stronger for victims and more fair for defendants.

But meanwhile, at least two of Vance's top lieutenants continue to defend a field of forensics that has contributed to at least 24 wrongful convictions and arrests around the country, despite numerous studies showing it lacks any basis in science, including one organized by the field's leading advocacy organization.

Finally, I noted in my original series that last fall, the National Institute for Science and Technology announced the members of the forensic odontology subcommittee that will study the scientific validity of bite mark matching. The committee is one of several that will study various fields of forensics as part of the federal government's push toward reform in light of the 2009 NAS report. Incredibly, 10 of the 16 members are either practicing bite mark analysts, or are open advocates of the practice, including the chairman, Robert Barsley. It's a development one critic of bite mark matching likened to starting a committee to investigate the scientific validity of astrology, then stacking it with astrologists.

Pretty and Freeman's study is a major development in the field of bite mark analysis. It's one you'd think would attract the attention of the committee charged with investigating whether bite mark analysis is suitable for court.

The committee held its first meeting on February 16. The results of the ABFO study were by then well known to the members affiliated with ABFO. According to the webcast and public notes from the meeting, chairman Barsley did include the ABFO "decision tree" in his presentation. He also incorrectly compared the uniqueness of bite marks to fingerprints, and noted that while he couldn't point to a citation of a study showing that human dentition is unique, "there are studies that lead us to believe this is true." (In fact, the only peer-reviewed, scientifically rigorous study of the uniqueness of human dentition has been conducted by Peter and Mary Bush's team, and they've found no basis for that assertion.) Curiously missing from Barsley's presentation was any discussion of the ABFO study showing that the decision tree failed to produce a consensus among even the ABFO's most experienced analysts.

As the ABFO hems and haws on this study and takes another year to redesign it, ostensibly to achieve more favorable results, bite mark evidence continues to be used in criminal cases, and existing bite mark cases continue to move forward. Over the last several months there have been new filings in the death penalty cases of Eddie Lee Howard in Mississippi, and Jimmie Duncan in Louisiana. At least 15 people convicted with bite mark evidence are currently awaiting execution.

Meanwhile, just last week a sheriff in northern Indiana announced that he'll be assembling a "forensic dentistry team" within his department. From the Chicago Tribune:

> Sheriff David Reynolds recently swore in three local dentists as part of the department's forensic dentistry team . . .
>
> The dentists will do everything from matching bite marks with suspects or victims, to using dental records to identify victim's remains, Reynolds said . . .
>
> Over the years, Reynolds has used forensic dentists a number of ways.
>
> "We used them for rape cases, investigating bite marks," he said, as well as for remains . . .
>
> "There were other cases where people were bitten and we were able to take (dental) models and pictures and match them up to bite marks on the victims."

So even as we await the results of the ABFO's do-over on its own study to assess the validity of this field, not only do those convicted due to bite mark analysis remain in prison, law enforcement groups are still using it to win convictions. It's almost as if those 24 exonerations never happened.

(*Forensic odontology or forensic dentistry, includes the controversial field of bite mark matching, but also the more accepted practice of using dental records to identify human remains.)

(**Senn did not respond to my request for comment. In an email, Pretty acknowledged the study, the results, and that the ABFO will be conducting another study to be published next year. But because the study was administered by the ABFO, using ABFO case studies, he wrote that “it would be wrong of me to make any comments on the work beyond those that were made at the AAFS.”)

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Exhibit

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PAPER

ODONTOLOGY

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Expert Interpretation of Bitemark Injuries—A Contemporary Qualitative Study

ABSTRACT: This study attempts to characterize the nature of disagreement among odontologists in determining the fundamental properties of suspected bitemark injuries. Fifteen odontologists were asked to freely comment on six images of supposed bitemarks. Qualitative analysis using a grounded theory approach revealed that practitioner agreement was at best fair, with wide-ranging opinions on the origin, circumstance, and characteristics of the wound given for all six images. More experienced practitioners (>10 years) tended to agree with each other less than those who had 10 years or less experience in forensic odontology. The differences in opinions can be at least partly accounted for by the inconsistent nature of approaches used by different practitioners in assessing bitemark evidence. The results of this study indicate that more definitive guidelines as to the assessment of bitemarks as patterned injuries should be developed to ensure the highest possible level of practitioner agreement.

KEYWORDS: forensic science, odontology, bitemark, Australia, agreement, reliability

There have been several studies to date that try to quantify the accuracy rate of odontologists when it comes to matching bitemarks to known dentitions (1–6). However, there have been none to date that ask the more fundamental questions posed to odontologists, and upon which the rest of their evidence rests—the ability to accurately identify a bitemark from another patterned injury. This is the most fundamental of questions and one upon which several cases have rested in courts of law (7–9).

Most forensic medicine textbooks warn of the dangers of interpretation of cutaneous wound patterns (10). The properties of flexible, living tissue such as skin as a medium add to the difficulties of interpretation of latent marks. Reports in journals have demonstrated that marks from teeth can be easily confused with injuries from other objects such as bottle tops (11); glass bottles, defibrillators (12), and other medical equipment (13); pathological lesions such as ringworm, lupus, pityriasis rosea, and other dermatoses (14,15); not to mention a myriad of other inanimate objects such as the heel of a shoe, childrens' toys, and jewelry (16). Even generic bruising has been demonstrated to sometimes resolve in a "ring" formation, where the center of the bruised area heals first, leaving a ring-shaped pattern of bruising with the passage of time (17). These examples demonstrate that objects that bear little resemblance to the shape of the healing bruise may in fact cause injuries that could be easily mistaken for a bitemark.

While most odontologists would suggest they can determine with a reasonable degree of certainty what is and what is not a bitemark, there is little evidence to support this claim. Whittaker et al. (18) established that there was no significant difference in the ability of senior or junior forensic odontologists to distinguish between an adult or child's bitemark, and that both forensic odontology groups outperformed police, social workers, and general dentists, yet this study says nothing about the fundamental ability of odontologists to decide whether patterned injuries are likely to be bitemarks or not. Simply relying on "experience" as a means of justifying forensic claims, including that of whether injuries are likely to be bitemarks or not, has been criticized widely (19–23). This criticism is particularly warranted when it has been garnered in situations where ground truth has never been known with certainty, as is the case with most legal contexts.

This study attempts to qualify the reliability of odontologists in the most fundamental area of bitemark analysis—that of the ability to identify marks as being of human dental origin. It also addresses, in a more minor way, other fundamental notions of bitemark interpretation that are necessarily performed prior to analysis beginning, including its suitability for spatial analysis and comparison, and its orientation.

Method

As part of a larger project involving an assessment of the practice of bitemark analysis in Australia, the principal author (MP) traveled to various forensic centers around the country to gather data via an interview process with practicing odontologists. Fifteen odontologists in Australia, representing the majority of those who carry out odontology work on more than an occasional basis in this country, agreed to be interviewed as part of this project. Anonymity was protected, and the identities of the participants were known only to the author carrying out the interviews. Random numbers were assigned to each participant as a means of identification using the random-number generator formula in Microsoft Excel. Both written notes and an audio

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recording of each interview were made. All subjects agreed to participate on this basis and were consented in accordance with the University of Newcastle Ethics Committee policies.

As part of the interview, odontologists were shown a series of six bitemarks (Fig. 1). These individual electronic images were from contemporary cases presented at one institution in Australia. None of the cases from which the images were associated were *sub judice*, and none of the interview participants had the opportunity to view or analyze the bitemarks before being shown during the interview. The images were suitably anonymized so as to prevent the participants knowing their origin. All of the images, with the exception of image B, were on living victims, and thus while ground truth is still not necessarily known for certainty, it could be assumed that images A, C, D, E, and F represented actual bitemarks in accordance with corroborative testimony offered by the victim; however, this is not necessarily a certainty.

The bitemark images were loaded into a Microsoft PowerPoint presentation, using a plain black background and labeled A to F. The resolution of each photograph was not changed or enhanced from the original image presented to the odontology department. Participants were shown the images using the full-screen "presentation" feature. They were asked to comment generally on the bitemark and to include as much or as little information as they liked regarding its quality, orientation, origin, or potential use as an identification tool. There was no time limit set, and participants could take as long as they wanted to assess each mark.

Once all six bitemarks had been commented upon, they were then asked to rate each bitemark in accordance with the severity and significance scale developed by Pretty (24). At first, only the written descriptions of each score were given to use as a reference guide (first pass). After all six images had been rated, the participants were then given a laminated color copy of the exemplar marks originally published by Pretty (24) to demonstrate each of the scores. They were then asked to again rate the bitemark images using the visual exemplar provided as a guide to scoring (second pass).

The comments made by each participant were transcribed and then analyzed using a grounded theory methodology. In this technique, participant statements were analyzed for key themes, which were then coded and clustered into groups that shared commonality in meaning (25). Variation between comments for the same bitemark image can then be assessed qualitatively. Fleiss's kappa scores (κ) represent a convenient way of expressing inter-examiner agreement across multiple raters ($n > 2$) for several items. Fleiss's kappa score was calculated to summarize numerically the relative level of inter-examiner agreement in assigning severity and significance scores. Weighted kappa scores were not deemed appropriate for this study due to the use of a qualitative interval scale rather than a pure ordinal scale (26).

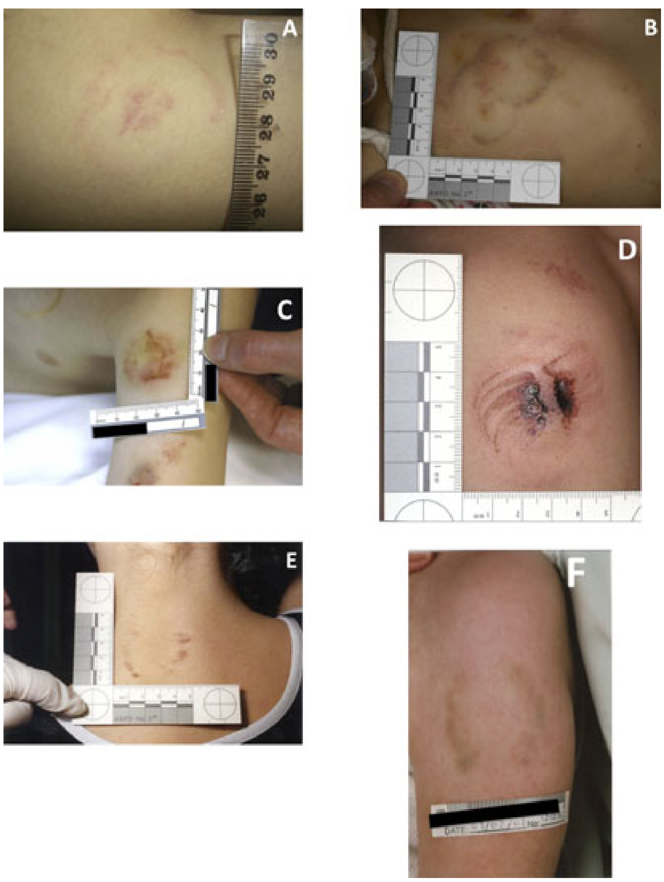

FIG. 1—*Bitemark images presented to interview participants.*

Results and Discussion

Demographics of Odontologists Interviewed

Interviewees were drawn from the members of the Australian Society of Forensic Odontology (AuSFO). While AuSFO is more than 50 members strong, very few of these members regularly conduct casework, and so potential interviewees were limited. Over a period of 18 months, 15 members of the 20 or so that routinely engage in forensic odontology casework in Australia agreed to be interviewed. While this number is relatively small, it still represents the majority of practicing odontologists in Australia.

Individual experience level in the field of forensic odontology varied from 4 years to 35 years. The median level of experience was 19 years, with the mean being 22 years of experience (Table 1). The highest level of postgraduate qualification attained (specifically in forensic odontology) ranged from nil to doctoral level (Table 2). The total number who had at least completed the coursework Graduate Diploma in Forensic Odontology (nominally a year-long qualification consisting of several 4- to 6-week blocks of course work, casework experience, and a minor dissertation) was 11, with one of these participants later completing a Master's level qualification in general forensic science (nominally a 2-year program consisting of coursework and a dissertation). Three participants had nonforensic-related Master's degrees, and one participant was in the process of completing a PhD. These qualifications are not reflected in the table.

All except four of the participants in this study had the same basic level of training—a graduate diploma in forensic odontology—and some had additional higher degrees. Generally, the more experienced practitioners (those with 11+ years) expressed

TABLE 1—*Experience of odontologists.*

No. Years Experience (years)	*N* Odonts	%
0–10	4	27
11–20	4	27
21+	7	46

TABLE 2—*Qualifications of odontologists.*

Postgraduate Qualification	*N* Odonts	%
None	2	13
Graduate Diploma	10	67
Masters	2	13
Doctoral	1	7

more uncertainty regarding the origin of the injury (i.e., appeared to give more "conservative" opinions). However, lesser-experienced practitioners (those with 10 or less years experience) demonstrated better agreement with one another than those in the other experience ranges. This could be a reflection of the fact that they were more likely to rely on their "training," rather than their "experience."

Whittaker et al.'s study (18) suggest that training is more important than experience when it comes to determining the origin of bitemarks as either adult or child, and this premise likely holds true for deciding the more fundamental question of whether a particular injury represents a bitemark or not. Those with the most experience (21 or more years) tended to have the widest range of opinions as to whether the mark was of human dental origin or not and thus demonstrated the poorest agreement within their experience category. This category also had the greatest variation in initial training. An interesting example of the fallibility of "experience" as a sole means of basing an assessment of a bitemark on occurred with image D, which drew a wide variety of opinion on whether the image represented a bitemark or not. One odontologist was certain that the image was a bitemark due to their experience, and stated as much:

> I know from experience that that's teeth because I did a case at the beginning of the year, that when I first looked at the images I didn't think they were teeth, because the injuries were so severe. But when I saw the models, and scratched them down my arm, they looked just like that.

Another participant expressed doubt that the image was a bitemark, based on the same reasoning that they had never experienced such a mark:

> Honestly I don't think it's a bitemark… there could be any number of things that could have caused that. Whether this is individual tooth marks here I doubt. I've never seen anything like that.

These results support Whittaker et al.'s (18) general notion that experience does not necessarily correlate with reliability and also supports the notion that training is vital to ensuring inter-examiner reliability. They also strengthen the notion that experience, by itself, is a poor substitute for training and research in the discipline, which are likely to yield far more reliable results.

TABLE 3—*Court experience.*

No. Times Testified	*N* Odonts	%
0	9	60
1	3	20
2-5	2	13
6 or more	1	7

Less than half of the participants had ever testified in court on bitemark analysis (Table 3). Only one person had testified more than five times in his/her career. Despite the relative proportion of odontologists who have had significant courtroom experience in the area of bitemark analysis being very low, the majority of participants were highly experienced odontologists, with only three having <10 years in the field.

Nature of Casework

Anecdotally, bitemark evidence in Australia is comparatively rare. Interviewees all expressed the relative infrequency with which they were asked to provide opinions on bitemark cases, and most noted that they were even more rarely asked to match a bitemark to a suspect. This situation was verified by a retrospective analysis of casework conducted by the same authors in 2010 (27).

More often than not, odontologists state that they are usually asked to provide an opinion on whether or not the mark could have been made by human teeth:

> Its not common to be asked to identify someone from a bitemark. They want to know if it is a bitemark or not, or if it is human or not. Then they can add it to the list of information they have about the injuries on the person. For example the child protection unit, they usually aren't interested in getting me to say who the person was, but they are often interested in whether it was an adult or a child, or whether they could have bitten themselves.

Another odontologist commented:

> For example, in one case … I didn't have to say who did it, but I just had to say which was upper and which was lower. In order to corroborate a victims story. That's a much more common scenario.

Most odontologists also revealed that they were generally dissatisfied with the quality of evidence presented to them for analysis:

> We often see photographs of poor quality, without scale markers, strange angles, perspectives, and they are rarely ever taken of the injury in the position the person was during the assault.

And:

> Often the police don't take the photo perpendicular to the injury, there is no scale, or it's not an ABFO scale, bad lighting, and sometimes there is only one photograph of one bitemark when there are others on the body.

Some odontologists recognize that the onus is probably on the odontology community to address such issues:

> I think it is because of poor education, poor awareness. I think a police photographer is a good photographer, but I don't think they realize the nuances of what we require, even in general dental forensic photography. They don't have the mindset of a forensic dentist. Often they take photographs for the sake of documenting something, which is

> fine for that purpose, but it isn't a good forensic photograph, if that makes sense.

> Also:

> They [police photographers] are improving. And I think that is a matter of education through the odontologist.

Photographic representation of the injury was seen to be no substitute for examination of physical evidence itself. This practice was generally believed to be useful by the odontology community, particularly given the poor quality of the photographic records they are given.

> Sometimes you just have to be there. It's like looking at photos of oral lesions, I know I've taken photos and, particularly if it hasn't been taken right, they tend not to look anything like they do in the mouth. Sometimes it just doesn't always represent what you think you are looking at.

Method of Analysis of Bitemarks

Most odontologists expressed a preference for using a hand-tracing on acetate, or generation of a digital overlay using Photoshop. The "other" methods included a purely qualitative description of the relationship between teeth and a model, creating a contour map of teeth by photographing a model submersed in ink, and creation of a clear acrylic replica of the dentition that is then placed directly over a life-sized photograph of the bitemark. Several odontologists commented that they would often use a supplementary method, such as a metric analysis of inter-canine distances, or individual tooth lengths, to strengthen their conclusions.

Use of a digitized version of a photograph, as per Bowers and Johansen's method (28), was the most commonly used technique, followed by hand-tracing with acetate (Table 4). It was generally those odontologists with more experience who expressed a preference for acetate and hand-tracing methods of comparison, rather than digital methods. This may be due to older odontologists being less comfortable with newer technologies (see [29] noting his reference to what he calls the "digital divide"); however, this preference for acetate hand-tracing is perhaps unfortunate in light of the research by Sweet and Bowers (30) and McNamee et al. (31). Furthermore, the digital production of overlays by those practitioners who used the method all involved scanning the models of the dentition, rather than of wax impressions of the incisal portions of the teeth. Bowers and Johansen initially recommend that wax bites be used for production of overlays (32), and express that digital scanning of models to create a "hollow" overlay is perhaps better only when a good quality bitemark (that demonstrates individual features of certain teeth) exists. It makes sense to generate models from wax impressions, bites, or scrapings initially.

While a number of practitioners expressed a preference for their own methods of comparison, including creation of a contour map of the dentition by immersing the models in ink, and creating a clear acrylic model of the incisal edges which can be directly compared, there appears to be minimal scientific evidence supporting the use of any of these techniques. The use of clear acrylic templates has been reported in the literature (33) but only in the form of a case report and has not yet been the subject of a study relating to its reliability either alone or compared with other methods. The ink-immersion technique also rates a mention in a comprehensive textbook on bitemark analysis (13), yet the author also cautions that there is yet to be any scientific proof of the validity of this method, noting that no inter- or intra-examiner reliability study has yet been conducted.

TABLE 4—*Primary methods of analysis of bitemarks.*

Primary Method of Analysis	*N* Odonts	%
Digital overlay	5	36
Acetate	7	47
Other	3	17

Consistency of Opinions on Individual Bitemarks

Interview participants were shown six images of bitemarks, all of them taken from actual casework presented to one odontology center in Australia. They were asked to assume that these were photographs given to them by an agency for their initial comments. No contextual information was given to participants, and they were free to express as much or as little opinion as they liked regarding the image before them.

The interview data reveal that there is considerable variation among odontologists in even the most elementary aspects of the forensic diagnostic sieve and that of deciding whether the injury was indeed a bitemark or not. After analysis of each participants' comments regarding origin of the injury, it became clear that there were five preferred ways of expressing the likelihood that the injury was a bitemark, ranging from definitively positive comments—"Well, this is definitely a bitemark, that's for sure"; moderately positive comments—"It is probably a bitemark"; weakly positive comments—"it might be a bitemark, it is possible"; comments expressing genuine uncertainty—"I'm not sure if it is even a bitemark"; and negative comments—"I don't think it is a bitemark." A number of practitioners did not specifically comment on whether the injury was a bitemark or not; however, their subsequent comments made it obvious that they had proceeded on the assumption that it was.

Opinions on the origin of the injury ranged for each separate image, from comments that implied "definite" or "consistent with a bitemark" to "I don't think it is a bitemark." This represents the entire spectrum of possibilities regarding the origin of a single injury pattern. For example, regarding image A, comments from different participants proceeded along the lines of the following:

> It's a bitemark, yes.

> On class characteristics, yes it's a bitemark and it is likely to be human.

> It could also be pathology. You can't assess something like that from a photograph. It could be a suction cup mark.

> I'd say its possibly a bitemark, and its possibly a human bitemark.

> I'd say it could be anything from a bottle top to a bitemark.

> I'm not sure that it even is a bitemark.

> I don't think it's a bitemark, I think it is a bit tiny. Even a child with deciduous dentition, I think its too small. I'm just looking at the ruler, its only 4 cm. It's very small.

The only unrepresented category for all of the images combined was that of "definitely *not* a bitemark," and this could have been be due to the nature of the interview process itself, which was knowingly about bitemarks and bitemark analysis, thus inducing a contextual bias. It is perhaps unsurprising that participants did not offer this definitive conclusion in the face of being offered images described as "bitemark photographs" to view.

Similarly disparate opinions were offered for image B, where a number of participants expressed uncertainty as to whether the marks represented bitemarks or not:

> …Well you do have more distinct areas of contusion. The pattern is extremely ovoid, which once again is a bit of a worry. The ones I have seen haven't been so round. I don't know whether they would be bitemarks at all. […] I don't know whether you would find them to be bitemarks at all. They might be caused by some sort of appliance, or something like that.

Others thought that it was very unlikely to be a bitemark:

> …I would say that I don't think it's a bitemark. It could be a juvenile bitemark. But that's highly unlikely. But what tissue is it on, have the tissues been stretched, and so on… I'd be very suspicious. There's the nipple there, there is often a sexual implication in that. Possibly a suction mark too. That could be anything though. I wouldn't necessarily say it was a bitemark.

Yet, other participants were convinced that image B definitively *did* represent a bitemark:

> Yes, you could say that he has bitten her twice. Was his head turned slightly to the side maybe? I think the centre line is there and going up like this, because of these two points there, so I think the head was tipped to the side, possibly. In all probability these are the two lower canines, and there is canine here and there might be one here. The bloke has obviously had a bit of a suck and we've got a bit of bruising and there might be something wrong with his central incisors.

It is interesting to note that the greatest agreement for comments regarding the origin of an individual bitemark was for image E. This was also the image about which there was the most uncertainty as to its origin, with the highest number of practitioners ($n = 7$) stating that it might only "possibly" or "could be" a bitemark. Given that image E was also that which demonstrated the least degree of agreement between practitioners for assigning of the severity and significance score, this seems to indicate that the more dubious the quality of the injury, the more likely it is that practitioners will agree that uncertainty prevails. The corollary of this is that odontologists seem to be more likely to agree with each other when there is uncertainty about the origin of the mark than when stronger opinions are expressed. This paradoxically suggests that practitioners are more likely to agree when they *do not* know rather than when they think they do.

The obvious question arises as to whether some odontologists are simply more conservative than others and are hence reluctant to offer definitive opinions. Could this possibly account for the variation seen in differences of opinion? The answer is, of course, yes. It appears that some participants do have a greater tendency to use stronger terms when characterizing the origin of an injury as a bitemark or not. Participant 14, who used two instances of "definite," two of "possible," and two of "I don't think it is bitemark," was compared with participant 5, who used only one instance of "probable," three of "possible," one of "unsure," and one of "I don't think it is a bitemark." While this can be identified qualitatively, it is difficult to quantify these differences in any way from one practitioner to the next. That is, it generally possible to say that one practitioner is more conservative than another (in this example, participant 5 can be seen to be more conservative than participant 14), but not in any particularly measureable way. The data merely verify the fact that there is a wide range of opinion over even the most basic assumptions in bitemark analysis: that of the origin of the mark itself.

Yet, it is not as simple a matter as to say that some odontologists are more conservative than others and that this accounts for the disagreement seen in bitemark casework. There was not necessarily a consistent relationship between "conservative" and "nonconservative" practitioners in the quality of their comments. For example, two participants were in complete agreement regarding the origin of the patterned injury in image A as being from human teeth, yet in complete disagreement regarding bitemark B, one claiming that they did not think it was a bitemark and the other claiming that it probably was. Similarly, another two participants were in complete opposite agreement regarding images B and C:

Regarding image B,

> That could just be something that has been pressed on their body. I'm not convinced that they are bitemarks.

And:

> Yes these look like human bitemarks

Yet regarding image C, the same two participants stated contrary opinions that were again reversed, although from the opposite viewpoint:

> I would probably say that that could be a bitemark, with the abrasions, here, he has had a go twice. Its been pinched in. This here could be the upper teeth, on the right side of the photo. Yes I think so.

And:

> No I don't think that is a bitemark.

The potential reasons for this inconsistency, aside from mere differences in opinion, are interesting. It can be seen from the comments regarding image A that there is often inconsistency in the reasoning for odontologists decisions regarding this fundamental call. Image A was classified as a bitemark by one participant on the basis of its class characteristics, yet it was dismissed as a bitemark by another participant simply on the basis of its size. Clearly when odontologists are using different standards to determine the origin of an injury, differences in opinion will likely be the result.

Despite standard protocols existing in other pattern identification sciences that describe latent marks in terms of class and individual characteristics, this does not appear to be followed to any great extent by odontologists, and this is potentially a problem that can lead to this sort of inconsistency between odontologists. The basis for including or excluding a mark as having been made by human teeth seems to be highly variable between practitioners.

Orientation and Other Details Regarding the Bitemark

Few participants commented on the orientation of the bitemark. Most were hesitant to make a call on which were upper and which were lower tooth marks. Several comments regarding the orientation of the mark were made for image C, yet one of the three participants indicated the opposite aspect of the injury as being caused by the upper teeth, compared with the other two:

> It looks like a bitemark. I'd say that the right hand side, closest to the thumb might be caused by upper teeth, and the left side caused by lower teeth.

> This here could be the upper teeth, on the right side of the photo.

A third participant then claimed:

> These are the upper anteriors here on the left.

A similar instance occurred during participant comments for image D, where the two odontologists who commented on the orientation of the mark gave a conflicting statement as to which were the marks caused by upper and lower teeth:

> I'd say that was the lower arch there on the left.

Compared to:

> If I had to have my arm twisted, I could probably say that this is the upper arch there on the left of the photo.

What may be of note in this situation is that all of these participants made comments regarding orientation based on their own opinion. None made specific mention as to why they had chosen a particular orientation over another. This practice is similar to stating "I think it is *x* because I said so." While this may have been circumstance-driven, in that because the participants were talking to a dental-trained colleague, they may have assumed it was obvious as why one particular orientation was clearly favored over another—but here, the point is made: at least one of the three odontologists who commented on image C got the orientation wrong,[1] and one of the two odontologists who commented on image D was also wrong. Of five opinions offered on orientation of bitemark injuries, two were completely opposite to the other three.

Consider also the range of opinions regarding image B. While some practitioners felt very confident in their ability to interpret this injury, offering tremendous detail regarding the position of the center line, position of the head while biting, and even the status of his central incisors, others in the same peer group (with roughly the same amount of experience and the same level of qualification) remained far more hesitant to even call the mark as being made by teeth. Compare:

> Yes, you could say that he has bitten her twice. Was his head turned slightly to the side maybe? I'd say probably. I think the centre line is there and going up like this, because of these two points there, so I think the head was tipped to the side… In all probability these are the two lower canines, and there is canine here and there might be one here. The bloke has obviously had a bit of a suck, but not as much as the other one, and we've got a bit of bruising and there might be something wrong with his central incisors.

with:

> I'm not even convinced that they are bitemarks

and:

> Well to me, my initial reaction is that that is not a bitemark.

There were several comments regarding the nature of the central bruising or ecchymosis in images A and B. This was variously attributed to "suction," "tongue thrusting," or "compression of surface vessels" during the biting process. Despite there being general agreement that the image quality was poor, the central area of ecchymosis drew a wide variety of opinion regarding its origin, with some describing it as a scraping or tongue thrust bruise:

> I'd say it possibly could be a bitemark… perhaps a scraping or a tongue thrusting in the centre.

Most attributed it to "sucking":

> There is an area around [sic] the injury that could be due to some suction force.

> This is someone that's had a bit of a suck, hasn't he.

> [There's] some bruising from suction in the centre, possibly.

Yet others attributed it to the artifact created when the tissue is squeezed between the upper and lower dentition:

> It's got the characteristic bruise in the middle, which is caused by compression of small surface vessels as the jaws close.

Initially, central ecchymosis within bitemarks was attributed to suction or tongue thrusting (16,34), yet this has been disputed since the 1980s (35). Despite common acceptance today, the theory regarding compression of capillaries remains to this day a theory based on anecdote (see 13, p. 65), and although more reasonable, is likewise untested. There has been little, if any, literature aside from the study conducted in 1974 regarding the

[1]It is also possible that two of the three participants were wrong and the one aberrant opinion was the correct one—it is impossible to deduce with certainty, as the ground-truth of the case was not known.

ability of a sucking action, or tongue thrusting to cause such an injury (and that study only involved measurement of sucking and thrusting forces, not production of any actual marks on tissue). Despite the lack of experimentally derived data, it appears that most authors now support the proposition that these areas are cause by compression and subsequent rupture of subsurface capillaries in the central area of tissue that is squeezed between the teeth during the biting process.

Few odontologists offered opinions on the age of the suspected marks. Image E represented a healing wound that was obvious to any clinician familiar with basic clinical pathology, and this was agreed to by all who commented. Eight odontologists made specific comment that this bitemark was "old." None volunteered any specific mention of how old, apart from one odontologist who suggested:

> It's been months and months since that was made.

Image F showed a mark that consisted entirely of bruising, and again odontologists were cautious in assigning a specific age to it:

> Its too old isn't it. It has been there for a long time. The bruises are beginning to go green, and everything fades.

> Yes it's an old one.

> The bruising is indistinct as it is late.

A recent systematic review of 167 papers on bruising concluded that "we cannot accurately age a bruise from clinical assessment in vivo or from a photograph. Any clinician who offers a definitive estimate of the age of a bruise in a child by assessment with the naked eye is doing so without adequate published evidence" (36, p. 189). An earlier review paper in 1997 also claimed that bitemark aging using bruises as a guide was highly unreliable and that odontologists should limit themselves to describing bruises as "recent" or "old" (37). Odontologists interviewed in this research generally appeared to adhere to these limitations regarding the aging of bitemarks consisting of only bruising.

Injury "Forensic Value" Analysis

There appears to be considerable variation in whether odontologists think certain bitemark images are suitable for analysis or not. Consider the following contrasting comments, which were made regarding image D:

> Well I don't think it's a bitemark. Possibly some drag lines here, maybe. Once again I don't think you'd get anything out of it. It may be a bite, but even if it was I'm not sure it would lead you to anything. […] I doubt you'd get anything out of that one.

And:

> Yes that's pretty good. Good for analysis. I wouldn't mind having a bit more of the lower ruler, but that's a pretty good image to work with.

Image C also represented a cause of contention for several participants, who commented on the poor angulation of the photograph and the quality of the scale. One commented:

> [This image is] absolutely not [suitable for analysis] […] I would have reservations about doing anything with that. If I were asked to analyse this I would probably say no.

However, another participant said

> No, that's a good bitemark, I could work with that, yes, definitely.

This inconsistency indicates a fundamental flaw in the methodology of bitemark analysis and should lead to concerns regarding the reliability of any conclusions reached about matching such a bitemark to a dentition. Pretty (24) developed a tool for assisting in this decision, the severity and significance scale; however, its own reliability and hence applicability in this regard is also a cause for concern.

The main concern with the use of this scale is the ability of practitioners to reliably apply it to casework. Overall agreement in assigning a severity and significance score varied according to the nature of the injury itself, and it appears that the scale is designed to be used for relatively recent bitemark injuries. Once older injuries are introduced, practitioners appear to lack certainty as to how to rate them in accordance with this scale. Practitioner agreement in assigning a severity and significance score was greatest when given a visual exemplar in addition to written descriptions of the categories (i.e., after the second pass). This suggests that the written descriptions may be ambiguous, or unclear when used by themselves, or that they do not necessarily correlate with the visual images. One odontologist commented on the difficulty of applying this scale to actual casework:

> This concept that, for example, you can get very mild bruising with no individual tooth marks present, but you can have very obvious bruising with no individual tooth marks present either, I mean, that depends on timing. I also have an issue with the line 'individual discrete areas are associated with teeth' – I can't be sure that they were caused by teeth, so technically I can't assign this score.

Using a kappa calculation after Fleiss (38), it can be seen that inter-examiner agreement in assigning a severity and significance score was greatest for those images at the extremes of the scale (Table 5); images A, D, and F—representative of the lowest and highest severity injuries—had agreement ranging from "moderate" (0.4–0.6) to "substantial" (0.6–0.8). Image E had poor agreement due to the difficulty in assessing the wound due to its age—and a number of participants refused to assign it a score on this basis.

During the interviews, a number of practitioners sometimes offered surprising inferences from images that were generally considered of poor quality (or of low significance) by others. Despite image F having the lowest severity and significance rat-

TABLE 5—*Inter-examiner agreement in assigning severity and significance score.*

Image	Relative Severity	κ
A	Low	0.55
B	Moderate	0.28
C	Moderate	0.41
D	High	0.63
E	Uncertain	0.19
F	Low	0.73

ing of all of the bitemark images, practitioner comments were generally weighted toward the positivistic end of certainty that the image was a bitemark—only three expressed that the image was only "possibly" caused by a bitemark or that they were uncertain. Pretty's severity and significance scale is a potentially useful tool here, in that images that are considered of low significance should have appropriately weighted conclusions and comments, although it is recognized that there is a potential need for either training in its use or refinement of the scale. Regardless, those that rate low on the scale should potentially have endorsed limitations placed on the strength and type of any remarks made regarding the marks origin, orientation, relationship to a dentition, and so on, so as to avoid situations where extreme conclusions are reached about dubious evidence.

Conclusion

There are a number of inconsistencies regarding the practice of bitemark analysis in Australia that appear to render conclusions between practitioners highly variable. Inconsistencies in method of analysis, reasoning, and terminology all ultimately lead to inconsistencies in opinions, and this is a failing of bitemark analysis practices that needs to be addressed. While the Pretty score is potentially a useful tool for assessing the severity and significance of a bitemark injury, the results of the inter-examiner comparisons demonstrate that the pictorial descriptors should be used as a reference guide when assigning a score to a bitemark so as to ensure greater inter-examiner reliability. Formal training in its use may be warranted in postgraduate courses to ensure consistency in interpretation. The data suggest that those bitemarks with lower Pretty scores (i.e., scores of lower significance value) might be subject to greater variation in interpretation of origin, but this is at best a weak correlation. A larger number of cases would need to be subject to this process to demonstrate a more definitive relationship between severity and significance scores and inter-examiner agreement on the origin of the injury.

The discovery of such wide-ranging comments from participants regarding the same bitemark image is concerning. It is acknowledged that these participants' comments may not necessarily be reflective of those that they would necessarily articulate in a written report; regardless, analysis of individual comments made about these bitemark images suggests that there is a lack of agreement between participants that is explainable on one level by the lack of consistency in the approach to the assessment of suspect injuries. While complex and/or meaningful statistical analysis is difficult due to the small sample size, the qualitative data plainly verifies the fact that there is a wide range of opinion expressed over even the most basic assumption in bitemark analysis: that of the origin of the mark itself. Fleiss's kappa calculation for this data set indicates that inter-examiner agreement on origin of injury is very poor, with a kappa score of 0.015. Such a low figure indicates that odontologists in this group are almost as likely to disagree than they are to agree whether a mark is definitely, probably, possibly, or probably not a bitemark when asked for their independent opinion. The inconsistency in approach, terminology, and conclusions regarding the initial assessment of bitemark injuries in Australia suggests that the development of sound guidelines for bitemark analysis and reporting is warranted.

Other forensic identification disciplines have long upheld the maintenance of standards through published guidelines, and this is one way in which these shortfalls can be addressed with relative immediacy. Guidelines for bitemark analysis will not address the more fundamental concerns regarding the ability of bitemarks to accurately reflect a given dentition; however, it is certainly one method by which we can achieve a rapid increase in reliability. Such guidelines also provide the basis for future research that will address these more fundamental claims, providing a consistent baseline practice from which these studies can then be designed.

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Short communication

Problem-based analysis of bitemark misidentifications: The role of DNA

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Abstract

The dental literature concerning bitemark methodology is surprisingly thin and sorely lacking in rigorous scientific testing. Contra to this fact, the bitemark legal caselaw is surprisingly strong and is used as a substitute for reliability testing of bite mark identification. In short, the Judiciary and the Prosecutors have loved forensic odontologists.

This paper will focus on the author's participation as a Defense expert over the last seven years in over 50 bitemark prosecutions and judicial appeals. This sampling will act as an anecdotal survey of actual bitemark evidence. Certain trends regarding methods and reliability issues of odontologists will be discussed.

Several of these cases have been later judicially overturned due to DNA analyses after the defendants were originally convicted. These diagnostic misadventures are being vocally discussed in the US media by news and legal investigators who are asking hard questions. The forensic dentistry community, however, is curiously silent. What actions are necessary by the profession to improve this assault on the 52-year tradition of bite mark identifications in the United States?

Keywords: Bitemark misidentification; DNA; Erroneous criminal conviction; Validity; Forensic science

1. Review of contemporary bitemark comparison techniques

A 1998 article reviewed five bitemark techniques used to create suspect dental exemplars [1] which are then superimposed [2] onto rectified and life-sized autopsy photographs [3]. The 1998 study ignored "direct comparison" methods. This technique of placing plaster models of teeth directly onto or adjacent to postmortem supposed bitemark injuries on human skin was rejected due to the dentist's inability to adequately visualize neither the injury pattern nor the dental minutiae of the dental array. This method had also been previously experimentally studied and considered unreliable [4]. The four most common methods were compared to a "digital image gold standard" which produced resulting recommendations to (1) eliminate hand drawn overlay exemplars of suspects' teeth and to (2) use digital images of suspects' teeth acquired through scanning of dental study casts due to greater accuracy.

No contradiction of these suggestions has been noted in the dental literature since their publication. A recent survey of 30 volunteer dentists of varying experience assessed their performance in digital overlay production and found favorable results [5].

As seen in mainstream dentistry, additional tools and therapeutics can be developed for improvement of health care expectations. These new forensic imaging tools have the same purpose. Since being introduced to the profession [6] these new tools have had little use in certain Prosecution bitemark cases seen by this author while acting as a Defense Counsel expert. This disregard of almost 10-year-old scientific literature possibly indicates the established dental experts (trained in the previous Millenium) do not consider common digital procedures will change their opinions or improve their accuracy.

This author's experience is that bitemark misidentifications have resulted from dentists not using high image resolution superimposition or even dental exemplars of any kind. The

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‘‘direct comparison’’ method appears frequently in a high number of bitemark mis-identifications where convictions have been later overturned by DNA (see Appendix A, LR1). Attitudes have also played a significant role as these same dentists assume every suspect’s dental array (including gaps, spaces and accidental enamel chipping) is unique in the human population (LR2).

DNA evidence has been used to clear 172 people wrongly convicted of crimes in 31 states since 1989 (LR3). DNA profiling in the US is having a serious impact on expert bitemark opinions regardless of the traditional bitemark methods or techniques utilized. The following section discusses the legal history of bitemarks in the US court system and will shed some light on the judicial attitudes surrounding established bitemark methods encounter with new scientific scrutiny and the biology of DNA.

2. History of bitemarks in court

Bite mark analysis has been used in the United States courts since 1954 (LR4). In this first legally published case from Texas, a certain Doyle was charged with burglary. At the crime scene, a piece of cheese was discovered that possessed tooth marks. A suspect was captured by the police and asked to bite a piece of cheese to which he voluntarily complied. A firearms examiner compared the two pieces of cheese to investigate similarities or dissimilarities of the tooth marks. This non-dentist concluded the marks were made by the same person. At trial, a testifying dentist made the same conclusion from plaster models of the original crime scene cheese and the defendant’s cheese exemplar. Appellate court review accepted this method. In later years, this acceptance was judicially stretched to include tooth marks in skin and occasionally other objects. Still lacking up to today is accompanying scientific validation of the chances for mis-identification in the processes used by court recognized bitemark experts (LR5). This void in scientific support for bitemark identifications reliability was ignored 20 years after Doyle by the Patterson (LR6) court, also in Texas. Both courts ignored the unanswered scientific questions and are mentioned here as a reflection of the persistent U.S. judiciary’s avoidance of scientific validation in certain forensic disciplines, with bitemarks being among them. This paper discusses the current legal climate where DNA exonerations of previous bitemark convictions have become the primary fuel to support earlier odontological and legal opinions doubting the reliability of the method.

3. Forensic mistakes in court

A recent article about forensic errors [7] targeted the judicial history of legal miscues, false confessions, witness, police, and scientific testimony in relation to the same cases later becoming DNA exonerations. Fig. 1 shows the distribution of trial court opinion and scientific evidence in 86 convictions that have been overturned in the United States. The original judicial decisions were waived in favor of better investigatory, forensic and biological methods.

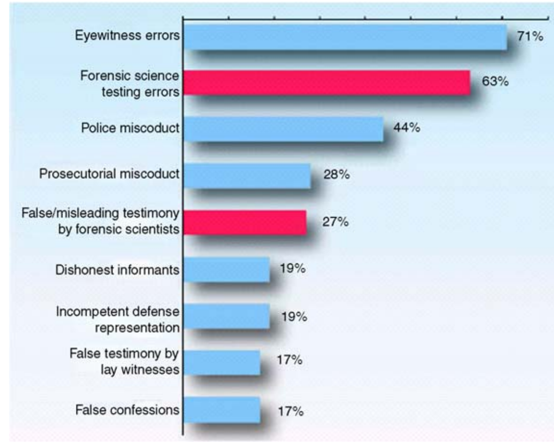

Fig. 1. Saks and Koehler [7] reported that of the 86 DNA exoneration cases they studied, 63% had erroneous forensic science testimony that contributed to the original conviction. They stated published results of bitemark proficiency workshops had false-positive opinions ranging as high as 64% (courtesy to Saks and Koehler [7]).

4. The judicial responses to bitemark evidence in criminal court

Scientific admissibility for bitemark evidence could be changing at some legal levels in States that have changed to the Federal Rules for scientific admissibility established in Daubert v. Merrell Dow Pharmaceuticals (LR7) in 1993. The most recent Daubert reviews in seven U.S. States (LR8), however, indicate no appellate court inclination to tackle ad hoc the underpinnings of bitemark assumptions and methodology. They appear content to expect either the trial court to allow opposing expert testimony or simply wait for DNA results to occasionally appear after conviction to finally settle the questions of guilt.

Proponents of positive biter identification methodology have always and still are (except in the state of Oklahoma) (LR9) allowed to render expert opinions that carry the same evidentiary weight as DNA results (LR10). This fact has fueled many pre-DNA bite mark opinions over the last 52 years that have helped criminal prosecutors influence juries regarding guilt of criminal defendants. The broad-based judicial admissibility of DNA evidence in the US has entered its second decade of use. The judicial problem or task in bitemark identification has always been whether the credentials of the testifying experts meet a modicum of respectability. The questions of science are presented to a jury who weighs the veracity and credibility of the expert. The scientific aspects of reliability are either assumed to be established or the instant case has the expert satisfying the court’s threshold of certainty. Little scientific progress can be accomplished by opposing bitemark experts debating their arguments in front of either a judge or jury as the general judicial rationale is the truth will come out during the judicial proceedings. This is an exceedingly poor venue for scientific review as the viewing participants are being asked to consider concepts beyond their knowledge. The ad hominem (adversarial) style of US court proceedings asks the layman jury to accept/reject dental experts' conclusions based on mere opinion evidence of (1) dental uniqueness in the human population being confirmed in bitemark injuries, and (2) the appearance and replication of dental features by court accepted dental experts on bruised and injured skin being reliable.

Opinions of positive linkage between injuries and a specific person are not arrived at via scientific rigor (LR11). Entering this 52-year tradition is the new (in its forensic context) independent source of bitemark identification via DNA analysis. This advent of independent scientific analysis is having a direct effect on the credibility of dental bitemark experts. The problems with bitemark opinion evidence have been well documented in the legal literature and are discussed below.

5. The history of divergence of opinions by bitemark experts

The legal history of bitemark experts shows dental experts seldom agree with one another at trial [8]. This is not only regarding the identification of a biter, as the record also indicates disagreement as to whether a bitemark exists at all. These disagreements are admitted by the judge, as a matter of course, and are then tasked to the jury to ponder and weigh during the deliberations. The subsequent jury decision is a layman's decision, as the professional experts are merely asked to render their varying opinions without reliability data as convincingly as their abilities allow. This author's opinion on the basis for such expert discord is the failure of the profession to set a minimum threshold for bitemark identification. The American Board of Forensic Odontology's (ABFO) attempt in the 1980s to achieve certain scaled minima of evidentiary value [9] failed, not surprisingly, due to inter examiner discord and unreliable quantitative interpretation of bitemark autopsy and human dentition data [10].

6. Data concerning reliability of bitemark opinions

The back and forth argument regarding the reliability of bitemark expert testimony has been going on for decades. Beyond the personal opinion arena, the science of this forensic specialty has the following foundation of data to support its adherents and, conversely, to support its detractors. The weight of these studies is a paucity compared to DNA basic and applied science.

- A 1975 study found that while bites made in wax could accurately be compared to dental models, matching bites made on pigskin, a medium akin to human skin, was vastly more difficult. Incorrect identification of the bites made on pigskin ranged from 24% incorrect identifications under ideal laboratory conditions to as high as 91% incorrect identifications when the bites were photographed 24 h after the bites were made [11]. The study concluded that "the inability of examiners to correctly identify bitemarks in skin in 25% of cases under ideal laboratory conditions and when examined immediately after biting suggests that under sometimes adverse conditions found in an actual forensic investigation it is unlikely that a greater degree of accuracy will be achieved". Due to the problems the study revealed, it concluded, "further studies to substantiate the reliability of the technique are clearly required".
- A 1999 American Board of Forensic Odontology ("ABFO") Bitemark Workshop where ABFO diplomats attempted to match four bitemarks to seven dental models found 63.5% false positives [12]. The ABFO supported publication of a contra response (with accompanying statistical analysis) to this finding by stating, in part, the 4th Workshop was never formally titled a "proficiency test", the samples were unusable for statistical determinations and the findings of this study generalize only to cases having moderate to high forensic value [13].
- A 2001 study of bites made in pig skin, "widely accepted as an accurate analogue of human skin", with dental casts found false positive identifications of 11.9–22.0% for various groups of forensic odontologists (15.9% false positives for ABFO diplomats), with some ABFO diplomats fairing far worse [14]. The study cautioned that the "poor performance" is a cause of concern because of its "very serious implications for the accused, the discipline, and society."

7. The availability of DNA and other forensic analysis information that contradicts bitemark evidence

The later 1990s showed the initial influence DNA profiling had on criminal judicial proceedings containing bitemark testimony. In Gates (1998) (LR12), DNA eliminated the suspect from investigation after a forensic dentist stated his teeth matched bitemarks on the victim. The multi-disciplines of DNA, hair and fingerprints excluded a suspect in Bourne (1993) (LR13)where the dentist stated the defendant's teeth matched bitemarks on the victim even though hair, and fingerprint excluded the defendant. Morris (1997) (LR14) was dismissed after the court had opposing dentists disagreeing on bitemark evidence and later DNA profiling arrived which excluded the defendant.

The new millennium has Krone (2002) (LR15). It is the most publicized case of this decade, as the defendant was sentenced to death (later overturned), reconvicted a second time and given a life sentence, and 10 years later exonerated and released. In a stroke of law enforcement luck, the real killer was identified from crime scene DNA and easily found as he was already incarcerated in the same prison as Krone. The primary evidence against Krone in both trials was bitemark testimony from a senior member of the United States odontology community. He successfully swayed the jury in both instances but lost out to a better identification science (Fig. 2).

It seems that manner and outer trappings of the State's dental expert lacked the scientific wherewithal to be sustainable. It is fascinating to read recounts from the jury regarding their certainty that the teeth marks were a "perfect match". Mr. Krone has recently received a considerable settlement from the State of Arizona and various other individuals.

Fig. 2. The Krone case had a senior forensic dentist testifying twice to the positive correlation between these plaster models of the defendant and the injury pattern depicted underneath. DNA proved the defendant was not involved in the murder and rape of the victim.

A forensic odontologist testified at a ''preliminary examination'' that Otero (2000) (LR16) was ''the only person in the world'' who could have inflicted the bitemarks at issue. After spending 5 months in jail awaiting trial, the State dismissed the charges after a newly available DNA test excluded Otero as the source of DNA on the victim.

A suspect arrested based on bite mark identification sued for false arrest after DNA tests excluded him (2005) (LR17). Twelve years after being convicted based on testimony from a forensic odontologist purportedly linking Young to a bite mark on the victim, prosecutors agreed to a new trial and dropped all charges after DNA testing excluded Young (2005) (LR18). A codefendant Hill was also released in separate proceedings.

2004–2006 has ongoing appellate proceedings in Brewer (LR19) that after conviction uncovered DNA obtained from the decomposed victim indicating two male sexual assault perpetrators. The man convicted for the crime in the early 1990s and sentenced to death was not a contributor to either DNA profile. The only remaining forensic evidence against the defendant is bitemark testimony that the trial county's District Attorney has indicated is sufficient to try and convict Brewer a second time. An example of the methods and evidence used in this trial is illustrated in Fig. 3.

Fig. 3. The State's use of hard plaster models placed onto decomposed skin of the murder victim. The correlation of the models is zero since there are no discernible teeth marks on the body. Note the similar method of ''direct superimposition'' that was used in Krone.

8. Conclusion

Since the above narrates the obvious diagnostic problems involving bitemark identification, my final statement is rather brief. When reputable practitioners strongly disagree with each other, there needs to be a reliable scientific method to prevent past and future errors. In a medical sense, if treatment is considered therapeutically faulty, new diagnostics and modalities must be found. It is up to the dental forensic community to accept this challenge. The legal profession and in particular the judiciary must realize that the proponent of bitemark evidence has the burden of proving its validity using the current available data. This data, however, shows a disturbingly high false-positive error rate.

Appendix A. Legal references (LR)

LR1.

Howard v. State of Mississippi, 701 So. 2d 274 (Miss. 1997); Howard v. State of Mississippi, 853 So.2d 781 (Miss. 2003) direct comparison was used by the State expert; Brooks v. State of Mississippi, 748 So. 2d 736, 747 (Miss. 1999) direct comparison used by the State; Mississippi v. Gates, No. 5060 (Humphrey Cty. Cir. Ct. 1998) direct comparison used by the State; Mississippi v. Bourne, No. 93-10,214 (3) (Cir. Ct. Jackson County Mississippi) direct comparison used by the State; Kennedy Brewer v. State of Mississippi. 725So.2d 106 (Miss. 1998) and 819 So.2d 1169 (Miss. 2002) direct comparison used by the State; State of California v. William Richards, Case #FV100826, visual comparison with no exemplars used by the State; State v. Krone, 182 Ariz. 319, 897 P.2d 621 (1995) Low resolution video superimposition used by the State; State of Illinois v Harold Hill, State of Illinois v Dan Young, 12 Years Behind Bars, Now Justice at Last (Chicago Tribune, February 1, 2005).

LR2.

Id. All cases had the State dental experts arguing either dental uniqueness existed in the bitemark evidence or that individualizing single tooth characteristics of the defendant were present in skin injuries. All defendants were convicted by the jury.

LR3.

DNA has help exonerate 172, Associated Press, January 13, 2006.

LR4.

Doyle v. State, 159 Tex. Crim. 310, 263 S.W. 2d 779 (1954). This was the first U.S. bitemark case that underwent appellate court review. The court rationalized that the individual steps involved in looking at impression evidence had been in use for decades, and therefore fell under the Frye scientific rules of admissibility of the time. The threshold rule of Frye held that general acceptance of the relevant scientific community made the analysis acceptable. This was not based on scientific rigor of the dental testimony, as at that time, the dental literature on bitemark scientific reliability was non-existent.

LR5.

Bowers C.M.: A statement why court opinions on bitemark analysis should be limited. American Board of Forensic Odontology Newsletter 1996; 4(2): 5. The author's opinion was that (1) dentists were testifying as to identifications from assumed bitemarks on the basis of general dental characteristics which are ambiguous for human identification, (2) DNA profiling would soon act as a higher standard of identification due to its scientific basis and population studies, and (3) the bitemark cases with conflicting DNA results would have dentists being questioned about their methods and attitudes on the reliability of their opinions.

LR6.

Patterson v. State, 509 S.W. 2d 857 (Tex. Crim. App. 1974).

LR7.

Daubert v. Merrell Dow Pharmaceuticals, 509 U.S. 579, 113 S. Ct. 2786, 125 L. Ed. 2d 569 (1193). This case and the subsequent Kumho Tire Co., Ltd. V. Carmichael, 526 U.S. 137, 119 S. Ct. 1167, 143 L. Ed. 2d 238 (1999). The federal threshold for admissibility of scientific evidence was raised to include published error-rates, and other protections against unsubstantiated opinion evidence. The majority of the U.S. States has adopted this opinion, but has struggled with the science of analyzing science.

LR8.

Garrison v. State, 2004 CR 35, 103 P. 2d 590 (Okla. Crim. App. 2004). A dentist was not permitted to testify whether the victim was the source of an alleged bitemark on the defendant. This was based on the holding of Crider listed below.

State v. Hodgson, 512 N.W.2d 95 (Minn. 1994). An appeal of admitted bitemark evidence was considered permissible under Daubert rules since the methods were not novel (new).

People v. Quaderer, 2003 WL 22801204 (Mich. Ct. App. 2003), appeal denied, 470 Mich. 867, 680 N.W.2d 899 (2004). This holding stated only novel science needs to be scrutinized by Daubert standards. These two cases raise the question regarding why the courts should think lack of ''novelty'' acts as a guard against scientific proof as Daubert itself stated the applicability of review to established and unconventional (new) evidence (Daubert v. Merrell Dow Pharmaceuticals, Inc., 509 U.S. 579, 593 n. 11).

Seivewright v. State, 7 P 3d 24 (Wyo. 2000). This court said Daubert did not require an evidentiary hearing prior to being admitted and relied on previous cases where it had been admitted under Frye rules. This hardly rises to a new standard of scientific review of the assumptions, empirical data, and proofs of a forensic science.

Howard v. State of Mississippi, 701 So. 2d 274 (Miss. 1997) and Howard v. State of Mississippi, 853 So. 2d 781 (Miss. 2003). These are two appellate reviews of bitemark evidence used in a Mississippi death penalty case. The first ruling reluctantly accepted the bitemark evidence and reversed the conviction. The second holding, denied Supreme Court review in 2004, failed to use the Daubert litmus testing of the testifying DA's dental witness use of extreme confidence regardless of DNA refutation, and his untested abilities to identify one human being from artificial partial removable denture teeth he compared to equivocal skin injuries.

In Brooks v. State of Mississippi, 748 So. 2d 736, 747 (Miss. 1999), the Court said bitemark expert testimony was admissible because the defense could bring their own opinions at trial and satisfy all the scientific issues. A dissenting opinion expressed considerable skepticism that these scientific issues were settled.

LR9.

Crider v. State, F-1999-1422 (October 11, 2001). The lower court only allowed the expert to express that the wound was a ''probable bitemark'', and the appellate court upheld the judge's ruling. The upper court did not state how this opinion was allowable under the state's newly adopted Daubert standard as no empirical data was presented at trial.

LR10.

Howard v. State of Mississippi, 697 So. 2d 415 (Miss. 1997), republished as corrected at 701 So. 2d 274 (holding bitemark expert testimony admissible). Brooks v. State 748 So. 2d 736 (Miss. 1999) (holding bitemark expert evidence admissible).

LR11.

D.L. Faigman, D.H. Kaye, M.J. Saks and J. Sanders, Modern Scientific Evidence: The Law and Science of Expert Testimony, Chapter 30, Thompson-West, California, 2005–2006. This chapter outlines, in detail, the case law and range of scientific areas of bitemark analysis that are both settled and contentious.

LR12.

Mississippi v. Gates, No. 5060 (Humphrey Cty. Cir. Ct. 1998).

LR13.

Mississippi v. Bourne, No. 93-10,214 (3) (Cir. Ct. Jackson County Mississippi).

LR14.

Florida v. Dale Morris (Pasco County, 97–3251 CFAES, 1997). Two Forensic Dentists Added to Wrongful Arrest Lawsuit (St. Petersburg Times, December 24, 1999).

LR15.

State v. Krone, 182 Ariz, 319, 897 P.2d 621 (1995).

LR16.

Otero v. Warnick, 241 Mich. App. 143 (Mich. Ct. App. 2000).

LR17.

Burke v. Town of Walpole, 405 F.3d 66, 73 (1st Cir. 2005).

LR18.

12 Years Behind Bars, Now Justice at Last (Chicago Tribune, February 1, 2005).

LR19.

Kennedy Brewer v. State of Mississippi. 725So.2d 106 (Miss. 1998) and 819 So.2d 1169 (Miss. 2002).

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Exhibit

R

remain outside the presence and hearing of the courtroom except while you are testifying. Do not speak with any other witness or any other person about this case except by permission of the Court. Do not read any report of or comment upon the testimony in this case. You may, of course, speak with the attorneys. Just be sure there are no other witnesses around when you do so.

I think it -- for purposes for laying you a predicate, it might be nice if the doctor take the stand, seat the jury, and then lay your predicate, and then we'll go into your slides.

Doctor, would you just come up here and sit down, please?

You may seat the jury.

(The jury returned into open court, and the following proceedings were had.)

THE COURT: You may be seated, ladies and gentlemen. You may begin, sir.

JIM B. HALES,

called as a witness by the State, having been duly sworn by the Court to testify to the truth, the whole truth, and nothing but the truth, was examined and testified as follows:

DIRECT EXAMINATION

BY MR. PASK:

Q. Would you please state your name?

A. Jim B. Hales, D.D.S.
Q. And where do you live, Doctor Hales?
A. Irving, Texas. 3000 Wingren, Irving, Texas.
Q. And how are you employed?
A. I have a private practicing dentist.
Q. All right. Where do you practice?
A. 3000 North MacArthur, Irving, Texas.
Q. How long have you been so in practice?
A. Twenty-two years.
Q. What educational background do you have?
A. Bachelor of Arts from Oklahoma University; dental degree from Washington University, St. Louis, Missouri.
Q. All right. Do you have any specialized training in forensic dentistry or forensic odontology?
A. Yes, I do. I have the training at the Armed Forces Institute of Pathology --
Q. Doctor, let me interrupt you just a minute. Would you lean forward and speak directly into the microphone?
A. Sure.
Q. Okay. Go ahead.
A. I had the forensic dental training at the Armed Forces Institute of Pathology, Walter Reed Hospital, Washington, D.C., in '73.
Q. All right. Is there any kind of certification that you are eligible for in forensic odontology?

A. Yes, after five years of being the chief dental consultant for Dallas County Medical Examiner, I was allowed to take the exam for certification, which means -- it's called diplomate of the Board of Forensic Odontology. It's just a fancy word for saying I'm a Board-certified forensic dentist because I have a broad range of experience and deep enough number of cases that I would qualify for that. So I was certified in 1978 and then recertified in '83, and I am currently under recertification consideration now.

Q. And do you also teach some courses in forensic dentistry?

A. Yes, uh-huh.

Q. Where do you teach that?

A. Various dental schools: University of Texas, San Antonio; Baylor University; various dental groups; dental societies; dental study groups.

Q. You said just a minute ago that you were associated with the Dallas County Medical Examiner. In what way are you associated with them?

A. I'm the chief dental consultant for that organization since 1973.

Q. And how long have you been chief dental consultant?

A. Since '73.

Q. Okay.

A. Continuously.

Q. What do you do in that capacity?

A. I'm the dental consultant so that means if there's a question about dentistry, they will call me and I will go there, review the case, do the work.

Q. All right. What is forensic odontology or forensic dentistry?

A. Forensic is just the word referring to the law. It just means that there is something in the dental business that has some law aspect or some law treatment to it.

Q. And what are the various sub areas of forensic dentistry?

A. Bite mark, I think, is what you're really asking, and bite mark analysis is one of the key areas. Identification of a body is a most important area, one that we do a lot of business in, but the bite mark analysis is definitely an area.

Q. All right. What is a bite mark?

A. If a bite mark is inflicted on your body or on an object, an object like an apple, piece of cheese, bubble gum, it will leave a definite characteristic mark. And with comparison, we can say if it's a human bite or if it's an animal bite, and then we can get down to saying it probably was or it probably is or definitely is made by a certain person.

Q. So it's possible to look at a bite mark and compare it to an individual's teeth and determine if that individual made that bite mark in some cases.

A. That's right.
Q. How do you go about doing this initially?
A. Real basic, and I use that word because I think the jury needs to know that it's not a real scary thing, it's not a far out thing that you're going to be scared off about. It's just simply a matter of comparing marks, looking with the eye, comparing in size and shape and position and so forth.
Q. All right. What is the first thing that you normally do in a bite mark investigation?
A. Look at the bite mark itself on the body.
Q. All right. And when you're looking at the bite mark, what kinds of determinations do you make?
A. How distinct is it? Is it an apparent bite mark as opposed to multiple marks made from whatever? Are they distinct enough that I can draw some conclusions from those marks?
Q. All right. Can you make a determination based on viewing the bite mark whether or not it was made by a human or an animal?
A. Yes.
Q. And how do you go about doing that?
A. The relative marks relative to each other. In other words, we'll use the analogy of a dog mark. A dog has real prominent canine teeth. That's where they get their name. And those are going to be a real tearing type of a tooth. And then the little teeth called incisors aren't going to do very much.

So there would be such a drastic penetration of the sharp fangs, the canines, that those are going to distinguish that from the human bite which is going to be more level, more even, more closely spaced.

Q. And how would you compare a bite mark to an individual -- an individual's teeth?

A. Reviewing, studying, looking, studying more, many hours of just reviewing the slides of -- that were taken of the bite marks, the photographs, which could be black and white prints or color prints of the bite marks, and then doing the same for -- of plaster models, plaster casts of the suspect.

Q. Okay. And what kind of a plaster cast do you take of the suspect?

A. We use the same technique to get a plaster cast for this analysis as we would do for just studying the case in dentistry in general. In other words, it's an impression of the mouth. Plaster is poured in, and then the plaster becomes the plaster cast which is an exact replica, an exact reproduction of that person's mouth.

Q. And once you get this exact reproduction of the suspect's teeth, do you then compare it to the photographs of the bite mark?

A. That's right.

Q. Okay. Why are photographs taken of the bite mark?

A. The only way to preserve the evidence. In time the bite mark will change. It deteriorates it, withers away.

Q. All right. Were you called in on this case, the case involving a John Sweek?

A. Yes, I was.

Q. And were you called in approximately on June 21st, 22nd, or 23rd to view the bite mark?

A. 23rd.

Q. All right.

MR. PASK: May I approach the witness?

Q. (BY MR. PASK) I'm going to show you what has been marked and introduced into evidence as State's Exhibit No. 48, and I'm going to ask you if this is the bite mark that you viewed.

A. Yes, it is.

Q. And this was the person identified to you as John Sweek.

A. That's right.

Q. And where is the bite mark on this photograph?

A. On his left arm, forearm, down midway closer to the wrist than to the elbow.

Q. Approximately when did you view this bite mark?

A. The 23rd, evening, probably 7:00 o'clock.

Q. So that would be June 23rd, 1987?

A. June 23rd, '87, yes, sir.

Q. And so that was a few days after the body had already been brought in.

A. About three days is my understanding.

Q. And was it a fact that pictures were actually taken of the bite mark sometime prior to your personal examination?

A. Yes. They are typically taken and they were taken on this case on Sunday, the 21st?

Q. Yes.

A. Yes.

Q. Sometime after you viewed this bite mark, were you asked to take a dental impression of a person you came to know as Steven Mark Chaney?

A. Yes, I was.

Q. And when did you take this dental impression?

A. July 21st, '87, at the county jail.

Q. All right.

A. Lew Sterrett Jail.

Q. And specifically how did you go about taking this particular dental impression on him?

A. I greeted Steven Mark Chaney, told him that I was a dentist, and I was here to take these impressions, that I would treat him fairly and properly, that I was clean, I was using clean materials. I told him it would be very easy and nothing to be excited about.

I mixed the impression material in one tray, took it of one arch, mixed another tray later on to do the other arch, and then I used a bite wax to record his bite.

Q. All right. When you say you took one arch, what are you actually referring to?

A. Of the upper jaw and then of the lower jaw.

Q. Okay. What kind of material did you use?

A. It's called alginate. It's the standard dental impression material that is -- it's like a jello.

Q. All right. And then after you made impressions of the upper and lower arch, what did you do?

A. I preserved those in a baggie so that there would be no drying effect and they were not in contact with any water so that they would distort, carefully carried those back to my laboratory in my office on MacArthur in Irving, and poured plaster in them.

Q. All right. You said you also took a wax bite?

A. Yes, sir.

Q. How did you go about doing this?

A. Just put the wax between his teeth and had him close on that.

Q. All right. Do you have the model with you today that you made from those impressions?

A. Yes, I do.

Q. And do you have the wax bite mark with you?

A. Yes, I do.

Q. Can you point out the individual in court that you took those impressions from?

A. This gentleman, brown suit with a blue pen.

MR. PASK: Let the record reflect this witness has identified the defendant in open court.

Q. (BY MR. PASK) Do you have those with you today?

A. Yes, sir.

Q. And could you produce those?

A. Yes, sir.

A. This is an upper arch --

Q. Just a minute. Let me hold on for just a minute.

A. Uh-huh.

(State's Exhibit Nos. 75, 76, and 77 were marked for identification purposes.)

Q. (BY MR. PASK) Let me show you what's been marked for identification purposes as State's Exhibits 75, 76, and 77, and I'll ask you if you recognize these exhibits.

A. 75 would be the replica of Steven Mark Chaney's upper teeth. 76 would be the replica of his lower teeth. 77 is the wax bite.

MR. PASK: Your Honor, the State offers into evidence at this time State's Exhibits 75, 76, and 77.

MR. TATUM: No objection.

THE COURT: Admitted.

Q. (BY MR. PASK) How next did you proceed in your investigation?

A. Detective Westphalen asked me to review this --

MR. TATUM: I'm going to object to any conversation that he had with Detective Westphalen.

THE COURT: Rephrase your question. Objection is sustained.

Q. (BY MR. PASK) What did you initially do in this case?

A. After taking these impressions and pouring them up in the plaster, then I reviewed the plaster models with the photographs that I had received from the Forensic Institute of the bite marks of Sweek and made a determination in my mind that there was a comparison and there were no obvious discrepancies.

MR. TATUM: I'm going to object that the predicate hasn't been laid to qualify him as competent to give the testimony he is getting ready to give, Judge.

THE COURT: Well, I'm not sure about that. Let's settle this by making it question and answer.

MR. PASK: Okay.

THE COURT: Ask one question. Sir, answer the question and answer the question and we'll proceed that way.

MR. PASK: All right.

Q. (BY MR. PASK) Pictures were taken of the bite mark. Am I correct?

A. Right.

Q. And obviously from a picture, you can make a color picture or black and white picture, blow it up, and it can also be life-size.

A. Yes, sir.

Q. And do you have pictures with you today of the bite mark?

A. I surely do have black and whites, colors, and slides.

Q. All right. Specifically in reference to these slides, what are these slides?

A. Slides of the bite mark, slides of the plaster casts of the accused, and slides of the wax bite.

Q. All right. So you also took some photographs of the actual models made that you have showed the jury.

A. That's correct.

MR. PASK: May I approach the court reporter?

Q. (BY MR. PASK) Doctor Hales, there are a number of slides that you just referred to, and they have been marked as State's Exhibits 56 through 74.

A. Yes, sir.

Q. And obviously you've had a chance to take a look at them, have you not?

A. Yes.

Q. And do they fairly and accurately depict the bite mark?

A. Yes.

MR. PASK: Your Honor, the State offers into evidence State's Exhibits 56 through 74.

MR. TATUM: I have no objection, Your Honor.

THE COURT: All right. They will be admitted. Let me be sure I'm straight. 56 through 74 are the slides that have been previously marked that are now in the projector. Is that correct?

Q. (BY MR. PASK) Doctor Hales, have you done this --

THE COURT: Mr. Pask, I don't think you heard me. I'm sorry. If I am correct, 56 through 74 are the slides that were previously marked that are in the projector. Is that correct?

MR. PASK: That's correct.

THE COURT: All right. Those will be admitted. Now, continue. I'm sorry, sir.

Q. (BY MR. PASK) Okay. Doctor Hales, have you done these sort of comparisons in the past?

A. Other cases besides this case?

Q. Yes.

A. Yes, sir.

Q. And how many cases approximately have you done?

A. Bite mark cases?

Q. Yeah.

A. A dozen.

Q. Okay. Are you talking about ones that have actually come to court or just --

A. I have to think just a moment. No, sir, they have not -- all those have not come to court.

Q. But you've had specialized training in it as you have testified before.

A. Yes, yes, I have.

MR. PASK: My I approach the witness?

THE COURT: You may, indeed.

MR. PASK: I need to mark some photographs, Your Honor.

(State's Exhibit Nos. 78 through 85 were marked for identification purposes.)

Q. (BY MR. PASK) Let me show you what's been marked for identification purposes as State's Exhibits 78 through 85, and I'll ask you to take a look at these. And what are they?

A. Various size duplications of the bite mark on the body of Sweek and different ratios of enlargement.

Q. Do they fairly and accurately represent the bite mark?

A. They do.

MR. PASK: State offers into evidence State's Exhibits 78 through 85.

MR. TATUM: No objection, Your Honor.

THE COURT: All right. 78 through 85 will be admitted.

Q. (BY MR. PASK) What general characteristics do you look for when you're comparing a bite mark to a suspect and evaluating a bite mark and making a comparison?

A. Yes. Good question. The first question I ask myself is are the teeth that are on the marks -- well, let's say the marks would -- they would require certain numbers of teeth to be there to make them. Are those on the mark and on the suspect? To give you one quick example --

Q. Okay.

A. -- if a front tooth is missing of the suspect, the very front tooth, let's say the right front tooth is gone, and yet there are marks on the body where that tooth should be, then that suspect is not a consideration.

Q. All right. What other things do you initially look for?

A. We look first to see if there are teeth in the suspect that will match up with the victim. Then we ask -- look for the size of the arches.

Q. What are you talking about when you're talking about arches?

A. The size of the arches, that's the shape of the jaw, somewhat of a horseshoe shape. For a big person, my face is rather large and I have a rather large curve. If I were a child, I would have a much narrow arch because I haven't grown.

Q. Could you point that out on your models?

A. Yes. The size of this arch is how far it is across here, here, here. At any given point if you measure across, that's the size of that arch. Then the shape of the arch is also important. It could be more of a "V" shape. The teeth can be real "V" shape, or they can be real flat across the front and square on the sides.

Q. Okay. What other characteristics do you look for?

A. We look for the position of the teeth and the position of the marks. Everything I say regarding the teeth of the suspect I would also say I'm going to be looking for on the marks themselves. In other words, the position of the teeth, if the tooth is jutting out toward the lip, is a very buck tooth, that's going to be characteristic as opposed to one that is positioned way back toward the throat. We look at each teeth on its relative position toward the cheek versus toward the mouth -- the throat.

Q. All right. What other characteristics?

A. Then the rotation of the teeth. If we have a tooth that's what we call straight, it's going to be in the -- what we consider a straight alignment next door to each other. That is a good, straight rotation. But if one tooth is turned 90 degrees from its normal, from the typical, that's going to have a definite difference on how we look at it and what kind of mark it will make.

And then the last thing is going to be the height, how pointed, how sharp versus a tooth is compared to its neighboring tooth, or another way to put it is how level are all the teeth. If they are very flat and they are all together, then it's going to make one big bunch of marks. If we have a real long, pointed tooth and then a real short one next door, the long point is going to make a real distinct mark compared to the little short one.

Q. And do you look at the spacing between the teeth, too?

A. Spacing is a real important thing. Let's use the jack-o'-lantern type analogy because we can all picture that. it was just a few weeks ago that we had them around our house. But if you have a great big gap and then a tooth and a gap and a tooth, you can see that that's exaggerated, but it's showing the relationship of one tooth to another.

If there's a long space between them, it will really show up on a bite mark. If they are next door to each other, close together, then it will just make one continuous mark.

Q. Are those all the characteristics that you look at briefly?

A. That's correct.

Q. All right. And what do you do after you look at these characteristics? What are you generally trying to do?

A. We have so many characteristics to look at for each tooth. We have its relation to its neighbor, whether it's rotated or straight, whether it's pointed or flat, whether it's out toward the lip or back toward the throat. So we have a lot of things to review, and I look at all of those and look at them many times.

Q. And after you look at all these characteristics and compare these characteristics from the teeth to the bite mark, what general conclusions can you arrive at?

A. Either there is a matchup and everything is what I consider the key word here is going to be consistent. Everything seems to be on the same path, everything seems to match up, and there is nothing glaringly wrong. There's no real blow-it-out-of-the-tub discrepancy.

Q. So you could eliminate someone. Isn't that correct?

A. We call it inclusion or exclusion.

Q. Okay.

A. You're included if you have things that are similar. You're excluded if there's an obvious discrepancy.

Q. All right. Is there any kind of sheet that you make tabulations on?

A. Yes. We have the American Board of Forensic Odontology -- that's the word for our certification board which I'm a member of, and we have used a scoring analysis sheet. And when we use that sheet, then we have some uniformity to how we are comparing bite marks. Bite marks are difficult to do and it's subject to one's interpretations, subject to one's experience. So this sheet gives us some uniformity. And the score on this particular case --

Q. Don't go into the score yet. Let's go through the individual case.

A. All right.

Q. All right. Let's talk about the individual case now.
A. All right.
Q. In this case--you may want to step down and show the jury on your exhibits--what conclusions could you make about the bite mark in general?
A. I would like to show some slides.
Q. Okay.
A. And also if I could have the floor, so to speak, I'd like to tell the jury some things I'm about to show them --
Q. All right.
A. -- kind of set the stage.
Q. All right. Why don't you step down. Do you need the lights off at this point?
A. Just for a moment. Comparing bite marks --
Q. Doctor, we've got to keep it in pretty much question and answer form.
A. Okay.
Q. Okay. What did you do in this case when you initially started making your comparisons?
A. I studied the slides, the plaster casts, the wax bite. I looked at them in every direction humanly possible.
Q. Okay. You're going to have to speak towards the jury, too.
A. Yes, sir.
Q. Can you educate the jury on some concepts that you're

going to be using? What is one of the concepts you're going to be using?

A. The concept is to look at every tooth and look at where I think the mark is that's going to match that tooth and see if they jive. If I find any place it doesn't jive, then that's going to be a negative. That's going to be a strike against it. On the other side of the coin, each tooth I see and each mark I see that seem to match, that's a positive point. That's another point in favor of saying there is a matchup. So we have --

Q. Okay. Are there any other kind of concepts you need to educate the jury on?

A. No.

Q. All right. Can we start with the slides?

A. Yes. I would like to show you some slides of the bite mark so we can be sure we are talking about the same thing, show you slides of the plaster casts of the suspect, then show you a keyword type tracing so we can talk together and use a word that means something to both of us, mean the same thing to both of us.

Q. Doctor, I believe we're going to have to refer to these slides by exhibit numbers.

A. This was 74.

Q. Here we are viewing State's Exhibit No. 74. What do we have here?

A. This is the left arm of John Sweek. This is the ruler indicating the medical examiner's identification name. These are rulers in inches. They are scale rulers that are just laid on the arm gently and then photographed. This will tell us the width of the arch. And then by comparison of the little spaces here, we can figure out how wide or how sizable a mark is.

Q. Obviously these aren't life-size. Obviously this isn't a life-size reproduction.

A. Uh-huh, that's right.

Q. We are talking about a projection from a slide.

A. That's correct. This is enlarged several times. This is a close-up, and what I did from the first slide to this slide is to invert it.

Q. Is this State's Exhibit No. 56?

A. This is 56, yes, sir.

Q. Okay. What do we have here?

A. This is inverted from the first slide. Inverted means it's turned upside down. And why did I do that, is because you can't read the numbers this way. So I didn't turn it that way because you can't read the numbers. It's because this is the orientation of the way the bite was made. In other words, I like to consider the top teeth making the top part of the mark and the bottom teeth making the bottom part of the mark.

So all the slides I show you from this one forward will be this orientation. These are the top teeth, bottom teeth. The numbers are typically upside down because that's the way the photographer did them.

Q. And State's Exhibit No. 57?

A. A different view of the same mark. Each view has a slightly different position up and down, left and right, forward and backward, which throws a different lighting or a different cast onto the mark themselves.

Q. Why is that important?

A. You can see one thing in one view, and you'll miss something. And then you'll pick up that same item in the next view and lose something there that you had on the first one.

Q. Obviously we aren't dealing with a totally flat surface here.

A. That's a curved surface, and things will look differently according to the way the light reflects on the marks.

Q. And it is therefore important to take different angles.

A. Very important. This is State's Exhibit 57 showing the same mark. It's a very clear slide. It does not have quite the sheen that the last slide had, so it shows some things that the other slide did not show.

Q. What number is this next slide?

A. 58.

Q. And what are we viewing here?

A. Same mark, different angle, not quite as clear as the previous slide in some aspects.
Q. Let me interrupt.
MR. PASK: Can all the members of the jury see the picture?
Q. (BY MR. PASK) Okay. You may continue.
A. In this particular case one of the workers at the Medical Examiner's Office was holding the slide down to show some curvature of the arm.
Q. This is State Exhibit 59 showing the plaster cast of the suspect Steven Mark Chaney.
Q. And is it a view of the plaster cast that's already been introduced into evidence?
A. Yes, sir.
Q. What angle are we looking at here?
A. Straight on in the lower front teeth.
Q. Straight on.
A. As if you were looking right at me looking at my lower front teeth.
Q. All right. What do we have here?
A. State's Exhibit No. 80 shows --
Q. 60, I believe.
A. -- 60, I beg your pardon, shows the right side of the lower plaster cast of Chaney.
Q. Okay.

A. And this is the left side of the plaster cast.
Q. All right. And here we have State's Exhibit No. 61 is the left side?
A. Yes, sir.
Q. All right. And State's Exhibit No. 62?
A. Shows a biting view, a straight-on look at the biting surface of the lower teeth of Chaney. Exhibit 61 shows a straight-on view of the upper teeth of Chaney.
Q. What about State's Exhibit 62?
A. I'm sorry. I backed up. This is the right side view of the upper teeth of Chaney. This is the left side view of the plaster cast of Chaney. I'd like to point out one thing here so that we can talk about it in a moment, and that is the spacing between this bicuspid and this cuspid. A while ago when we were talking about spacing, it's a key thing to realize there's a lot of space between this sharp point and this point here. This area here when pushed onto something won't make a mark.
I don't know which exhibit this is.
Q. What do we have here?
A. This is the biting view of the upper arch of Chaney. This view is the wax bite looking at the bottom teeth biting into a wafer of wax.
Q. And it is a picture of State's Exhibit No. 77 here?
A. Yes, it is.
Q. Of this impression right here, Doctor?

A. Yes, sir.

Q. And is this another view?

A. Exhibit 77 is the upper teeth on the wax wafer bite registration of -- made by Chaney.

Back to the bite mark to give another view to try to correlate what we have been seeing of models and seeing how it might relate to the bite mark themselves.

I beg your pardon. Pushed the wrong button.

Another view of the bite mark in a very oblique angle photograph of the bite mark, then a straight-on view of the wax bite upper part made by Chaney.

And that's all the slides.

Q. Doctor, are there some keywords that the jury needs to know?

A. Yes, there are. Using this tracing, we can place it here so we can all see it and talk about it together.

Q. Okay. You might move it just a little bit the other way. There we go.

A. The keywords are going to be front teeth. Everybody knows what front teeth are. There are going to be four incisors. That's our name for it in dentistry. It just means the very front four teeth. We have the two in the very center and then the next ones after those are also incisors.

So we have four incisors. And I use the word jack-o'-lantern to depict again that is where if we want to make a jack-o'-lantern up, we'll leave a tooth right in front and then we'll cut a space after that and then leave another tooth and space after that. Now, we are talking about front teeth.

Then the next keyword we'll use are the canines.

Q. What does that mean?

A. The canine teeth are the dog teeth, the ones that are long and pointed, and they are on the sides of our mouth, right at the corner of our mouth. And those are going to be right next door to those four incisors. So now we've got four incisors that are about the same length in size. We'll have two pointed teeth that are called canine teeth.

Q. Are we talking about the top teeth and the bottom teeth or --

A. Yes. In the typical lay usage of these teeth, we'll refer to them as eyeteeth because they are right in line with our upper eye.

Q. Why don't you point out on the model where these teeth are located for the jury?

A. You bet. We have one, two, three, four incisors, one, two, three, four. And then we have these rather pointed ones here and here, pointing to right here, right here, that are called the eyeteeth or canines. So we're using the same words meaning the same tooth. Eyeteeth because they are right here by our eye and canine teeth because they look like dog's teeth because they are long and pointed.

And then the reverse of that are the teeth down here at the bottom. We call those the stomach teeth because they are down lower. But they are going to be these corner teeth that are rather long and pointed, right here on these two corners. And in between those we have four incisors. This is for you and for me. This is typical.

The size of the arch -- we've covered a lot of these questions, but I'll try to do it one more time.

Q. Why don't you show us the arch on the model?

A. Yeah. The size of the arch for this person is -- we can measure anywhere across that arch and measure that on this person, compare it with anybody else or any bite mark. And you will either say they seem to jive or they seem to not jive. They match or they don't.

His size of the arch is from there to there, or if we want to measure from here to here, it's the same thing. We just measure across and that's going to be the size of this person's arch.

Q. Do we measure the upper arch and the lower arch?

A. Yes.

Q. Would they necessarily be the same size?

A. No. The lower arch is typically smaller because the lower arch, when closed together, fits on the inside or underneath the top teeth. In other words, the top teeth typically will overlap the bottom teeth. So therefore the size of the upper arch has to be bigger than the size of the lower arch or they couldn't overlap.

The shape of the arch is important. Earlier I was mentioning a broad look versus a V-shape look or a real uniform look. This has a definite shape because of these four front upper teeth here having caps on them. They are very even and very straight.

Q. How do you know those teeth have caps on them?

A. Because I examined Steven Mark Chaney's mouth. And, number two, on the models these are apparent to a dentist, to the trained eye, that they are caps as opposed to natural teeth. But the point I want to make about this is the four incisors here are very even. And when we have capped teeth we typically have very even teeth because that's the intention of the lab technician is to make them very even and very nice and very straight. We wouldn't want to make them crooked when we have a choice of making them straight. Now, in the natural dentition, the natural teeth where they are not capped, we typically will have slight, little variations in length, rotations, and positions.

This is important to notice on these they are very straight. And then on the other hand it's very important to notice on the lower model they are not very straight. They are very erratic, very uneven.

Q. Okay. I guess now we move on to the position of the teeth and the rotation of the teeth, and I guess you have sort of outlined for that.

A. I think we have.

Q. All right. Could you show us there on your model what you mean by position of the teeth and rotation of the teeth?

A. Yes, sir. We might need better lighting now. If I can show you in the middle here where everybody can see, the position of this pointed tooth right here has quite a space between it and this pointed tooth right there. So I said that this is from this point to that point is long. There is a distinct gap in the middle. There's a distinct space right in this section where there is nothing.

Q. So we are talking about spacing there.

A. Spacing. Then when we go from this one incisor to the next incisor, there is no space or such a small, little bitty, V-shape gap here that it's essentially no space. So we have a large space here. We have almost nothing between these two. So we have a good comparison of spacing. We have a lot in one area and we have almost nothing on another area. We have the very straight look of the front upper teeth.

Then let's look at the lower teeth here. This is the point of position. This tooth here that I have got my pen on is very much back toward the throat in its position compared to its neighbor tooth right there. That's another key thing. That tooth is very much toward the back, toward the throat. This tooth is somewhat toward the back, toward the throat. These teeth on the other hand are forward. The stomach teeth are more forward.

Q. What do you mean by rotation of the teeth?

A. Rotation, on one tooth here we have a definite rotation, but it is somewhat hard to show you. From that distance it's going to be hard for you to visualize perhaps, but this tooth is slightly rotated out toward the front. It's not a real significant rotation, so the key thing here is you might ask, "Well, why are you talking about rotation?" The point is we don't have any rotation up here. Everything is straight. The point being if we have rotation on the marks we don't have here, then we don't have a matchup.

Q. What do you mean when you talk about biting edges?

A. Biting edges will be if we laid this down on the table and could look right at it, we could say, "Well, these teeth all seem to be about the same length right there." Everything is about the same length on the biting edges. And on this one basically the same biting level except one seems to be taller. That taller one may do something on a mark that's significant so we want to keep our thought about that.

Q. All right. And I believe you have already gone over spaces, haven't you?

A. Yes, sir.

Q. And, again, you're looking to see whether the bite mark is consistent or inconsistent with a suspect's teeth.

A. That's correct. And my conclusion at this point --

MR. TATUM: I'm going to object to any conclusions as to this if that's what he's getting ready --

THE COURT: I beg your pardon, sir?

MR. TATUM: I'm going to object to any free narrative conclusions as to this case if that's what he's getting ready to do.

THE COURT: Sustained.

MR. PASK: Okay.

THE COURT: Let's make it question and answer.

MR. PASK: All right.

THE COURT: Does he need to continue down there to demonstrate or do you want him sit down?

MR. PASK: May we approach the bench?

THE COURT: Yes, you may, indeed.

(There was a discussion out of the hearing of the jury and the reporter.)

THE COURT: Ladies and gentlemen, the attorneys tell me that they think that this is probably a pretty good place for us to conclude today's testimony. It is 4:00 o'clock, and they think this is as good a place for us to stop and start up in the morning.

Let me see the bailiff just a moment, please.

(Off the record.)

THE COURT: Ladies and gentlemen, I am going to release you at this time. Let me remind you one more time not to discuss anything you have heard so far among yourselves nor let anyone else talk about this with you. And, once more, when you go home, you have to not say anything to family or friends. And we'll start up in the morning at 9:00 o'clock.

And I do believe that we're going to need to visit with Mr. Hamby for a moment, so if the jury will be retired and excused save and except for Mr. Hamby.

Sir, you may step down at this time, if you would like to gather up your things.

THE WITNESS: Yes, ma'am. Thank you.

(The jury was retired, after which time the following proceedings were had out of the presence and hearing of the jury.)

THE COURT: If Doctor Hales could leave the courtroom at this time, I need to take up this with Mr. Hamby, please. We won't be a minute and you can come right back, sir, and pick up all your things. I need to let him go home, too.

(Doctor Hales was excused from the courtroom.)

THE COURT: Mr. Hamby, would you come forward, please? The bailiff has told me that you have done exactly what I asked you to in that if I asked you if you heard anybody talking about this case, to please notify us. Will you simply let me know what you heard and what happened?

JUROR HAMBY: I was on the elevator behind the first medical examiner. He was talking to one of his friends, and he said it was okay, "I got -- I was able to do something with number one and then number two --" And I tapped him on the shoulder and I said I was in there and don't -- you know, you don't need to talk about this. And he said, "I didn't say anything."

THE COURT: Well, I really appreciate you telling us. I'm so pleased to know that you stopped him before he could have said anything that would have in any way been any evidence for you to receive outside. That is absolutely all you heard and you stopped him.

JUROR HAMBY: Yes, ma'am.

THE COURT: Thank you very much. I appreciate that. I was going to ask the attorneys if they wanted to ask him anything. Sir, do you have anything to ask him?

MR. PASK: That really doesn't mean anything to you, does it?

JUROR HAMBY: No, sir.

MR. PASK: Okay.

JUROR HAMBY: To me the only thing it could possibly mean was he was getting ready to say something about the other girl, the girl, and he didn't say anything because he was just talking shop with a colleague, and I was just somebody that was on the elevator. And, you know, I didn't pay any attention to him as we got on the elevator nor he I. And when he started talking, I recognized his voice. That's when I recognized who he was.

THE COURT: Go ahead if you have something else you want to ask him.

MR. PASK: So you'll just disregard that entirely.

JUROR HAMBY: I didn't hear anything that would changed anything whatsoever. It's just that I felt that I needed to say something about it in case there was --

MR. PASK: Okay. Thank you.

THE COURT: Sir, would you like to ask a question?

MR. TATUM: I didn't hear what you heard.

JUROR HAMBY: The medical examiner was standing there, and he was talking to one of his colleagues. He said something about "I got through number one okay, and I was getting ready to do something with number two." And then I tapped him on the arm and told him I was in there. He saw the jury badge, and he said, "I didn't say anything." And he said nothing else on the ride down.

MR. TATUM: I don't have any further questions.

THE COURT: Well, I want to tell you how much we appreciate it. You did exactly what I wanted you to do so I sure appreciate it. How's your back holding up?

JUROR HAMBY: I'm fine.

THE COURT: Good.

JUROR HAMBY: I'll be okay.
THE COURT: Thank you.
JUROR HAMBY: Just a little uncomfortable --
THE COURT: You feel free anytime you need to get up to let us know. I'll see you in the morning at 9:00.
JUROR HAMBY: Okay. Thank you.

(The juror was excused from the courtroom, and State's Exhibit Nos. 86 through 111-g were marked for identification.)

(Court was adjourned on the 9th day of December, 1987, and reconvened on the 10th day of December, 1987; at which time, the following proceedings were had:)

THE COURT: Is everybody ready? Seat the jury.

(The jury returned into open court, and the following proceedings were had.)

THE COURT: Please be seated. Good morning, ladies and gentlemen of the jury.
Mr. Pask, if you're prepared to go forward, you may continue.
MR. PASK: Thank you.

DIRECT EXAMINATION continued

BY MR. PASK:

Q. Are you the same Doctor Jim Hales who was testifying yesterday?

A. Yes, sir.

Q. Doctor, I have some pictures down here on the counsel bench that you've had a chance to take a look at --

A. Yes, I have.

Q. -- I believe, previously. And the first stack is marked State's Exhibit 87, and then we have 87-a right here.

A. Yes, sir.

Q. Could you identify this?

A. Yes. Those are photographs I have used in my analysis.

Q. All right. What do we have here on top?

A. That's a tracing of those photographs. It's called a clear overlay tracing.

Q. And will this aid your testimony to the jury?

A. Yes, it will.

MR. PASK: Your Honor, the State offers into evidence State's Exhibits 87 and 87-a.

THE COURT: Let me ask you, sir: Is "A" the tracing?

MR. PASK: No.

THE WITNESS: No.

MR. PASK: 87 is the tracing. "A" is the picture.

THE COURT: Thank you.

MR. TATUM: Can I take the witness on voir dire, Judge?

THE COURT: You may, sir.

MR. TATUM: May I approach the witness?

THE COURT: You may, sir.

VOIR DIRE EXAMINATION

BY MR. TATUM:

Q. Let me show you what's been marked State's Exhibit 87 and 87-a, the combination of both, and you said that the clear transparency is a tracing?

A. Yes, sir.

Q. Okay. A tracing that you did?

A. Yes.

Q. Okay. And you traced it by -- How'd you do it? You tell me.

A. Laid it over this photograph and got the upper left corner so that the alignment of the paper to the photograph was basically where I could put it back again each time. And then I traced over the marks that I could see through on the transparency.

Q. Did you lay it over 87-a?

A. Yes, I did. And each one of the other ones at various times I have used all of them to put it over to see -- get characteristics from each different photograph.

Q. So you have overlaid 87 over a number of pictures?
A. Yes, sir.
Q. Not just 87-a?
A. That's correct.
Q. Okay. So the transparency overlay, 87-a, is not a true outline of 87-a.
A. No. I beg your pardon. Let me just check one moment, please. This particular one is my actual tracing over 87-a. I did use the same tracing on the other photographs to try to verify and confirm various points, but this is the overlay on this particular photograph only.
Q. Okay. Well, let me ask you this: Can you position this and show me how you traced the whole mark?
THE COURT: Yes, sir?
MR. PASK: Never mind.
(Witness complies.)
Q. (BY MR. TATUM) So your tracing does not include the whole bruising area or mark here, does it?
A. That's correct.
Q. Okay. So you're not saying that this overlay, 87, accurately represents this whole mark here, are you?
A. That's a fair statement.
Q. Okay.
MR. TATUM: If this is offered to show a duplicate of the mark on 87-a, I'm going to object to it on that basis,

Judge. If it is offered for a different purpose, maybe we can explore that possibility. But as far as showing an exact rendition through outline or otherwise or tracing of the mark shown on 87-a, he said it doesn't accurately show that.

THE COURT: Do you have anything to say for that, sir?

MR. PASK: May I ask the doctor one more question?

THE COURT: You surely may.

Q. (BY MR. PASK) What does State's Exhibit 87 show?

A. 87-a is the photograph of the bite mark. It shows a lot of the characteristics as we have all seen in various forms. The tracing, 87, is part of the salient features, the key points of comparison that I feel are significant. I deliberately excluded some marks because there are some marks for instance that I would not want to trace, for instance, a mark way down on the other part of the hand, near the hand, that has nothing to do with the bite mark probably, nor would I trace the hair or the whatever. The point is this tracing is trying to extract key features only.

MR. PASK: State offers it.

MR. TATUM: Let me ask him another question if you don't mind, Judge.

Q. (BY MR. TATUM) In regard to your tracing, you excluded the bruised area down here which has nothing to do with hair or the mark down here. Is that correct?

MR. PASK: Your Honor, I'm going to object to this as going beyond the scope of voir dire.

THE COURT: Let's keep this down into the voir dire section. So if you can tie this into the voir dire portion of what I'm allowing you to do, that's all right.

MR. TATUM: That's what I'm saying.

Q. (BY MR. TATUM) So this does not accurately reflect the whole mark?

A. That's right.

Q. It represents your interpretation essentially in regard to the mark.

A. Yes, sir.

Q. Is that a fair statement?

A. That's a fair statement.

Q. Okay.

MR. TATUM: We would still object if it was offered to show an exact tracing duplication of the whole mark.

THE COURT: Objection overruled. It will be admitted. Let the record reflect that both 87 and 87-a are admitted.

DIRECT EXAMINATION continued

BY MR. PASK:

Q. Doctor Hales, let me show you what's been marked for identification purposes as State's Exhibit No. 88 and State's Exhibits 88-a, 88-b, 88-c, 88-d, 88-e, 88-f, and 88-g and ask you if you can identify that.

A. Yes, I can. The 88 is the tracing that I made over the photographs 88-a and 88 through g.

Q. All right. And will these also aid your testimony to the jury?

A. Yes, they will.

MR. FASK: State offers into evidence State's Exhibits 88 and 88-a through 88-g.

MR. TATUM: A couple questions on voir dire, Judge?

THE COURT: For voir dire purposes, yes.

VOIR DIRE EXAMINATION

BY MR. TATUM:

Q. In regard to State's Exhibit 88, which is the transparency --

A. Yes, sir.

Q. -- the same thing, the outlines that you have made on the overlay do not encompass the whole marking area. Is that correct?

A. That's correct.

Q. Okay. It's just parts of it that you have outlined.

A. Yes, sir.

Q. Okay.

MR. TATUM: We would object to 88 if it's offered for the purpose of showing the whole mark.

THE COURT: Objection is overruled. 88 and 88-a through g will be admitted.

DIRECT EXAMINATION continued

BY MR. PASK:

Q. Let me show you what's been marked for identification purposes as State's Exhibits 90, 91, 92, 93, 94, 95, 96, 97, State's Exhibits 105, 104, 103, 102, 101, 100, 99, and 98, and also State's Exhibits 106 and 107. I'll ask you if you can identify these.

THE COURT: I'm going to have to ask you, sir, to give me the numbers again. I got lost.

MR. PASK: Actually they all did run consecutively from --

THE WITNESS: 90 through 107.

THE COURT: 107?

MR. PASK: 90 through 107.

THE WITNESS: Yes, ma'am. I recognize these as photographs of the bite mark, the plaster casts of the suspect, and wax bites of the suspect.

Q. (BY MR. PASK) And do they show various angles of the bite mark and --

A. Yes, they do.

Q. -- the wax impressions?

A. That's correct.

Q. And would they aid your testimony to the jury?

A. Very much.

MR. PASK: State offers into evidence State's Exhibits 90 through 107.

MR. TATUM: No objection.

THE COURT: Admitted.

Q. (BY MR. PASK) Finally, let me show you what's been marked as State's Exhibit No. 111, 111-a, 111-b, c, d, e, f, and g, and I'll ask you if you can identify these.

A. 111 is the tracing that I made. 111-a through g are photographs that I have used the tracing in various ways to make it from these other photographs that I just mentioned, a through g.

Q. Would these exhibits aid your testimony to the jury?

A. Yes, they will.

MR. PASK: State offers into evidence State's Exhibit 111 and 111-a through g.

MR. TATUM: Let me ask a couple questions.

<u>VOIR DIRE EXAMINATION</u>

BY MR. TATUM:

Q. As to the overlay transparency 111 --

A. Yes, sir.

Q. -- it's a tracing from the wax bite. Is that right?

A. Yes, sir.

Q. Okay. Does it show all the teeth? Did you trace all the teeth?

A. Just the ones in the front portion of the mouth, so not every tooth is on the wax bite.

Q. Okay.

MR. TATUM: I would object if it's offered to show all the teeth of what it was traced over.

THE COURT: Objection overruled. Be admitted.

DIRECT EXAMINATION continued

BY MR. PASK:

Q. Doctor Hales, do you want to step down and show the jury some actual characteristics of the bite mark and comparison to the defendant's teeth?

A. Yes, sir.

Q. All right. Okay. What are we looking at here on State's Exhibit No. 111?

A. This is a tracing of -- made over, rather, the photograph like this particular photograph which is the photograph of the wax bite showing the upper teeth of the suspect.

Q. And what number is that, Doctor?

A. 111-a.

Q. 111-a. What are we looking at here in 111-a? Why don't you come show the jury? 111-a is a black-and-white photograph looking down on the wax bite, down on meaning the biting direction made by the suspect.

Q. And is this the same picture right here?
A. This is the wax bite. This photograph, 111-a, is in this direction.
Q. Is this an actual size photograph?
A. This is enlarged.
Q. Do you know how much this is enlarged?
A. No, sir, I do not.
Q. All right. But you do know it's enlarged.
A. It's enlarged, and it's done so to portray certain points.
Q. All right.
A. Then photograph number 2 is of the underside of the wax bite, which means it's the recording of the lower teeth --
MR. TATUM: Can I interrupt you? Can we do it by exhibit number?
THE WITNESS: Yes, sir. I'm sorry. 111-b is a black-and-white photograph looking at the lower teeth of the wax bite. This is the wax bite, Exhibit No. 77, looking at it this direction.
Then I used photographs 111-c through g. I placed the tracing over these different areas -- excuse me -- I put the tracing over this to see if the points match up consistently. And from that I extracted --
MR. TATUM: Judge, I'm going to object to any conclusions on a free narrative situation.

THE COURT: Let's make it question and answer.

Q. (BY MR. PASK) Okay. What did you do next?

A. I used this tracing first to record the front teeth from the wax bite. So this is to record the marks of the victim.

Q. Do we see every tooth there on the tracing?

A. We do not. This is stopping in the area of the front teeth because apparently there were not back teeth involved in the mark.

Q. So you only traced the teeth that you felt were involved in the bite mark?

A. That's correct

Q. And which teeth are on top there?

A. These are the upper front teeth like the canines, as we were talking about yesterday, or the pointed teeth, and then there are four incisors in between. Down below there's a canine and a canine and four incisors in between. This mark is one back tooth, a bicuspid, we call it.

Q. All right. And what does this tracing allow you to do?

A. The tracing is made over the wax bite of the suspect. Then I used that to put over the photographs of the bite mark of the victim to see if they match or don't match.

Q. All right. After you did that, how do you next proceed?

A. Just put the tracing over these marks and just look and look and look.

Q. All right. Can you show the jury that?

A. Yes. A little more light would be helpful.

Q. Okay. What do we have here first in State's Exhibit No. 111-c?

A. Well, 111-c is a black-and-white photograph of the bite mark of the victim Sweek.

Q. Is it an actual size of the bite mark or is it enlarged?

A. It's enlarged.

Q. And is it enlarged to the same degree as the wax -- the photograph of the wax impression?

A. That's correct.

Q. All right. And we're talking about the picture here. First of all, what do we see here when we're looking at this black mark here. This is obviously the bite mark. But when we look at this black area, what exactly are we looking at?

A. We're looking at an injury to the skin with subsequent bruising, drying damaging effect.

Q. All right. And then what do you do with your tracing?

A. The tracing will show the general outline of the arch form. We talked about the curved amount, the curve of the jaw. That's the arch form. So I want to see first if it's matching the arch form, and it is.

Q. All right. How can you tell that?

A. Just by placing the suspect with the bite mark, there is a matchup.

Q. All right. Could you show the jury, this group of jurors first, how that matches up?

A. The upper teeth have a very smooth curve, very smooth arch form. There is no particular tooth sticking way out, no particular tooth that is like a buck tooth. Everything is in a nice, smooth curve. When the bite is made -- was made, it made a smooth curve on the upper teeth.

A JUROR: Can we see that down here?

MR. PASK: We're going to move down there in a minute.

Q. (BY MR. PASK) You haven't really shown these jurors.

A. Yeah. Maybe we can show them.

Q. You may have to tilt it a little bit.

A. Okay. We have a smooth curve of the upper teeth here. Then we have some different points down here on this lower mark which represent the unevenness of the suspect's teeth.

Q. Now, obviously we have some marks outside the actual teeth.

A. Yes.

Q. Why does that occur?

A. Okay. In the biting action, the actual mechanics of the bite, the bite starts with the given point of contact. And then as it's squeezed together, it's going to tend to have a scraping action, a bruising effect down deeper. But it won't have a bruising effect away from the bite. So, in other words, the outer parameter, the outer limits of the bite mark first engage. Then everything will be bruising toward each other. It's as if the forces are the lower teeth and upper teeth toward each other.

Q. So the bruising is going to be larger than the actual teeth.

A. That's correct.

Q. All right. And were both the upper arches and lower arches consistent?

A. Yes.

MR. TATUM: I'm going to object to him saying any conclusion. The proper predicate has not been laid to show that he's competent to state any conclusion as to what is being asked, Judge.

THE COURT: Are you speaking of the witness?

MR. TATUM: Yes.

THE COURT: Overruled.

MR. TATUM: Thank you.

Q. (BY MR. PASK) How did you tell the lower arch was consistent?

A. By the particular arrangement of the teeth, meaning that we have some spaces that we discussed yesterday, we have spaces between some teeth; we have some protrusions and retrusions, or we have a tooth that is more toward the cheek on one case and another tooth that's more toward the throat on another tooth. So it's this erratic arrangement that makes this specific pattern of marking.

Q. Okay. Why don't you step down here and just show as an overview how the arches match up.

A. The upper arch is a very smooth curve. The suspect has a very smooth arch form on the uppers as I've shown many times. The lower arch, there's an erratic pattern of a rather pointed or sharp tooth, there's a space to another tooth. That tooth sits behind some of the other ones. It's an uneven arrangement which the suspect has.

Q. All right. Why don't we step back down here and go over each individual tooth and space.

A. In dentistry in order to keep some uniformity --

MR. TATUM: Can we have this question and answer and not free narrative, Judge?

THE COURT: Yes, you may. Question and answer, sir.

Q. (BY MR. PASK) Okay. How do you number teeth?

A. In dentistry we have uniform nomenclature and that's to number everything from 1 through 32. There are 32 normal teeth. We start on the upper right side with number 1 as the very back tooth which is a wisdom tooth, and we count right around the arch, meaning 8 and 9 are going to be the front ones, ending up here on 16, drop down to the lower arch and count from

17 on around to 32.

Well, that's hard for you to remember, I'm sure. There are a lot of numbers there and there doesn't seem like there's any sequence. But at least I can talk about it and keep on referring to tooth No. 8 and know exactly what tooth I'm referring to. And I will help show you that each time.

Q. Now, do we see all 32 teeth here in this bite mark?

A. No.

Q. Approximately how many teeth do we see?

A. 13.

Q. All right. Okay. Okay. Why don't you point out the key characteristics tooth by tooth.

A. Okay.

Q. Okay. Let me show you what's been admitted into evidence as State's Exhibits 87 and 87-a, 87 being the tracing and 87-a is again the picture.

A. Yes, sir.

Q. And what do we see here?

A. This is a very good photograph of the bite mark after reviewing many of them. This is a real clear one, straight on, very good material to work with. We have tooth No. 5 right in this area. Tooth No. 5 is going to be my right bicuspid which is the tooth behind my eye tooth, and there's a space to tooth No. 6 which is the eye tooth.

On this particular model of the suspect, this is going to be tooth No. 5, and there's a considerable space to tooth No. 6. This is tooth No. 5 -- I beg your pardon. I have turned it backward showing you. I beg your pardon. Tooth No. 5 to tooth No. 6.

I would like to point out that the mouth is a mirror image of itself. The left side, right side look the same depending on how you are looking at it. The spacing here and the key thing that I want to demonstrate is tooth No. 5 is right here, a big gap to tooth No. 6 on the bite mark itself.

Q. What tracing is this of right here? Is this a tracing of this actual picture?

A. This particular photograph is the one I used to make this tracing and that's the only one I used to make this tracing.

Q. Okay. So this isn't actually a tracing of the suspect's teeth. It's just a tracing of this picture.

A. That's correct.

Q. Okay. And you're just going to point out some key characteristics --

A. Yes.

Q. -- of the bite mark.

A. That's correct. So we have tooth No. 5 and then we have a considerable space. We have tooth No. 6 and there's some space. On the actual model of the suspect we have tooth No. 5, space, tooth No. 6, space, then 7, 8, 9, 10, four incisors.

That will be represented here as 7, 8, 9, 10, a long, continuous bruising effect. Why is that? Because --

MR. TATUM: Judge, can we have it question and answer.

THE COURT: You may.

Q. (BY MR. PASK) Okay. Why is that?

A. Because they are essentially the same length and the same thickness and the same position relative to each other. They are a nice, smooth, straight curve.

Q. Okay. We are again looking at the upper teeth here.

A. That's right.

Q. Okay. And I believe you said yesterday that the suspect had had some dental work up in here. What kind did he have?

A. Four incisors are caps. And when the technician, the laboratory person makes caps, he deliberately will make them to be very even for aesthetics. We want them to look pretty.

Q. All right. And so would that account for this even bruise here?

A. That does.

Q. All right. Okay. And moving over to 11, what do we have here?

A. 11 is the rather strong, triangular shaped tooth called the eyetooth on the upper left side.

Q. Again, you are looking at the actual -- these are the suspect's teeth.

A. That's correct.
Q. All right. Okay.
A. Then behind 11 there is a considerable space back to 12.
Q. Okay. Is that space depicted on the bite mark?
A. On the bite mark there is a space between the heavy bruising of 11, space, heavy bruising of 12.
Q. And why don't you show the jury where that space occurs on the actual model of the suspect's teeth.
A. This is heavy bruising on 11, the eyetooth; space; heavy bruising on 12.
Q. All right. So you can actually see that space.
A. Yes.
Q. Okay. Moving down, is that all the impression that we see from the upper arch?
A. Those are the key characteristics of the upper arch.
Q. Okay. Let's move down to the lower arch now. What do we initially have?
A. The lower arch is -- we would like to turn it around this way to look at it, but that's going to throw you off because the left and right become very confused. So the proper way to do it is to hold it this way because this is the way the mouth would actually engage into the bite mark. So when I show you, I'll have to look at it this way.
Q. What do we have here on 22, right there?

A. 22 is this stomach tooth, real strong, heavy, tall tooth called the canine or stomach tooth on the lower left. On the mark it's a very strong mark right here.

Q. All right. Is that entirely consistent with that suspect's tooth?

A. Yes, it is.

Q. All right. Move on to 23. What do we have here?

A. I think the key thing is to know as we were talking yesterday about relationships of one tooth to another so it's like one neighbor to another. This neighbor is in this one position and next-door neighbor is sitting way back, which in this case the suspect has 22 out in this curve of his mouth and then considerably behind that tooth is No. 23.

Q. Okay. Is that entirely consistent with the suspect's teeth?

A. That's consistent with, and a strong characteristic is the relationship of one to another. This kind of mark would be impossible to make if --

MR. TATUM: Judge, could we have this question and answer?

THE COURT: Yes, you may.

Q. (BY MR. PASK) Comment a little more on this, on 23.

A. 23's relationship to 22 is it's impossible to have been made if the teeth were real straight as if the upper front incisors--8, 9, and 10--are very straight, very even, very next-door-neighbor type arrangement.

Q. Okay. Obviously there's some bruising outside of the areas that you have marked.

A. That's correct.

Q. Okay. Again, what does that come from?

A. It's pure speculation as to how this took place. Obviously there was -- I assume there was a scuffle. I assume that there was --

MR. TATUM: Judge, I'm going to object to whatever he assumes. And if he is going to talk about speculation, I would ask that he not. I object to speculation.

THE COURT: Excuse me just a minute. I cannot allow you to speculate or to assume, save and except in a hypothetical situation.

Q. (BY MR. PASK) Well, what reasonable inferences can you make from the bite mark?

A. There was more than one initial and final point of contact of teeth to the skin.

Q. All right. What do we have down here that you haven't marked, that you haven't circled? What are these little areas?

A. Those are probably --

Q. What inferences can you make?

A. The same kind of inference in that there is a strong mark here from the tall, pointed tooth and there's a space to another tooth.

Q. Okay. Can you actually see those teeth?
A. There's a tall tooth here and there's a space to this here.
Q. So basically what we have here is an initial point of contact and then --
MR. TATUM: I'm going to object to the prosecutor testifying through his question and leading the witness, Judge.
THE COURT: Let's keep it question and answer, sir.
Q. (BY MR. PASK) What conclusions can you draw from these initials marks when you compared them to these marks behind them?
A. They are similar.
Q. All right. What do we have here in 24, 25, and 26?
A. Those three teeth are relatively the same length in the same position, that is, right here No. 3, 4 -- excuse me, 24, 25, and 26.
Q. Okay. And why are they -- why does it appear to be a straight mark?
A. Because they are the same height and same relationship to each other which would make a rather long, continuous bruising effect.
Q. And can you match this up to the suspect's teeth?
A. Yes, they match up.
Q. All right. What do we have right here?
A. Between 27 and 26 there is a space on the bite mark.

On the suspect's plaster cast, we have 26 and 27 with a considerable space, same as on the mark.

Q. All right. What tooth are we looking at here, 27?

A. 27 is the lower right stomach tooth, canine.

Q. Okay. Would you consider this a weak mark or a prominent mark?

A. Prominent.

Q. Why was this prominent on the bite mark?

A. Because the tooth is a heavy, tall, bulky tooth.

Q. Okay. We'll move down here now. Do I have the tracing in the right place?

A. Yes, sir.

Q. Okay. Again, what are we looking at here on top?

A. The top shows the upper teeth beginning with No. 5, which is right here. No. 5 is the -- going to be making the mark in this manner.

Q. Again, this photograph is larger than real life.

A. It is.

Q. And these tracings were made from the photograph. They weren't made from the wax bite or the teeth in any way.

A. That's correct.

Q. All right.

A. No. 5 is the strong, pointed tooth. This is No. 5.

Q. And where do we see it on here?

A. Right here. And there's no bruising, representing a large space between the 5 and the next tooth called No. 6.

Q. Can we see that spacing here on the views?

A. This is No. 5, big space, and then 6.

Q. All right. Where is tooth No. 6, right there?

A. No. 6 is the upper right canine or eyetooth.

Q. All right. And are these marks consistent with the suspect's teeth?

A. Yes, they are.

Q. And what do we have here between 6 and 7?

A. 6 and 7, space. We have a rather sharp, bulky tooth on No. 6. We have a considerable space between the point of that tooth and the next tooth over, No. 7.

Q. And are these consistent with the suspect's teeth and the bite mark?

A. Yes, they are.

Q. And what do we have here in 7, 8, 9, and 10?

A. 7, 8, 9, 10 are the very four incisors on the top, consistent with the nice, smooth curvature and essentially the same length.

Q. And what caused them to be straight?

A. The laboratory procedure making real straight caps.

Q. And do we see a straight line here on the bite mark?

A. We do.

Q. All right. Can you make any reasonable inferences why there is no bruising below here where you believe the teeth actually made their impression?

A. Yes, I can. When a bite is made, the initial contact with the skin is going to make marks which would be the largest curve. It's going to be -- the marks would be the furthest part of that point. And then as the person squeezes together, he is going to have a damaging effect to the tissue closer and closer together. So the bruising necessarily go from initial point of contact toward each other instead of as opposed to away from the initial point of contact.

Q. For instance, you haven't marked it, but could you match up this area right in here with the tooth?

A. This area here is heavily bruised, and the cause of it is the force, the mechanics of this area hitting whatever was in this area which we call leaders of the wrist.

Q. Okay. And moving over to No. 11, which tooth is that?

A. No. 11 is the upper left eyetooth. It's a strong, pointed tooth.

Q. And we see 11 here?

A. 11 is depicted right here.

Q. And we have spacing between 11 and 12? Where does that spacing appear?

A. There's considerable space between No. 11 and No. 12, space from 11 to 12, representing this point right here.

Q. Okay. And where is 12?

A. 12 is right behind the spacing. We have the eyetooth, No. 11; some spacing; and then No. 12.

Q. Again, we don't see all of the upper teeth, do we?

A. No.

Q. Why is that?

A. They weren't involved in the mark. You have to have a very large mouth to get all the back teeth on there.

Q. Right. And does that conclude the upper arch?

A. Yes, sir.

Q. Can you determine anything about the width of the suspect's arch -- well -- from these pictures, or would it be better to look at the life-size photographs?

A. Life-size.

Q. Okay. All right. Let's go to the lower arch. Okay. Where is No. 22?

A. No. 22 of the model would come in like so. No. 22 is this lower left stomach tooth or cuspid. It's right here, a tall, bulky, pointed tooth.

Q. And what do we have here just below 22? What reasonable inference can you make regarding that?

A. There is either another point of contact. No way to know whether it is before this contact was made or after. A point of contact.

Q. Okay. And where is 23?

A. 23 is sitting behind 22 on this model. 22 is here, 23 sitting behind back toward the throat. And on this photograph, 23 made a mark considerably behind the general curve of the other teeth.

Q. And what about 24, 25, and 26?

A. 24, 25, and 26 are right in this section here. They are all about the same length and about the same position next door to each other, making a continuous bruising effect.

Q. And what do we have here with this space?

A. Then the space between the incisor and the canine is heavy, long mark, and that would be evident on the suspect in that there is a space from this 26 to 27 and they are considerably out of alignment and there would be a space between those two points of contact.

Q. And all of these marks in your opinion match with the suspect's teeth.

A. Yes, they do.

Q. Okay. How did the analysis next proceed?

A. A one-to-one ratio photograph.

Q. All right. Where are those one-to-one ratio photographs?

A. Right here.

Q. Okay. What are we looking at in State's Exhibit 88 through 88-g?

A. This is a one-to-one ratio photograph. One-to-one ratio refers to no distortion, no larger, no smaller. Actual-size photograph is the key word here.

Q. And what is depicted in State's Exhibit No. 88?
A. That's a tracing I made from the wax bite photos of the wax bite made by the suspect Chaney.
Q. Okay. Why don't you show the jury how you made that tracing.
A. This wax bite was made by Chaney, looking at the upper teeth. This photograph here is the actual reproduction.
Q. Life size.
A. Life-size reproduction. Turn it over, this is the lower view. This is a life-size photograph of the lower view, lower teeth, the wax bite of the suspect.
Q. And then did you trace this on --
A. The technique then was to trace the marks on the wax bite on this overlay and then put that over life-size photographs of the bite marks to see if there was a match or a non-matchup.
Q. And did you trace here both the upper arches and the lower arches?
A. Yes, sir.
Q. And the upper arches are depicted at the top and the lower arches are depicted at the bottom?
A. That's right.
Q. And these are tracings of basically the suspect's actual teeth, the way he would bite.
A. That's correct.

Q. All right. And then you laid them over the life-size photographs?

A. Yes.

Q. Okay. All right. Why don't you step forward here. Okay. Which is the upper arch? Which is the upper arch?

A. Upper arch is here, lower teeth right here.

Q. All right. And based on this comparison, what can you say about the upper arch that's on the bite mark in comparison to the defendant's upper arch?

A. Everything is consistent.

Q. What about the size of the arch, the overall size of it?

A. Perfect match.

Q. And do people have different sized arches?

A. Everyone's different.

Q. And do they come in different sizes and shapes?

A. Very much.

Q. And what conclusions did you make about the suspect's upper arch when you compared it to the upper arch contained on the bite mark?

A. There is a consistent matchup.

Q. All right. Now, let's go down the individual teeth. Okay? Okay. Which tooth is depicted here in No. 6?

A. No. 6 is the upper right eyetooth. On the model it's the one that's very pointed, upper right canine.

Q. It would lay down like this. Am I correct?
A. Yes, sir.
Q. All right. Show the jury where No. 6 is again on the model?
A. (Points.)
Q. And where is that depicted here?
A. Right here. Mark right here.
Q. Okay.
A. Tracing.
Q. All right. And we have a little spacing in there?
A. Space to No. 7.
Q. All right. Show the jury the spacing on the actual model.
A. Between 6 and 7, there's a space right in this section.
Q. Is that entirely consistent with the suspect's teeth?
A. Very much.
Q. Okay. And what do we have right in there?
A. 7, 8, 9, 10, one long bruising effect but in a very smooth curve.
Q. Okay. Would you show the jury where these teeth are?
A. 7, 8, 9, 10 are the front upper incisors, the four incisors that were mentioned; a smooth curve; nice, straight relationship to each other.
Q. Okay. Can we see these teeth here on the wax

impression?

A. Yes. The wax bite is made like that. So if we pull it down, then you're looking at No. 6 and then 7, 8, 9, 10, the four incisors, a very smooth curve.

Q. And do we see exactly that straight line in the photograph?

A. Yes.

Q. And, again, going around, what do we next see here after these straight lines?

A. The space between 10 and 11 and then the definite or heavy bruising on the left.

Q. Okay. Where do we see No. 10?

A. (Points.)

Q. All right. And where is No. 10 on the model?

A. (Points.)

Q. And do these match up?

A. They do.

Q. Okay. And do we see the spacing in there?

A. We see some spacing--and I'll pull the tracing off so it won't confuse you--some spacing between 10 and 11, right in this section.

Q. And, again, show us the spaces here on the bite mark?

A. Between 10 and 11. Between 10 and 11 there is some spacing in this section.

Q. And we see that here on the wax impression?

A. Between 10 and 11 there is a space.

Q. All right. And moving around what do we next see?

A. This is the No. 12.

Q. All right. Would you point that out on both these models?

A. No. 12 is this tooth behind the eyetooth, upper left. A lot of space between 11 and 12.

Q. And what do we see here on the picture?

A. There's 11 and then a space to 12.

Q. And, again, these tracings are what you actually made from the picture of this wax impression the suspect made.

A. That's right.

Q. All right. What conclusions can you draw about the upper arch?

A. A matchup, no discrepancies, no inconsistencies.

Q. All right. Are we through with the upper arch?

A. Yes, sir.

Q. All right. Let's go to the lower arch. All right. Which tooth are we going to start with?

A. 22 mark would be like that. Raise it up this way. 22 is the lower left canine, lower left cuspid, also called the stomach tooth.

Q. And where do we see this on the tracing and in the photograph?

A. Right in this section here.

Q. Okay. And how does this match up with the suspect's teeth?
A. Very well.
Q. All right. What tooth do we next go to?
A. Next door to 23 which sits behind 22. It has a mark more behind than the actual bite mark as does the suspect's teeth.
Q. And what does this tell us?
A. There is a matchup in the relationship of 22 to 23.
Q. All right. And then where do we go from there?
A. Then the other remaining incisors, 24, 25, and 26, are relatively in a straight line, same height, and have a general long line of bruising.
Q. All right. Where do we see these teeth?
A. It's going to be 23, 24, 25, 26.
Q. And do these match up with the bite mark?
A. They do.
Q. And moving down the line, what do we have next?
A. The space between 26 and 27. Space between 26 and 27 is depicted on the tracing from here to there, on the bite mark itself as a rather clear space between these two marks.
Q. Okay. I'll get you to lay this picture down for just a second. Obviously when you put these upper arch and lower arch side by side, it's much larger than the actual bite mark, is it not, when you do it like this?

A. Yes, it is.

Q. How were the teeth positioned when the bite was being made?

A. If this person -- if the suspect was standing here where his teeth would be together like this, like you are right now, the teeth are just relaxed together. Then when the bite mark was made, it was opened to a degree as much as one can. If it made engagement into the tissue at that point, this front section then will contact the skin. The back, there's no skin to get back that far.

Q. Okay. Let's move down to the end. All right. Again, what do we have in State's Exhibit No. 88?

A. 88 is a tracing that I made from the wax bite photos of the suspect. These are actual reproductions, actual size.

Q. All right. And are they from State's Exhibit 88-f and 88-g?

A. Yes, sir.

Q. All right. What do we have in 88-f?

A. The lower wax bite of the teeth.

Q. And what do we have here in 88-g?

A. The upper teeth wax bite.

Q. And what is contained in State's Exhibit 88-a?

A. 88-a is an actual photograph of the bite mark.

Q. And is it --

A. Life size.

Q. And what do we have finally in 88, actual tracings of 88-g and a?
A. Yes.
Q. Okay. Okay. Let's take a look at the upper arch first. Where in the photograph is the upper arch?
A. The upper arch is right in this section (indicating).
Q. All right. And does that match the suspect's arch?
A. Yes, it does.
Q. Could you show the jury how that matches?
A. (Witness complies.)
Q. Again, do people have unique arch sizes?
A. Characteristic arch sizes. As the spaces are unique, so are the arches.
Q. Does this arch on the bite mark match up in terms of size and shape to the suspect's upper arch?
A. Yes, they do.
Q. All right. Shall we get into the individual teeth?
A. Yes, sir.
Q. Okay. State's Exhibit 75 is a model of the suspect's upper arch.
A. Yes.
Q. And how would it be positioned down here on the photograph?
A. The position as this demonstration (indicating).
Q. All right. I guess we'll start with tooth No. 6?

A. Yes, sir.

Q. And where is that located?

A. Upper left canine, upper left eyetooth.

Q. Show the jury where it is.

A. This section here, take the tracing away so that you can see the bruising effect, it's right in this section.

Q. Does this match up with the suspect's teeth?

A. Yes.

Q. Could you show the jury how that does match up?

A. (Demonstrates.)

Q. Could you make a reasonable inference why that mark might have been weaker than some of the others?

A. Yes. The inference is that there was more power, more stress put on the upper -- toward the upper part of the arm than there was on the lower part of the arm. That could be because there is a fleshier part of the arm, the more tissue to grab. Closer to the wrist it's very, very tight and very skinny compared to the upper forearm.

Q. Okay. And right next to tooth 6, we have a space?

A. Space and then tooth No. 7, which is right here. And you have to realize that when you pull this back like this, it changes lefts and rights. So you might be looking at the opposite side.

Q. Why don't you show us the gap here between 6 and 7.

A. 6 and then there's a gap right in this section to

No. 7.
Q. Can we see that in the photograph?
A. This is 6, and then there's a gap to No. 7.
Q. Okay. Does this match up with the suspect's teeth?
A. It matches.
Q. All right. And moving down the line to No. 8?
A. 8, 9, and 10 are in a smooth curve making a smooth outline of bruising.
Q. And, again, is this indicative of the suspect having caps on the front teeth?
A. Yes, it is.
Q. Okay. Why don't you go down the row and show us the front teeth?
A. Space between 10 and 11, referencing on the bite mark in this section, 10 to 11, there is a lack of bruising effect which is represented in the spacing. No. 11 is this upper left canine eyetooth. Space between 10 and 11 is right in this section.
Q. And, finally, what do we have here at the end?
A. There is considerable spacing between 11 and 12. 11 to 12, there is considerable spacing there represented on the mark in this section here.
Q. And does this match up to the suspect's teeth?
A. It does.
Q. Okay. Is that the end of the upper arch?

A. Yes, sir.

Q. Now, let's go to the lower arch of the defendant. How is this laid down?

A. The lower arch is going to come together like so (indicating) as if it were going to be biting up toward the upper front teeth, and you turn the model down like this to keep the left and right sides in the proper orientation.

Q. Okay. What general conclusions can you make about the suspect's lower arch and the arch impression made in the life-size photograph?

A. It's a good match.

Q. Okay. Now, let's go to the individual teeth. What do we have here right here, tooth No. 22?

A. 22 is the canine tooth right here, the lower left stomach tooth, bulky, tall, heavy tooth within the mark.

Q. Do we see 23 next door to it?

A. 23 is sitting behind back toward the throat on the mark and on the suspect's model. That's 22, and then back toward the throat is 23.

Q. Now, can we actually see that on the bite mark?

A. We can. We have -- pull the tracing away and show you 22 is in this section and 23 has the bruising effect toward the back of the throat.

Q. And is this consistent with the suspect's teeth?

A. Yes, it is.

Q. All right. Which tooth are we looking at now?

A. 24, 25, 26 are relatively the same height right here, the three remaining incisors. These are essentially the same height, next door to each other in a very nice, straight line.

Q. And do we see that here on the tracing and the bite mark?

A. We do. Take the tracing away and you see that we have these teeth in this section right here, 23, 24, 25, in a relatively straight row.

Q. And is this consistent with the suspect's teeth?

A. It is.

Q. Okay. What tooth do we have next?

A. Then there's a space between the incisor 26 and the next tooth, stomach tooth, 27. Considerable space between 26 and 27 on the suspect's model and on the bite mark itself. 26, space, 27. Pull the tracing away and show you 26, space, 27.

Q. And, again, when a bite mark was made, it was made similar to this (indicating)?

A. Yes, sir.

Q. In other words, the teeth weren't open all the way.

A. The back teeth are never very far apart because of the mechanics of the jaws. It's impossible.

Q. So it would be somewhere in this area right here?

A. Yes, sir.

Q. Okay. Where does our analysis next proceed to?

A. The key features.

Q. Now, if you would retake the stand. What do we have here in 88-b, c, d, and e? Are these just different views of the bite mark?

A. Yes, sir. Different lighting effects. They are the same size. They are actual-size photographs similar to the one that I have just been demonstrating, but they have a different light intensity. This area here is real shiny in this photograph, and the same area in this photograph is very dark. It's strictly a photographic technique. We can make them simply brighter or darker.

Q. And did you match up this tracing with these photographs?

A. I have reviewed every photograph many times, many hours worth, looking for everything possible.

Q. Let's move down here. Okay. What do we have here in these other photographs?

A. Photographs b, c, d, e, f, g, are all -- f and g, I exclude, but these photographs 88-b, c, d, e are same size, same direction of the photograph that I just used to demonstrate to you, which was called 88-a. It is different only in that they are either lighter or darker, making for instance one area here very shiny, this area very dark. It's strictly a photographic technique. It does not distort the size. It just makes simply either brighter or darker.

Q. Based on your experience and your analysis, were you able to come to a conclusion about whether or not Steve Chaney made that bite mark?

A. I believe Steven Mark Chaney made those bite marks on the body of Sweek.

Q. And that would have been John Sweek?

A. Yes, sir.

Q. Now, you actually viewed the body, I believe you said, Tuesday, June 23rd, 1987.

A. That's correct.

Q. And you know the photographs were taken on Sunday, June the 21st.

A. Yes, they were.

Q. Are you satisfied that the precautions were taken to preserve that bite mark in a sufficient manner for you to make these conclusions and observations?

A. Yes, I am.

Q. Is it your opinion that the bite mark had altered itself through natural -- natural processes --

A. It would --

Q. -- or decomposed?

A. It would have to a degree.

Q. All right. And would this alter your conclusion in any way?

A. No, sir.

Q. And why is that?

A. Because there's too little time and too little alteration and the conditions were appropriate to slow down or inhibit any change. In other words, the body was in the refrigerated compartment to restrict this kind of alteration of the tissues.

Q. You said yesterday that you've made comparisons of ten bite marks. Were you referring to actual court cases?

A. Yes, sir. I have reviewed between 40 and 50 bite marks in depth. That means many hours of study each, not just a flashing picture but many hours of study. Then actual testimony or deposition type cases, maybe 10.

Q. Approximately how many hours did you work on this case?

A. 20. I'm referring to reviewing photographs, tracings, in-depth study. That's not including testifying or visiting with you or whatever.

Q. Okay. Shortly after you took the impressions from Steven Mark Chaney and made your initial comparison, you made a report to Investigator Westphalen of the Dallas Police Department, did you not?

A. Yes, sir.

Q. And what was the general purpose of that report?

A. To tell him that there was a chance of a matchup and to rule out an exclusion type decision.

Q. All right. What did that report consist of? What were your conclusions in that report?

A. The conclusion was that there was enough of a matchup and there were not any obvious discrepancies, that further study would be indicated.

Q. Okay.

THE COURT: Sir, let me stop you. It's time for our mid-morning break.

Ladies and gentlemen of the jury, please go ahead and take your 15-minute break. Please do not discuss anything you have heard so far among yourselves nor allow anyone else to talk with you about anything regarding this case.

You may retire the jury.

(The jury was retired,
and a recess was taken.)

THE COURT: You may seat the jury.

(The jury returned into open court, and
the following proceedings were had.)

THE COURT: You may be seated, ladies and gentlemen.

You may continue, sir.

MR. PASK: Thank you, Your Honor.

Q. (BY MR. PASK) Doctor Hales, we were talking about your conclusions, and you just stated that it was your conclusion that Steven Chaney made the bite mark on John Sweek.

A. Yes, I did.

Q. And that you had submitted a report on July the 22nd, 1987, to Investigator Westphalen of the Dallas Police Department?

A. Yes, sir.

Q. And, again, what was the purpose of that report?

A. To respond to his request: Is there a matchup enough that we should investigate further, or is there an exclusion situation which would mean we stop the investigation.

Q. And what did you report at that time?

A. There is an inclusion, there is a matchup to the degree that it should be researched further.

Q. Okay. And subsequent to that report, did you yourself research the bite mark and the comparison to the suspect's teeth further?

A. Yes.

Q. And did the bulk of your investigation occur before you made this report or after you made this report?

A. The bulk has been since.

Q. Okay. And in that report you basically state that there was a positive matchup of the suspect's teeth with the victim's bite mark. Is that correct?

A. That's right.

Q. And you also go on to say that they were not so definitely clear --

MR. TATUM: I'm going to object to the leading, Judge.

If he wants to ask him what his report --

THE COURT: I sustain. Make it question and answer.

MR. PASK: May I approach the witness?

THE COURT: You may.

(State's Exhibit No. 112 was marked for identification.)

Q. (BY MR. PASK) I'm going to show you what's been marked for identification purposes as State's Exhibit No. 112 and ask you to identify it.

A. Yes. This is my report to Inspector Westphalen.

Q. And, again, when was it made?

A. July 22nd, '87.

Q. And you did state that there's a positive matchup of the suspect's teeth with the victim's bite marks?

A. Yes, I did.

Q. And what did you also go on to say at that time?

MR. TATUM: Is he offering this into evidence or just going to testify to a unoffered exhibit?

MR. PASK: I'm providing it to the witness to refresh his memory.

MR. TATUM: Well, he didn't say that, Judge.

THE COURT: I understand. Lay the proper predicate for refreshing.

Q. (BY MR. PASK) Does the report refresh your memory --

A. Yes, it does.

Q. -- about exactly what you said in that report?
A. Yes.
MR. TATUM: I'm going to say that's not the proper predicate. He didn't ask the --
THE COURT: Sustained.
Q. (BY MR. PASK) Let me just ask you: Can you paraphrase what you said in that report?
A. Yes. I said that there was a matchup, there were no obvious discrepancies, there were no inconsistencies, but at that moment I wasn't sure that Steven Mark Chaney was the only person in the world that could have made those marks.
Q. And what led you to believe that Steve Chaney did in fact make those marks?
A. Many hours of further research and study.
Q. In all of your investigation, did you find any inconsistencies between the bite mark and the suspect's teeth?
A. No, sir.
Q. And, again, what is your final conclusion at this point?
A. That Steven Mark Chaney made the bite marks on John Sweek's body.
Q. And how certain are you?
A. Very.
Q. A few minutes ago you said that there might have been more than one point of contact between the suspect's teeth and

the victim's skin. Okay. What did you mean by that?

A. In the photographs of the marks, there are some marks that are outside of and inside of the major curved marks. Those marks are pure speculation as to what made them, who made them, how they were made, by what they were made.

Q. Okay. Could you sort of show us that pattern on one of these color slides?

A. Yes, sir. This mark would be one in question, this set of marks. Those are the basic ones.

Q. Before you said that there might have been some slippage during the bite. What do you mean by that?

A. In the clamping down, the mechanics of biting an arm in this section, there's going to be contact on some tissues are harder than others. The leaders that feed down here to the hand are going to be harder, more firm than the tissues between those leaders. And there's going to be a different bruising effect due to that.

Q. Now, over here on the right side of the mark, it appears to be stronger than over here on the left side. In your opinion what is this due to?

A. Just more force.

Q. More force on this right side than there was on the left side?

A. Yes, sir.

Q. Okay. You may retake your seat. All right, Doctor.

Before, you mentioned that there was a scoring sheet for bite mark analysis. Did you score this bite mark in your subsequent comparison to the defendant's teeth?

A. Yes, I did.

Q. And how did you do that?

A. Following the guidelines set up by the American Board of Forensic Odontology on bite mark analysis.

Q. All right.

MR. PASK: May I approach the witness?

THE COURT: You may.

Q. (BY MR. PASK) I'll show you what's been marked for identification purposes as State's Exhibit No. 89 and I'll ask you to identify this if you can.

A. This Exhibit 89 is my scoring sheet on the matchup of Steven Mark Chaney with the bite mark John Sweek.

MR. PASK: Your Honor, at this time the State offers into evidence State's Exhibit No. 89.

MR. TATUM: I have no objection.

THE COURT: Admitted.

Q. (BY MR. PASK) Okay. On this scoring sheet, it has a column for features analyzed and number of points and then it has a scoring column. What features did you analyze that are on this sheet?

A. The gross inspection, the tooth position.

Q. All right. And how did you score this case?

A. On the upper arch, I scored the maximum, which means that all the teeth in the mark are present in the suspect's mouth for both the top and the lower jaws.

Q. So the suspect wasn't missing any teeth. Is that correct?

A. That's right.

Q. And did you see any missing teeth on the bite mark?

A. None.

Q. All right. And what next did you score?

A. The size of the arches being consistent as opposed to, say, being smaller or larger.

Q. And did they exactly match up?

A. They match up exactly, so there's a point scored for each arch, one for the top, one for the bottom.

Q. All right. And would that be for both for the size and the shape of the arches?

A. Then on another category, the shape is also a category. And the shapes matched, top and bottom. So that's a point each for the shapes.

Q. All right. And then it goes down to tooth positioning. Am I correct?

A. Yes, sir.

Q. And what does that entail?

A. On tooth position, we're looking at the things that we've discussed now for two days, and that is position, position of the tooth--let's say, a buck tooth which is out toward the lip versus a tooth that's pushed back toward the throat--and its relative position to its neighbor.

Q. And what kind of a score did you come up with there?

A. That gets one point for each tooth in each arch, and so we have six points on the upper and six on the lower.

Q. So you actually found six teeth that matched in the upper arch to the bite mark and six teeth that matched to the lower arch in the bite mark?

A. Yes.

Q. All right. What next does it entail?

A. The tooth -- the rotation or the straightness versus the rotated factor of any particular tooth.

Q. And how did you score that?

A. Six for each arch. Six for the upper, six for the lower.

Q. Okay. What next do we look at?

A. The length of the teeth, which is also referred to the vertical position of the teeth. In other words, where the tooth is the same length to its neighbor or is it extra long or is it extra short. That deserves a point per matching tooth, and that on this position I was able to record one for the upper arch and not any for the lower.

Q. All right. And then it goes on to the category of spacing between adjacent marking edges?

A. Uh-huh.

Q. What do you mean there?

A. The spacing between two teeth, meaning that if we have a mark such as we had on which I call No. 6 and then a space to the next tooth, No. 7, that space is a definite space. And in this case I had one mark for the upper and one mark for the lower -- one score, rather.

Q. All right. Were you able to come up with a grand total in this case?

A. Yes. Fifteen points for the upper arch, 16 points for the lower arch, grand total of 31.

Q. Do those actually represent points of comparison between the bite mark and the suspect's teeth?

A. Yes, they do.

Q. So, in other words, you could say there are 31 points of comparison that you found --

A. Yes, sir.

Q. -- 31 similar characteristics between the bite mark and the suspect's teeth.

A. That's right.

Q. Would you classify this as poor, average, very good, or excellent?

A. This is good.

Q. And would it be consistent with your findings?

A. Yes, it is.

Q. Doctor, the name Juan Gonzalez has surfaced in this trial.

MR. TATUM: I'm going to object to him telling what the prior testimony has been in this trial, Judge.

THE COURT: I'll sustain the objection. Just rephrase your question.

Q. (BY MR. PASK) Have you recently had an occasion to take a wax impression of a person you came to know as Juan Gonzalez?

A. Yes, I have.

MR. TATUM: In that regard, Judge, I'm going to object to any testimony about this as having failed to have been turned over pursuant to discovery request.

MR. PASK: Your Honor, the --

THE COURT: How about we let the jury out while we talk about this?

MR. PASK: Okay.

THE COURT: Why don't you retire the jury.

(The jury was retired, after which time the following proceedings were had out of the presence and hearing of the jury.)

THE COURT: You know the objection. What's your answer? Do you want your witness to remain in the room or do you want your witness to leave?

MR. PASK: He can stay here. Your Honor, the defense attorney has injected Juan Gonzalez' name by his questioning --

THE COURT: That wasn't his objection.

MR. PASK: As I read the discovery motions, we weren't required to turn over that information. Doctor Hales did not make a report regarding that. The defense attorney was given ample opportunity to speak to Doctor Hales, too.

THE COURT: When was this report supposedly made?

MR. PASK: There was no report. That's my point. Your Honor, just a moment I'll find out when the impression was taken.

THE WITNESS: November 12th, '87.

MR. PASK: November 12th, 1987.

THE COURT: Prior to mistrial.

MR. PASK: What?

THE COURT: The impression was taken prior to my granting the mistrial.

MR. TATUM: Right. And we've never been told. It's been kept a secret until five minutes ago as far as a forensic or lab test done by somebody at their request. In other words, there was ample opportunity to tell us about this which we could have either asked for samples to make any other comparisons to rebutt his testimony. Now, we are left in the situation of only having learned this five minutes ago.

Whether an actual final report was done, I think, is immaterial in regard to the total request for forensic types and scientific types of information. I specifically asked for any forensic odontology research.

THE COURT: I direct State's attention to the motion for discovery and inspection, page 4: All laboratory reports, odontology or dental reports, autopsy reports, or other scientific or forensic test results and fingerprint identification of the defendant or anyone else obtained at the scene of this crime or otherwise in any way connected with this prosecution.

Let us go forward and hear what the testimony would be regarding this outside the presence of the jury.

Sir?

MR. PASK: Okay. Thank you.

Q. (BY MR. PASK) When did you take the wax impression of Juan Gonzalez?

A. I stated while ago it was November 12th. It was November 18th, 11:00 a.m., in my office.

Q. And did you ultimately make a model of Juan Gonzalez's teeth from that wax impression you took?

A. Yes.

Q. And did you have a chance or opportunity to compare that model to the bite mark that was on John Sweek?

A. I made an initial determination just from reviewing the models of Gonzalez that there was not a matchup, and I stopped the research at that point.

MR. PASK: That's all that I would have, Your Honor.

THE COURT: You renew your objection?

MR. TATUM: Yes, Your Honor.

THE COURT: And what would you have the Court do about it?

MR. TATUM: Exclude the testimony, Your Honor.

THE COURT: At this point in time, it will be excluded.

MR. PASK: Thank you, Your Honor.

THE COURT: Anything else?

MR. PASK: May I have a moment?

THE COURT: Sure. My anything else goes to outside the presence of the jury.

MR. PASK: Nothing else, Your Honor.

THE COURT: All right. You may seat the jury.

(The jury returned into open court, and the following proceedings were had.)

THE COURT: You may be seated, ladies and gentlemen. You may continue, sir.

MR. PASK: Your Honor, the State passes the witness.

THE COURT: Mr. Tatum?

MR. TATUM: Thank you. May it please the Court --

THE COURT: Now, Mr. Tatum, please speak up because I have trouble hearing you sometimes.

MR. TATUM: Yes, Judge.

CROSS-EXAMINATION

BY MR. TATUM:

Q. Doctor Hales, we have had an opportunity to meet once before, have we not?

A. Yes, we have.

Q. Okay. And when I went out and met you at your practice where you practice family dentistry; is that correct?

A. Yes.

Q. And that's on MacArthur Boulevard?

A. Right.

Q. Okay. And that's really where the majority of your work, everyday work, comes from is being a family dentist. Is that correct?

A. Right.

Q. Okay. You have a suburban office out there which you see the public, see patients.

A. That's right.

Q. Okay. And we had an opportunity to sit down and talk, and do you remember telling me that your testimony would not send my man to the gallows? Do you remember saying that?

A. No.

Q. Okay. Do you want to think about it for a minute? It was a very --

MR. PASK: Objection, Your Honor. The witness has already answered the question. I would object to the defense attorney badgering the witness.

MR. TATUM: This is cross-examination.

THE COURT: Now, wait, wait just a moment, gentlemen. Overruled. Just sit down. Sit down.

MR. PASK: My objection is also hearsay.

THE COURT: Sit down. Overruled. Go forward.

Q. (BY MR. TATUM) Do you want to think about it for a minute? Let me set the scene. We're sitting in your office and I'm sitting in front of your desk and you're sitting behind it. And we had a brief interview because you had a patient in the chair that needed some attention. Do you remember?

A. Yes.

Q. Okay. As a matter of fact, I asked you in preface our conversation what training you had. And do you remember what you told me?

A. I don't remember, but I would assume that I said that I took the training at the Armed Forces Institute of Pathology, et cetera.

Q. Right. And we talked a little bit about the bite mark, and one of the things I asked you was whether you had any points of comparison. Do you remember me asking you that?

A. Yes.

Q. Okay. And at the time would it be fair to say that you acted a little befuddled and you told me you didn't have anything right then?

MR. NANCARROW: Your Honor, we're going to object to the characterization of that question.

THE COURT: Let's make it a straight question, shall we, sir?

A. Would you remind me of the date when we visited?

Q. (BY MR. TATUM) Well, it was sometime, I guess, around the first of November, wasn't it? Sometime in that area?

A. Probably.

Q. Actually I think it was sometime before the first of November, sometime the end of October. Do you remember?

A. Yes, sir.

Q. Okay. Do you remember who was with me?

A. Joe Saal.

Q. All right. Do you remember when I asked you whether you had any points of comparison like you would in a finger-print?

A. Yes.

Q. Do you remember me asking you that?

A. Yes.

Q. And do you remember what you told me?

A. I had a hesitant answer because I wasn't certain of what you and I -- what our relationship was at that moment, what it should be, what I should tell you, what I should not tell you.

Q. Oh, I see. I see.

MR. NANCARROW: I'm going to object to the sidebar comments of counsel.

THE COURT: Overruled. Continue, sir.

Q. (BY MR. TATUM) Are you saying that there were things in that interview that you did not reveal to me?

MR. PASK: Your Honor, this is improper impeachment technique. If he wants to bring up a specific quote and a specific time, that's fine. But this is just a general fishing expedition at this time.

THE COURT: Continue.

Q. (BY MR. TATUM) Will you answer the question? Are you saying there are things in that interview that you did not reveal to me?

A. At the time I revealed to you my general impression at that moment. And I'd like to go on to say that I had not done the research at any degree that I have done since that visit.

Q. Right. You said that on direct examination, right?

A. You bet. Yes, sir.

Q. Okay. But in our discussion, did you ask me whether I was familiar with some of this terminology about being --

A. Yes.

Q. -- a dental --

A. Right.

Q. Okay. As a matter of fact, you loaned me one of your outline books. Is that correct?

A. Right, yes.

Q. Okay. And in that, I -- you did make the statement, did you not, that your testimony would not send this man to the gallows?

A. At that moment, I said that based on what I had done in my research and my study.

Q. Right. And do you remember that I told you that it wasn't a death case?

A. Yes.

Q. Okay. Now, as part of our discussion, we talked about the photographs, did we not, the quality of the photographs?

A. Uh-huh, yes.

Q. And what is your opinion as to the quality of the photographs?

A. Excellent.

Q. Okay. We also talked about the quality of the bite mark, and do you remember what you said about that?

A. The quality was not as good as the photographs.

Q. Okay. Did you have some characterization of the bite mark?

A. It was a little heavy, too heavy, rather intense.

Q. Okay. Do you remember calling it a class C bite mark?

A. Grade -- grade C, yes.

Q. Now, is part of your training at the Armed Forces Institute of Pathology; is that correct?

A. Yes.

Q. Okay. Isn't most of the training in that area directed toward identification of remains of soldiers from injury?

A. At the point that I took that course, the bite mark activity was not as nearly as strong as it is currently, so there was more emphasis on identification than there was bite mark analysis.

Q. Okay. As a matter of fact, isn't it true that the greater work in forensic odontology is identification of victims like in plane crashes and things like that?

A. That consumes perhaps more time, yes.

Q. Okay. So most training or text or research is done in that area, is that correct, compared to the other subspecialty?

A. No, that's not a fair conclusion.

Q. Okay. Now, in your process of analysis in this case, you made a mistake as far as your initial conclusion as to the time the bite mark was placed on the body.

A. There was some confusion, correct.

Q. Okay. And is it not true that the movement of the victim or how the victim's body is treated or processed could affect the actual tissue?

A. Yes.

Q. Okay. And as a matter of fact I think you testified that there is possibly a post mortem shrinkage.

A. Right.
Q. Tissue shrinks as time goes on, so to speak.
A. Yes.
Q. Okay. And this also affects your comparisons, does it not? It places a variable into your analysis.
A. Very small variable.
Q. But it is a variable, is it not?
A. Almost none, but, yes.
Q. Okay. Now, as far as photographing these or any bite mark, isn't it preferable to make one photograph of one arch and a separate photograph of the lower arch or different photographs of different arches?
A. Yes.
Q. Isn't that a more preferable technique?
A. As opposed to --
Q. One shot of two arches together?
A. Right.
Q. Okay. In other words, in the photography technique of your specialty, that would be a more accurate type of processing. Is that correct?
A. That's the typical way, yes.
Q. Okay. But that was not done in this case, was it?
A. Yes, it was.
Q. Okay. A single photograph of a top arch and a single photograph of the lower arch of the bite?

A. Oh, I'm sorry. I was misled. I was referring to photographs of the models, the biter. I beg your pardon.

Q. Okay. Do you want me to go back and ask that --

A. Please.

Q. Okay. As far as taking photographs of the bite mark on the victim --

A. Right.

Q. -- because the surface is not as flat as like a table or a flat surface, there is some rounding to the arm, so to speak, convexness of it, isn't it a preferable technique to take a separate photograph of a top arch and a separate photograph of the lower arch?

A. No. That's never done, to my knowledge.

Q. The book you gave me contained an article by Lowell Levine, did it not?

A. Yes.

Q. And who is Lowell Levine?

A. A forensic dentist based in the state of New York.

Q. Okay. Would you disagree with his statement that if the bite mark is on a curved surface, this otherwise attempt to capture the bite mark pattern of both arches in a single photograph results in focusing or distortion problems?

A. I would agree to that to the point of saying, yes, it's possible, but not in every case.

Q. Okay. So there is a situation in which experts in your field feel that the separate photographs are more preferable as a technique of photographing bite marks.

A. Separating the upper from the lower arch --

Q. Yes.

A. -- marks? No, I don't agree with that.

Q. Okay. Did you take any of these photographs?

A. No.

Q. Okay. Is another technique is looking for saliva in bite mark?

A. Yes.

Q. Okay. The processing of the victim prevented you from actually doing any saliva washings. Is that right?

A. That's right.

Q. Okay. So you had nothing to do with that.

A. Nothing to do with the on-site investigation.

Q. And so that prevented another aspect of your analysis that could have been done.

A. That's right.

Q. Okay. Isn't it true that it's possible for a tooth not to mark on a surface?

A. Surely.

Q. Okay. Even two teeth that are side by side to each other and bite with the same pressure, one may mark and one may not mark.

A. Depending on the angle or application to it, yes, that's very possible.

Q. Okay. Does that also put a variable into your analysis?

A. Yes.

Q. Okay. Now, the comparisons that you have done are basically static comparisons, are they not?

A. Static?

Q. Static in being fixed in place.

A. Yes.

Q. Okay. The actual bite itself is a dynamic action.

A. Yes.

Q. Okay. It is not static, right?

A. Right.

Q. Okay. Does that also place a variable into your analysis?

A. For sure.

Q. Okay. As a matter of fact, the dynamics of the biting action, would it be fair to say that the upper jaw remains fixed while the lower jaw pulls?

A. Typically, that's right.

Q. Okay. May or may not happen all the time?

A. That's right.

Q. Okay. Now, you have to be careful when you actually get a wax impression from which you make your plaster molds, do you not?

A. For sure.

Q. Okay. And because the amount of pressure that's applied into the wax can distort the wax in an unnatural way, maybe.

A. I could clarify that and answer better --

Q. Okay.

A. -- with a qualifying answer. In the wax bite registration, it requires pressure by the person making the wax bite to either bite hard, softly or hard. If he bites hard, he's going to crush right through the wax and get tooth-to-tooth contact or as close as possible to tooth-to-tooth contact. If he bites lightly, he'll barely make any imprint. But it has nothing to do with me.

Q. Okay. But you're the person who actually administers and tells him how to bite.

A. I instruct them.

Q. Okay. And this is a variable that enters into the making of the plaster cast, is it not?

A. That's right. May I clarify that, please? The impression of the mouth to make the plaster cast is not done with wax. It's done with alginate which is like a jello.

Q. Okay.

A. And that material is placed in the tray, and the tray is pushed until there's general contact of the tray to the teeth. And that stops the pressure. Then the alginate material is like the jello material, just flows around the teeth until it becomes a rubbery substance and then it's removed.

So I'm saying to you that, generally speaking, the amount of pressure I do is not going to change the replication of that person's mouth.

Q. Is that because of the type of material they're biting into --

A. Right.

Q. -- the jello type?

A. The technique involved overall just eliminates that.

Q. Okay. Are there any other types of machines or anything that are used in the analysis of bite marks?

A. Yes. There are some sophisticated techniques of photo enhancement, electronic scanning of photographs. The CAT scan has been used. There are various efforts to try to find if there's a better way to make an analysis.

Q. Okay. What is the photo enhancement? What kind of process is that?

A. Electron microscope. It just uses the electron microscopy type approach to bring out features.

Q. Okay. Does it generally provide a more accurate analysis?

A. No.

Q. Not necessarily?

A. Not necessarily.

Q. But it could?
A. Possibly.
Q. Okay. And was that done in this situation?
A. No.
Q. Any of the other types of analysis that you just spoke of, were any of those done in this situation?
A. No.
Q. Okay. Isn't there another type of procedure in your analysis of actually making an impression or to preserve the impression in the actual bite mark?
A. Yes. We can take an impression of the bite mark itself on the arm using dental impression material.
Q. Okay. Was that done in this situation?
A. No.
Q. Okay. Could it have been done?
A. Yes.
Q. Okay. Does this give the three-dimensional part of the bite mark?
A. Yes.
Q. Okay. And is there any other type of technique as far as preservation of the three-dimensional part of a bite mark?
A. A tissue sample. In other words, the bite mark can have tissue cut right out of the bite mark and then pathologically reviewed.
Q. Okay. In other words, preservation of an excise of

the tissue? Preservation?

A. Yes.

Q. Was that done in this situation?

A. No.

Q. Okay. Would that have aided you in being more certain about the things you did in your analysis?

A. No.

Q. Okay. Even though it would have given you a three-dimensional look to the bite?

A. Right. It still wouldn't of helped me in my opinion.

Q. Do you recognize the name of Irving Sopher?

A. Yes.

Q. Okay. Who is he?

A. Forensic dentist in Washington, D.C., and he's an M.D. pathologist as well as a dentist.

Q. Okay. Are you familiar with any of his work or text?

A. Right.

Q. Okay. And is he a recognized author in your field?

A. Yes. I have his book.

Q. Okay. If he said that even dental experts in the field of bite mark analysis admit to the difficulties inherent in the bite mark comparison, would you agree with that?

A. Yes.

Q. If there had been tissue shrinkage in the arm of the victim, would that have distorted the pictures and your comparisons?

A. If the pictures had been taken sometime after the bite was inflicted, the longer the delay, the longer -- the more the change or more the shrinkage, yes.

Q. All right. In the picture, there was a rule placed in there. Do you know the scale of the rule that was placed in those --

A. It's in inches.

Q. Wouldn't it have been preferable to have a millimeter rule which is a more finely defined?

A. I can't say it would be better. It's just you would be European as opposed to American.

Q. Millimeters? I thought millimeter was a scientific type measurement commonly used in America.

A. In certain areas it surely is, but in most of our industry inches is still the scale used. We talk about socket wrenches, they are in inches, not in metric scale.

Q. Okay. Do you know if there was any impression made of the deceased, Mr. Sweek?

A. Impression of --

Q. Dental impression.

A. Oh, no, sir.

Q. Isn't this a form of procedural analysis that should be done to remove the possibility of a self-biting or having the arm forced into his own mouth?

A. Rephrase the question?

Q. Isn't this a procedure in the analysis of bite mark analysis that is necessary to remove the possibility that the deceased themselves either self-bit or was forced to self-bite?

A. That's a consideration. It is not a standard procedure.

Q. But it was not done.

A. That's right.

Q. Okay. So we don't know if the dental impression of the deceased himself could have made that bite mark. Is that right?

A. That's right.

Q. As a matter of fact, when we talked, you said that other people could have made that bite mark. Is that correct?

A. That was the statement at the time.

Q. Okay. Didn't you say that you may have models in your closet or room or storage that could match up to that bite mark?

A. That's right.

Q. Okay. And, now, these analysis and conclusions that you have come to, you haven't once said that you've expressed your opinion with reasonable dental certainty, have you?

A. That's my feeling, but I haven't used those words.

Q. All right. Now, isn't that the way that your -- the people that do bite mark analysis, that work in the area that you, do express their opinion, in reasonable dental certainty?

A. That's a real standard use phrase.
Q. And you haven't used that yet.
A. No, sir.
Q. Okay. As a matter of fact, the literature says that the analysis should be done such that you can express an opinion with reasonable dental certainty. Right?
A. That's right. I don't construe that to mean that one has to use those very words.
Q. Now, the skin itself is a real elastic type of medium, is it not?
A. Right.
Q. Okay. It's much more elastic than the alginate that you use.
A. Yes.
Q. Okay. So when a bite is made in the skin, it's being made into a totally different medium than the alginate. Right?
A. Right.
Q. A much more elastic type of material.
A. Yes.
Q. And being elastic, it has a tendency to move after being released. Is that correct?
A. Elastic to me would say that it's going to return.
Q. Or return. If it was stretched out, it would return.
A. Right.
Q. Okay. And whether it returns to the appropriate shape

or not depends on the amount of damage. Is that correct?

A. That's right.

Q. Okay. So you could get a distortion from the actual bite itself because of the elasticity of the skin.

A. Right.

Q. Okay. Another phenomenon in the bite mark is either the effects of the mouth or lips on it, too. Does that affect it, also?

A. Rephrase that, please?

Q. Another phenomenon in the bite as it's being done is the effect of the lips possibly?

A. The lips could produce a sucking action, but I don't see that it's going to change what the tooth does to the tissue, per se.

Q. Okay. But it does add another aspect or phenomenon to the actual dynamic of the biting.

A. Yes.

Q. It does add possibly --

A. It could.

Q. -- another aspect of injury?

A. It could.

Q. Did you find any characteristics of that in these?

A. No.

Q. Okay. Due to the broad nature of the injury, could you really tell?

A. There is no generalized bruising effect that would be what I would expect to see in a sucking action. The lips can produce the sucking action, but they can't produce a hard enough force pressing down or pressing on the tissue to make a bruising effect.

Q. Okay. Isn't there a problem of specificity in bite mark analysis because there's a lack of scientific core or basic data for comparison?

A. There is some gray area in this field, for sure.

Q. In other words, even though you've come to this conclusion, there could be other people who could have made that bite mark.

A. In this entire world? Yes.

Q. Okay. What basically you're saying, are you not, is that the classified bite mark characteristics on large segments of the population are basically unavailable at this time. Is that right? It's not like fingerprints, is it?

A. No.

Q. Okay.

MR. TATUM: May I approach the witness, Your Honor?

THE COURT: Yes, you may.

MR. TATUM: Thank you.

Q. (BY MR. TATUM) Let me ask you: Was there an overlay for the one-to-one comparisons? Is that the only overlay? Oh, here it is. Let me show you what's been marked State's Exhibit

88 and an accumulation of 88, subprefix.

A. That's correct.

Q. Now, these are your drawings. Is that correct?

A. Right.

Q. And could you have taken any of these exhibits and actually made an exact overlay through some type of photographic or xerographic process rather than doing it freehand?

A. I don't know of a technique to do that, but it's feasible. It seems possible.

Q. Okay. Now, maybe you ought to come down here so we can talk.

A. Yes, sir.

Q. These are the actual scale, one-to-one photographs, right?

A. They are.

Q. And this 88 is from what now? What did you make it of?

A. Photos of the wax bite made by Chaney.

Q. Okay. And you elaborately testified about these, right?

A. Yes.

Q. Okay.

A. This is a reverse here. I'm sorry.

Q. Let's look at it in reverse.

A. Okay.

Q. Now, there's some matching even if you turn it around, is there not?
A. Yes.
Q. Okay. And there is some areas outside of your designated drawing just like if we turned around, there's some areas outside the designated drawing here.
A. Yes.
Q. In other words, there's damaged areas out here, too.
A. Right.
Q. Okay. And if we put this here, there are some comparisons here, are there not?
A. Yes.
Q. Okay. So if you reverse the arches, you can have some points of comparisons in reverse.
A. Right.
Q. And even though you have marked a tooth position here, that's a -- what did you call that tooth?
A. Canine?
Q. Okay. There's no real marking there, is there?
A. Not in this particular orientation.
Q. Right. But then you testified it is possible for a tooth not to leave a mark.
A. True.
Q. And there are some matchups on this arch here in this area, are there not?

A. Yes.
Q. Is that the orientation that you testified previously?
A. Yes.
Q. You spoke of a gap here between these teeth, right?
A. Right.
Q. Okay. Is this the separation of arch or what?
A. That is the separation between No. 11 and No. 12, a canine and the next tooth back.
Q. Let me just get in the middle more. There is some bruising or damaged tissue between that, right?
A. Right.
Q. Okay. And so if there was a gap, there's no tooth there to make that damage, right?
A. That's right on the upper.
Q. Am I pointing right?
A. Yes.
Q. So you had not circled a tooth here that would have made that damaging area of that black right there. Is that right?
A. Right.
Q. And you talked about this tooth here. I forgot the number. Wasn't it around 23?
A. 23.
Q. 23?
A. Right.

Q. And right in front of 23 is some damaging or bruised area to that mark?

A. Right.

Q. And there's no tooth there, is there?

A. That's correct.

Q. Okay. And then to the side of 23, there's also some damaged area here with no tooth in there.

A. Right.

Q. But teeth are like tools, and they make their marks, right?

A. Yes.

Q. Okay. And up in here, there's another tooth in here to make this mark; is that right?

A. Right.

Q. Now, I think you testified in part of the explanation here is that you could have some slippage?

A. Yes.

Q. Okay. If this tooth made this mark here to this extreme and this one made this one to this extreme, are you saying that this slipped, and this slipped in here?

A. Slippage is one way to place it or explain it. Another way is to say that it's a bruised area just due to the force itself, particularly never slipped, actually moved, but just the force was so great that at the directional force toward the top teeth, bottom teeth would create this bruising effect

that will migrate toward each other.
Q. Okay. Could you also make the same assumptions for these other areas that are encapsuled with your diagram?
A. Yes.
Q. So that's a variable or something that would come into play in making your opinion.
A. Yes, it is.
Q. Okay. Do you know what number that one is?
A. 12.
Q. There's only a partial marking on No. 12; is that right?
A. Right.
Q. Okay. There's no -- it's a fading out. Is that a fair way of describing it?
A. Yes.
Q. And that part right in there, I guess, could have been made by what you said, the no tooth in the crushing effect?
A. That's true. I think another way to say it better would be we don't know exactly where top and bottom stopped and one takes over. We also have top to bottom actually touching each other, perhaps.
Q. Okay. Isn't one of the important techniques of getting down to the individual characteristic the measurement of the continuous -- the gaps between the continuous center.
A. Yes.

Q. You really can't do that in that mark, can you?
A. In certain parts of the mark you are looking at, yes, right.
Q. But in the heavily damaged areas here and here, there's nothing to measure as far as gapping in teeth.
A. That's right.
Q. And that is an important aspect.
A. Right.
Q. If I said something like measuring the radius of the tooth or something, is that important?
A. Yes.
Q. Okay. And I take it you can't do that from these marks.
A. Certain part of those marks, no.
Q. Actually when you rotate this around opposite of what you testified to before, there is a smooth pattern here, is there not?
A. Right.
Q. And you said this is the marking by the lower arch --
A. Right.
Q. -- in your opinion, even though there was a smooth pattern right there.
A. Yes.
Q. As a matter of fact, right there where there's no marking, there could be a tooth that actually went down in that

area and did not mark.

A. If they were of the same length as this neighboring teeth, it would have marked.

Q. But I thought we said before that it is possible for two teeth the same size, same position, to come down, one mark and one not mark.

A. That's a fact.

Q. So this one marked and this one marked depending on the length right there.

A. But I would like to clarify that if we have a tooth, a tooth, and a tooth, and they are all about the same level, you're not going to have that middle one not mark. If the two outer ones do mark, the center one will mark, too.

Q. Absolutely every time?

A. If it's the same general length and position, yes.

Q. Okay. But it is possible that you had a lower tooth, even though a tooth existed, it maybe was chipped or something.

A. Right.

Q. And just a little bit lower than the two neighbors --

A. Right.

Q. -- bite down and that may not mark.

A. Yes, sir.

Q. Okay. And these are all variables that go into the analysis.

A. Certainly do.

Q. Okay. Let me show you State's Exhibit No. 80. You said there were some unidentifiable marks out here, is that right, outside this here?
A. Right.
Q. And there's also -- is this some marking in here?
A. A bridging effect, looks like.
Q. Some type of bridging effect here, is there not?
A. Yes.
Q. Is there any way for you to tell whether there was one bite and then a release or a multiple biting?
A. In this case, no.
Q. So both phenomenons could have existed.
A. Right.
Q. It could have been a bite and a release and then reangled bite --
A. Right.
Q. -- and release, however many number of times.
A. Right.
Q. No way of telling.
A. Yes, sir.
Q. Is that because of the obscurity of the wound?
A. The intensity is heavy.
Q. This -- it looks like here that the depth here, there is depth here in this, is there not?
A. Yes, right.

Q. This depth here in the wound may have gone almost down to the -- through the subcutaneous -- is this -- is that what you call it, subcutaneous --

A. Yes, sir.

Q. -- tissue?

A. Right.

Q. Might have been a little bit of breaking in there in the subcutaneous tissue?

A. Could have been. It doesn't look like there is in that photograph.

Q. Okay. If you did break that skin or lower epidermis or whatever it is, would that also distort?

A. Yes.

Q. The relaxation of tissue?

A. Right.

Q. Thank you.

A. (Retakes stand.)

Q. When you made your report of 7-22-87, did you make any statements in there that a further analysis is needed?

A. I don't think I did.

Q. Okay. Would it help you if I showed you a copy of it?

A. If you are reading it and I did say something further, then I'll stand corrected.

MR. TATUM: May I approach the witness?

Q. (BY MR. TATUM) Let me show you this piece of paper and ask you if that kind of refreshes your recollection.

A. Yes.

Q. Did you say anything about further analysis is necessary?

A. No.

Q. Okay. Did you make any supplement report to this?

A. By phone to --

Q. Written report.

A. No.

Q. Okay. And at that time your opinion was such that the marks were not so definitely clear as to state that Chaney was the only person in the world that could have made these marks. Is that right?

A. That's what I said at the time.

Q. The comparison of the arch, as you testified before, is a measurement of the dome shapeness of the arch; is that correct?

A. Right.

Q. Okay. And would you call this a determination of gross characteristic?

A. Right.

Q. Okay. And it's the initial step you go through to see if, number one, you have a human or an animal bite.

A. Right.

Q. Okay. And given certain parameters of the domeness of the arch, you determine it's a human bite as opposed to animal. Is that right?

A. That is one characteristic and many others, too, yes.

Q. Okay. And teeth, the markings, and the type of injury.

A. Right.

Q. As far as -- is there any data that you know of that says that each individual has a different arch pattern or measurement?

A. Through my experience of seeing mouths eight hours a day every day, yes, there's no question about it, different sizes, different --

Q. Visually. You say that visually. You didn't get out there and measure everybody you saw, did you?

A. No, sir.

Q. Okay. It is possible that I might have the same arch pattern as somebody else as far as measurement.

A. Correct.

Q. I mean, human beings are -- well, they come in various sizes, that's true, but there's generally an upper and lower limit as to our sizes.

A. Right.

Q. And most of us exist somewhere in a middle range, do we not, in size?

A. Right.

Q. Okay. In other words, as far as proportions of our body, more people fit a normal size pattern somewhere in the middle of the human race. Is that right?

A. Right.

Q. Okay. Would the arch sizes that you found on this bite be in that middle area?

A. Yes, sir.

Q. Okay. In other words, they are not so grossly distorted that they would be as to a real small person or as to a real large person.

A. That's right.

Q. Okay. So it would be consistent with most of the people in the world --

A. Right.

Q. -- the arch size. Okay.

MR. TATUM: I think I'll pass the witness.

THE COURT: Sir?

REDIRECT EXAMINATION

BY MR. PASK:

Q. Mr. Tatum brought out the point that you didn't use the language "to a reasonable dental and medical certainty." Can you express your opinion using that language?

A. With reasonable dental certainty and scientific certainty, I feel that Steven Mark Chaney made the bite mark on John Sweek.

Q. And you also testified that someone else in the world possibly could have made that bite mark. Do you have any odds?

A. One to a million.

Q. Does that appear in the scientific literature?

A. Yes.

MR. PASK: Pass the witness.

THE COURT: Sir?

<u>RECROSS-EXAMINATION</u>

BY MR. TATUM:

Q. What was the scientific literature that appeared in?

A. The American Academy of Forensic Sciences Journal.

Q. What year?

A. I don't recall.

Q. You just don't remember? How many years ago did it appear?

A. In the last five.

Q. And was it more than five years ago or just recently?

A. Closer to five than in the last one or two.

Q. I see. And the data base of study of all of these arches and teeth and bite marks have been compiled back then that you could make this statement?

A. Right. Our American Board of Forensic Odontology committee on bite mark analysis made in-depth study with just huge amounts of data, and this is their conclusion.

Q. Even though I asked you before that there was no general data base that existed for these before? Remember I asked that question?

A. Right.

Q. And you agreed that there was not. You remember that?

A. I remember how I stated it, but I don't think that I am understanding the same thoughts that you are.

Q. Do you remember me reading this to you from Sopher's work: "The problem with specificity in the bite mark analysis results from the lack of a scientific core of basic data for comparison?"

A. Right.

Q. Right. And you agreed to that, right?

A. Yes, I do. And also I'd like to point out that book was written a number of years back.

Q. I also read to you the statement that "classified bite mark characteristics on large segments of the population are unavailable." Do you remember that, and you agreed?

A. Yes.

MR. TATUM: Pass the witness.

MR. PASK: No further questions.

THE COURT: Thank you, sir. You may step down.

You may call your next witness.

MR. PASK: State calls Jack Rasnic. Your Honor, may

Exhibit

S

THE COURT: Mr. Pask, you may begin.

MR. PASK: Thank you, Your Honor.

HOMER R. CAMPBELL,

called as a witness by the State, having been duly sworn by the Court to testify to the truth, the whole truth, and nothing but the truth, was examined and testified as follows:

DIRECT EXAMINATION

BY MR. PASK:

Q. Would you please state your name?

A. Yes. My name is Doctor Homer R. Campbell.

Q. And where are you from?

A. I am from the small town of Tijeras, New Mexico, which is just right outside of Albuquerque.

Q. How are you employed?

A. I am self-employed. I'm a private consultant.

Q. And whom do you consult?

A. I consult mainly on matters concerning forensic dentistry or forensic odontology.

Q. What is your educational background?

A. I attended the university at Baylor University in Waco, Texas; dental school at Baylor University College of Dentistry here in Dallas, Texas, is my degree education; and then subsequent short courses over the years.

Q. And were you a practicing dentist for a while?

A. Yes. I practiced for 28 years.

Q. And when did you move on to consultation?

A. About almost three years ago I had a decision to make, and I sold my practice and went into private consulting.

Q. What is forensic dentistry or odontology?

A. Forensic dentistry or odontology is essentially the gathering, preserving, and presentation of evidence, dental evidence, in a court of law, be it either civil or criminal, and covers three main basic areas.

One is dental malpractice and personal injury. The next is identification of unknown remains, be they either skeletonized or such as air crashes similar to the one that happened here in Dallas a while back and also the PSA that just happened in California. And then the third area is bite mark evaluation.

Q. What kind of training do you have in the area of forensic dentistry?

A. As far as formal training, my training consisted of one-week course at the Armed Forces Institute of Pathology in Washington, D.C; and several courses, many courses, in medical-legal investigation of death--these are all short courses, normally four or five days long--and meetings I attend, seminars, and this type of thing.

Q. What kind of practical experience do you have in forensic dentistry?

A. I became involved in forensic dentistry in 1973 and have served as -- first of all, I served as a consultant with the State of New Mexico in forensic dentistry beginning at that time and am currently the chief of forensic dentistry and have been for many years for the State of New Mexico.

Q. And are you certified in forensic dentistry?

A. Yes, I am.

Q. And what does that certification consist of?

A. I'm a diplomate of the American Board of Forensic Odontology, which is a specialty board in forensic dentistry or forensic odontology.

Q. Have you done any research in this area?

A. In the field of forensic dentistry itself have I done any actual, formal research and the answer is really, no, other than practical experience.

Q. All right. In a bite mark investigation, what is the first thing you do?

A. The very first thing you do, of course, is you need to look at the injury and make the determination is it animal or is it human. That's the very first thing you do.

Q. And how do you do that?

A. You can do that essentially by the way the injury looks. Different animals--dogs; cats; coyotes; mountain lions; snakes of various kinds; rats; you know, even down to cockroaches---all leave different types of marks or bites that you don't want to confuse with a human bite. And these are rather distinct for the most part, and it's very easily done.

For instance, in an animal, especially a dog or a large cat--now, by large cats I am speaking of mountain lions and this type of thing--they leave the marks of the front teeth. But where the eyeteeth, the canines, are, since they are very long and pointed, they usually leave a tearing or what we call a stellate type injury that's very easy to recognize.

Q. Is it possible to look at a bite mark and make a comparison between that bite mark and a suspect's teeth?

A. It's possible if the class characteristics of the human bite mark are present and if the individual characteristics of that injury are present.

Q. What do you mean by class characteristics?

A. Well, a human bite mark, the class characteristics of a human bite mark is that the injury itself is ovoid, semi-ovoid, or a portion thereof in shape. And when I say a portion thereof, you may only see half of it and not the whole thing; in other words, sort of egg-shaped in size. So this is a class characteristic of a human bite mark.

Along with that, is there enough class characteristics, again, of the individual teeth to be able to tell the upper teeth from the bottom teeth? You have to be able to do that, also. And if you think about it, your own teeth, of course, the upper two teeth on the upper arch are wide teeth. The ones adjacent to that are more narrow; and then, of course, the canines back behind are the stomach teeth, as opposed to the lower four front teeth which are relatively the same size.

So if those class characteristics are present, then you can tell which is the upper and which is the lower. And that's the next thing you need to know.

Q. What are individual characteristics?

A. Well, the individual characteristics are the characteristics -- they fall in really two classes or two kinds. Number one is the types of marks that you'd expect the teeth to make. The incisors or the four front teeth on the top and the bottom pretty much leave linear or rectangular type of marks; the canines leaving anything from dots to triangles to round, blunt type markings. So this is an individual tooth characteristic, an individual marking.

Likewise, is there anything specific that's in the mark that you see that you can identify such as such things as a broken tooth or a tooth that's got a corner broken off of it. That's a very individual characteristic. Some seamstresses that have sewn for a good number of years or women that open bobby pins with their front teeth tend to get little notches in them, pipe smokers.

There are a whole lot of different things besides the normal chewing habits of each and every one of us which are not the same as well as the dental intervention that causes individual characteristics in teeth.

Q. Have you had a chance to examine the evidence in this case?

A. Yes, I have.

MR. PASK: May I approach the witness?

THE COURT: You may.

Q. (BY MR. PASK) Let me show you what's been marked and introduced into evidence as State's Exhibit 75, 76, and 77. Have you had an opportunity to examine these?

A. Yes, I have.

Q. And have you had an opportunity to compare those exhibits to actual photographs of a bite mark?

A. Yes, I have.

Q. Specifically those pictures numbered State's Exhibit 81, 82, 106, and 107?

A. Yes, I have.

Q. Were you able to form an opinion as to whether or not the person possessing those teeth contained in the model made the bite mark?

A. Yes, I was.

Q. What possible conclusions could you have reached?

MR. TATUM: Let me enter an objection. I want to object to there hasn't been a proper predicate for the competency of this witness to be established to give that conclusion.

THE COURT: Overruled.
MR. TATUM: Thank you.
THE COURT: You may continue.
Q. (BY MR. PASK) You may answer the question.
A. Of the different categories of conclusions I can come to, I use basically three, the first being exclusion. In other words, the models that I am looking at could not possibly have made that injury. The second conclusion I can come to is that the models that I am looking at are consistent with that injury. And the third conclusion I can come to is that to a reasonable degree of dental certainty, those models produced that injury.
Q. What conclusion did you reach in this case?
A. In this case it's my opinion to a reasonable degree of dental certainty that that injury was in fact produced by the set of teeth represented in State's Exhibit 76 and 75.
Q. Now, I'd like to take the jury through the analysis you used to make your determination. What is the first thing you did?
A. The very first thing I did was to look at the photographs and from those photographs determine several things: Was it a human bite mark, which my determination it was.
Q. What information did you use to make that opinion?
A. Here, again, using the class characteristics, it's an ovoid type injury. Actually it's a multiple injury. In this case you're looking at more than one. You're looking at

several. I can identify which was made by the upper teeth and which was made by the lower teeth.

So once I could make that, then I could determine it was a human bite mark, I could orient myself, and I could proceed.

Q. How did you next proceed?

A. The next thing that I do is look very closely at the photograph, number one, to determine how many injuries I am looking at. Am I looking at one? Am I looking at two? Am I looking at three? Is one overlapped on the other one? What am I looking at at that point?

Q. What did you find in this case?

A. In this particular case, it's my opinion that there were at least four separate bites made.

Q. Okay. Would you step down from the witness stand? Can you show the jury, using the pictures, what you mean by that?

A. We need to orient the picture--this is State's Exhibit 81--with the number towards the top because where the number is, this represents the upper teeth, and the area to the bottom of the photograph represents the lower teeth. So it's -- just orienting the photograph is the first thing. And then by observing repetition of marks--in other words, what do I see that repeats itself more than once--is how I determine it.

In looking at the bottom of Exhibit 81, you notice this particular bruise which is located near to the ruler and then a very faint area that's semicircular in shape below that. So there is a mark. Over here is the other side. Immediately above that is another mark, and then the injury fades off at that point. Immediately above the darker mark by the ruler is another one; and by looking at the photograph you can see an area of contusion or abrasion, a little red stripe, joining these two where this just drug up.

So when a person bites, the upper teeth normally hold and the lower jaw, you know, the lower jaw's the one that moves. The upper one doesn't. It's adjoined to your head. So as the upper jaw holds and the lower jaw bites, as you will, it struck once here, another time here, and--it's faint--another time in here.

And then to look at the injury itself, you have an ovoid in the center that's rather dark, and yet there is one more ovoid that's even lighter. And that's the one that comes and cuts inside on the right-hand side of the photograph. So you actually have two. So there's one, two, three, four. So that's how I determined that.

Q. Why don't you briefly go over what you just said for this half of the jury.

A. Again, on State's Exhibit 81, with the lower jaw doing the biting, the first that I see is towards the bottom of the photograph, is this bruised area. And by looking real closely at the photograph, there is a semicircular area that ends at this point that's semicircular in shape. Immediately above that, there is a light bruise and, again, a light area of injury, not a dark one. It's very, very faint. And you have to look very close to see it.

Immediately above the most prominent bruise next to the ruler, if you look above, there's a dark-appearing area and there's actually a little red line that connects the two. Just runs from this one to this one. So he bit once; again, twice; again, three times. And then there's the ovoid shape that I was speaking of. But also there's one more, and that's another ovoid shape that cuts inside of this one, which means that things moved a little bit and then bit again.

So it's my opinion that there are four injuries here.

Q. And what did those injuries come from?

A. They come from human dentition.

Q. All right. How next did you proceed in your investigation?

A. The next thing I did was to look at the photographs and see what individual teeth exactly -- could I identify the individual teeth; and at that time, once I could identify the actual individual teeth, how many could I identify and be certain of what I was looking at.

Q. Let me take you back for just a second. You mentioned that up at the top of the photograph, we're looking at the upper arch.

A. That's correct.

Q. How did you make that determination?

A. Made it two separate ways. Number one -- and I'll get to it when we get to the bottom of the photograph, that's definitely the bottom. So in all probability this is the top. But also there's another thing that made it possible because by looking at the injury very closely and looking at segments, there is a wider tooth right here and one that's narrower here. One wide one, one narrow one. So the only arch that has this particular configuration in most people's mouths is the upper arch.

Q. So you're actually looking at individual teeth.

A. Actually individual tooth marks, yes.

Q. All right. And how did you start in your analysis of this individual tooth expedition?

A. Well, is to identify the individual teeth, which teeth am I looking at. Am I looking at the right side? In other words, the right front one or the left front one, you know, and determining exactly which teeth I could see marked. So that's the very first thing.

Q. Okay. Would you show the jury how you proceeded?

A. Yes. As I said, with the top you've got a wider and a more narrow. So if the wider one is in this position and the more narrow is adjacent to it to the right, then I am looking at the left side of the upper arch. And the reason for that is if you would bite into something, bang. As this goes the front and then immediately--and I'm saying right, it's actually immediately left. It's a mirror image of the teeth that they will mark in the upper arch in every way. So I've got a wide one and a more narrow one. So it has to be the upper left, central, and lateral incisors that mark in that case.

Going to the lower portion of the photograph -- and here's where I had to look both at State's Exhibit 81 and State's Exhibit 82 because State's Exhibit 82 actually shows the lower teeth more clearly than 81 does originally. But I also would like to verify it on both of them, if possible.

And that's possible in this particular case because the lower arch's got four teeth all relatively the same size. Again, one, two, three, four. So those four teeth are all relatively the same size and are marked by little rectangles. The lower teeth left almost a rectangular shape.

Q. Can we see those rectangles?

A. Yes. The clearest ones to see, of course, were left by the two centrals. This is a very clear rectangle as is this one, very clear. Likewise, this one in here is very clear. And you'll notice it's back behind these two right here, and that's fine. We're not to any point of making a determination, anyway, other than to know that it does sit back. Likewise, this one sits back to the side here.

And then the circular marks -- and they are nice and round, and they correspond to the marks. In other words, if you would compare the mark left by the canine here and the canine, they are consistent all the way. So that's what I'm talking about.

Q. Why don't you step down and tell the other members of the jury what you're talking about.

A. Okay. The lower -- the rectangles, the four of the same size, and these are very plain rectangles. There's just hardly -- anybody can see them. Likewise, the one that comes in in this position. And it's more faint on this edge, but it's still a nice rectangle. The same thing here and the canine marks that are round that correspond to the other marks that I spoke of earlier.

See here, here, and then a lighter, bruised area here with a red mark in between it. That's a darker area. Just almost straight in. But the rectangles are very, very clear and very discriminating on State's Exhibit 82. If you compare that to State's Exhibit 81, they are not as clear. And that's simply a matter of photographic light is all it is. In other words, there's more light here than there is here so they are clearer here than they are here. You can still see the rectangles.

Here's the rectangle left by one of the inside central incisors. Here's the same rectangle right up here, but only the outer portion of it may be seen. The same way here. As far as the tooth that sits back in on this side, the same thing here, only it's not as clear as on 81 as it is on 82.

So it's a combination of using both of the photographs to really make a determination of what you're looking at. And you have to look at every photograph there is because many, many times one photograph will show you one thing, another photograph will show you something else. And the only reason it does is because the lighting has changed. It's a little brighter, it's a little darker. Who knows?

Q. Did you review all the evidence in this case?

A. Every photograph.

Q. How next did you proceed in your investigation?

A. Once I could determine what I was looking at, the relative position of the teeth one to another in the arch, the individual positioning of each tooth, then I looked and took the dental models, made an impression of the biting edges of those models, and compared then from the model to the wax bite to the photograph, just a straight comparison point by point to see whether all the points were consistent in every detail.

Q. Can we go through that analysis?

A. Yes, you can. State's Exhibit 75 is actually a dental stone model of the upper dentition, in other words, the top teeth. Again, the front two are wider; the adjacent teeth on the underside are smaller, the canines. You can take the model and by impressing it into a wax--an Alu-wax is what I use and what most people use--you can make a bite, if you will, or a registration of how the biting edges mark in the case.

Q. What do we have here in State's Exhibit 77?

A. And State's Exhibit 77 is a wax bite of these teeth.

Q. Does it comport with State's Exhibit 75?

A. Yes, it does. And it can be checked because you can actually take and sit State's Exhibit 75 into the impressions on State's Exhibit 77.

Q. We're looking at the upper arch here in State's Exhibit 75?

A. Well, you're looking at both. On this side is the upper arch. It's the one that is sort of swayed out, if you will, much flatter. On the other side of State's Exhibit 77 are the lower teeth. Doctor Hales made this particular wax bite.

And, here again, the wax bite on the lower is the same way. You can either do this right in the person's mouth or do it with the models. It doesn't really make any difference. So by having them bite into it or you pressing down, you can actually make the marks in the wax.

Q. All right. And what comparisons could you make?

A. Well, then it's a comparison, like I said, of going from the model to the wax to the photograph. And it's done this way. First of all, let's look and concern only with the lower arch, only with the lower one. You notice that the lower arch is irregular in shape. The two centrals sit out towards the lip; or, conversely, the two teeth on other side of the laterals sit back towards the tongue, whichever way you want to put it. But you have a zigzag arrangement across there.

Is this represented likewise in the wax? And what do the marks in the wax look like? Here is the wax in State's Exhibit 77. Again, a very irregular pattern here in this area.

Q. Why don't you bring it down to this end and let's show these members.

A. Here again, by comparing the models and then the way the wax impressed from the teeth of the individual, you can see that it's very irregular. In other words, these two teeth, the two centrals, are represented by these two that sit out in front sort of very prominently. And then the two on either side are tucked back, which is represented here in the two eyeteeth, one being much closer to the other. So the wax really shows how the teeth mark.

Also, by looking at the wax very carefully on the biting edge, you will notice that right at the bottom of these impressions you will see little rectangular shapes all the way across with the exception of the canines, which, of course, are going to leave a rounder, triangular mark.

Q. And then what did you do?

A. Well, then it's a matter of comparing it directly to the photograph one tooth at a time. So in the lower I used State's Exhibit 82 to compare that to.

Q. What comparison did you make?

A. Take the lower teeth, and this time to look at the lowers, you have got to turn it around because when the lowers bite in, they bite in this direction. So if you flip it right directly over and look at the models with the wax or the models with the photograph, you'll see the two centrals sitting out in front, the laterals back behind this very plainly, and then the round circles produced by the canines.

And there's a gap that really shows on this side, and you don't see a corresponding gap on this side. Likewise, if you look at the wax in this case--and the wax has to be looked at this way because that's how it was made and so you flip it over--you'll see that there is a gap on one side and not a gap on the other side.

Q. Could you show the jury the gap on the wax and on the picture?

A. Here again, just directly compare the two, here are the two centrals, the two laterals sitting back. This particular eyetooth sits very close to the lateral. So consequently these two marks are right together almost as opposed to the other side where the lateral sits back and then right here the wax sort of pooches out. That would leave a space, and then the other tooth mark. And that's exactly what it does.

Q. Why don't we move down and show the other members of the jury that.

A. Okay. To orient the two very front teeth or the two centrals, you can see the little rectangular marks. Now, they are different sizes because this is life-size and this is about two and three-quarters bigger. But that's all right because you can see it better. But the two centrals sitting out, the laterals sitting back in on both sides.

But look very closely: Here is the eyetooth on this side. And if you notice, it's very, very close and adjacent to this one, as opposed to the other side, here's the lateral and then the wax is sort of pooched in there where there's a space, not a space in the teeth but a space between the biting edges--okay--of the two, and that corresponds to here.

So everything in the lower arch to the position and even down to the very center -- if you look in this impression, there are little rectangles right to the very bottom of it, and you have to sit down and look at it. And that represents what you're seeing here, and they are the same in here. So it's a direct comparison of the models to the wax to the injury itself in every case.

Q. I'd like for you to step back down here and point individual teeth out on the model and show them where it is on the wax and then show them where it is on the picture, if you can.

A. Okay. Remember that this model to make the thing bit into it this way or the teeth bit in this way, so flip this over in this manner. Can everybody see? Here is an eyetooth that's very close -- actually overlapping this particular lateral incisor. So here's the tooth, the canine tooth. Likewise, the same canine tooth is in the wax at this point right here. Lateral incisor tucked back towards the tongue.

If you could hold that, that would help.

The lateral incisor that is back towards the tongue at this point is represented in the wax here. The two centrals, likewise here; the lateral to the laterals sticking back towards the tongue; and then the canine. And the space I'm talking about, if you look at what marks the marking, there is a space in here and is almost nonexistent here. So that's the difference. Likewise, let's go from the canine to the canine to the canine. They are round type marks.

Q. Can we see that mark there in the picture?

A. Yes, you do. So the lateral incisor to the lateral incisor. And it's in here. You've got to look for it real hard.

Q. Can you see it right there?

A. Yes, I can see it upside down right here. It's hard to see.

Q. Does it take someone with a trained eye to see it?

A. Yes, it does. You've got to be used to looking at photographs and looking at photographs in detail because photographs contain much more information than the eye can see.

Until you only look one, little bitty photograph and then you see what's in that little bitty piece instead of looking at the whole thing. It's sort of like you look at the tree and not the forest type thing.

The centrals, both centrals, very clearly marked out in front a little bit. They are here in the wax the same way and in the photograph at this point.

Q. Looks like you can see those a little bit better.

A. Those are very clear. There is no doubt about those at all. Then the other lateral incisor tucked back towards the tongue. Here again, remember this is the central and here is the lateral right back behind it, a nice triangle that's in there. So it matches well. And then the eyetooth, leaving the round mark here and it appears around and here with the space in between it which is on here. So that's how you -- it's just direct comparison. There's nothing magic about it.

Q. Let's go down here and show the other members of the jury.

A. Again, in a direct comparison of tooth by tooth from the eyetooth on the model to the eyetooth mark in the wax, and you'll notice that this is somewhat rounded to the rounded mark on the photograph; the lateral incisor which is tucked back and crowded in between these two teeth here. And it's the same on the wax from the model to the wax to the photograph.

Then the most clear ones you see are the two centrals, this tooth and this tooth represented by the marks in the wax the same way, and again to the photograph, showing the individual rectangles of those two teeth; to the lateral incisor that's back towards the tongue, to the wax that shows the same thing, to the photograph that shows exactly the same thing right here in this position. And it comes out to here.

Then there's a little space in between. And, as I said, that's only because the points that hit, there's actually a gap in between the two of them. Doesn't mean anything is missing. There's just nothing in there. And so to the eyetooth, to the round marking on the wax. They are the same in the photograph.

Q. What do we see right down here?

A. What this is is the same mark as this one. This is the lower canine that hit at this point. Do all the teeth mark at that point? No. Why don't they? I don't know. Maybe just, you know, wasn't biting hard at that time. Maybe something was interposed. I don't know. It's not rare to see only one arch or a portion of an arch mark. And, here, again there's no reason for it.

Q. Okay. What next did you do?

A. Well, then it was a matter of doing the same thing as best I could on the top.

Q. Why don't we move back down here?

A. Okay. And the top is similar -- we've got to go to the other photograph. This is State's Exhibit 81, which shows more detail in the top marking, and 82 because both of them are pertinent in this particular instance. The first thing is to look at the general shape of the model. These teeth have crowns on them. They are artificial crowns placed on the teeth. They have been capped, in other words, or they appear to have been capped.

Look at the contour. The overall contour is relatively straight. In other words, one tooth isn't sitting back towards the tongue or isn't twisted out towards the lip or that type of thing. So in just looking at the general area of bruising, it's relatively semicircular. Nothing really sticking out, rotate, you know, out of place at all, and fairly clear here.

Remember that I said that we're looking at more than one injury. Here is one, but also remember that here is another ovoid and here comes the other one around it. So there's two, and they are both regular in shape. Of the top teeth that I can really identify is the upper left central and the upper left lateral, two teeth, one leaving a mark in this position, the other one right here .

Q. Could you point those out on the wax impression?

A. These two, this one and this one.

Q. And now on the model?

A. This one and this one, okay? And this one and this one, those two teeth. Those are the clearest ones to see in the two. As far as anything else that I can determine, I can't find the individual teeth themselves.

Q. What about the bruising? Is that consistent with this model?

A. The bruising is consistent. The width of the bruising is consistent. There's a whole lot of things in there that's consistent. There's nothing inconsistent. Let me put it that way. But those two teeth are very readily identified and even identified to the point, if you'll look at these -- now, okay, remember that in the upper, the upper teeth hit this way.

So we're going to look at this tooth and this tooth. Okay? These two. And these two, if you notice, come at a little bit more of an angle around to the corner than these with this one or a little bit out but not much. But these are pretty much in line coming down. Likewise, this tooth and this one, the central and the lateral marks are identical. Can you see those? Okay.

Here are the two marks, and you must look closely. Remember this is almost three times life-size. So here is the central and then the lateral. And they are pretty much right straight in line with one another.

Two teeth we're looking at is this tooth and this tooth. And if you look at the biting edges of them, they are pretty much right in line this way.

Q. Why don't we move down and show the other jurors.

A. Here again, it's a matter of looking at the upper arch --

Q. Why don't you get down here?

A. Good. The upper arch is rather regular. In other words, it's relatively smooth all the way across. There's nothing that really sticks out badly in any place or goes in or is twisted. So it's a rather smooth type injury. The same thing is present if you look at the general overall injury of the pattern. This is a regular arch form.

Now, there are two arch forms in here. There is one and here is another one. They are compatible one with the other one entirely, but there's two overlying it. And the only individual teeth I can see in the upper that I personally wish to talk about is the central incisor, which is marking in this position, the lateral incisor in line with it in this position. This would correspond if this came down to this tooth and this tooth which are in good alignment pretty much right in a line all the way down.

So it's a direct comparison and a direct comparison arch width, tooth position, and everything else.

Q. And what next did you do?

A. And the next thing I did was to go to the one-to-one photographs and just visually recheck myself. I don't do that initially because this particular technique you tend to cover things up and cannot see it as well. But I do it to check it if I've got an one-to-one photograph, and I did that with the one-to-ones in State's Exhibit 106, 107, and just took and compared them by actually placing the models on them and seeing if everything matched up.

Q. Can you show the jury how you did that?

A. Yes. Here again, the injury, the bottom portion of the photograph is represented by the lower teeth. So take the lower dentition and to place it, remembering that on State's Exhibit 76, this is an eyetooth and this is an eyetooth and here are the two centrals. So that gives you four key points to go from. And you can line it up is by putting the eyetooth on there, the two centrals where the two centrals belong, and the other eyetooth on the other side.

And, as you see, you can't see anything. You say, "Well, why did you do that?" Well, the thing to do is instead of putting it right there over the top is just to move it back and, again, just check the alignment of the teeth to the photograph. Does everything go where it's supposed to go?

Q. And what conclusion did you reach?

A. They did.

Q. Can you make a determination as to the consistency of the size and shape of the arches based on this comparison, too?

A. Of course. Here, again, if the two canine teeth markings are in the right position, you can lay this on there and say, "Well, the arch size from this point to this point is consistent," or from this point to any point in there, or you can take a simple set of dividers and just say, "Well, there are those two points and here are these two and they are relatively the same."

Now, I say relatively the same because they may not be exactly the same. When you talk about exact, that's one thing. When you talk about approximate, that's something else.

Q. Why don't we show the other members of the jury this lower arch before we move on.

A. Oh, okay. Here again, using the two eyeteeth and the two centrals as guides and the marks representing the two eye-teeth and the two central teeth, it's a matter of just lying this right over the top. And when I do, you'll see that you can't see anything, which is one of the reasons I wouldn't do this to start with. And this is just simply a check. And it's a check that will tell you is the arch width consistent, which in this case, it is.

But if you will take and you just scoot these back a little bit, then you can start to see the photograph and the teeth themselves and how they, you know, what made what injury. Here again, this is just a check that I use to see if really that's where everything is. I do exactly the same thing on the top.

Q. Okay. Why don't we go back here and do the top?

A. Now, in this case, using State's Exhibit 75--well, and State's Exhibit 107, 107 is a little bit clearer--again, it's a matter of placing the teeth as far as the arch shape is concerned over the front and is it consistent with the arch shape. And just moving the model back, yes, it is. But there are also two injuries in here. And so you have to come down, and is the next one that goes from the lighter shaded area over around, is that consistent? And moving it down and, yes, it is.

So it's just a comparison and only two teeth to guide by in that particular instance.

Q. Why don't you move on down?

A. Here again, the same thing as on the bottom. Using the darker area, is the injury consistent in width? And the answer is, yes, it is, and in shape and what have you. Now, in this particular portion, there is no definitive tooth markings, and yet in the other one, remember there were two, the central and the lateral, which were right in here. And, correspondingly, is that particular arch marking the same? And, yes, it is.

So there are two on the top you can see a shift where the arm has turned or something, you know, that caused it to change. That was the final check.

MR. PASK: You may retake your seat.

Q. (BY MR. PASK) So to summarize your testimony, you're stating that the person who has these teeth depicted in this model made that bite mark to a reasonable dental certainty?

A. That's correct.

MR. PASK: I'll pass the witness.

THE COURT: Mr. Tatum, are you prepared to cross?

MR. TATUM: I have a little bit, Judge.

CROSS-EXAMINATION

BY MR. TATUM:

Q. Now, when you give an opinion of reasonable dental certainty, that's what members in your profession look to as at least a minimum level of certainty, is that right, to give that opinion?

A. Yes. Not an absolutely, positively, beyond a shadow of a doubter, so to speak, but to a reasonable certainty, yes.

Q. Reasonable dental certainty.

A. Reasonable dental certainty.

Q. Okay. And that's the way, really, part of your analysis is directed to give an opinion. Right?

A. That's correct.

Q. Okay. Can you really give an opinion without stating those words that's valid?

A. Can I give an opinion? I can give an opinion --

Q. That's valid and recognized.

A. That is consistent with, yes, I can give that opinion.

Q. Is that a recognized way of giving and expressing the opinion of what you've looked at without using reasonable dental certainty?

A. Yes, that's a valid opinion.

Q. Either way?

A. Either way. It's degree.

Q. Okay. Can you find each of those teeth that you said that you were talking about on the upper and lower arches in each of the four separate bites you were talking about?

A. No, I cannot. They are just not there. Some teeth marked, some did not. I am just saying that there was an instance that in my opinion represents the striking of the teeth four times.

Q. Okay. Is it possible and did you mark the midpoint of the teeth that you're talking about within plus or minus one millimeter to the center point of the two? Can you do that?

A. That's interesting. Can I do it? Probably I can come pretty close in most of them. And by pretty close, you know, is it in the center of the tooth or in the center of the marking area? And that's two different things. If it's in the center of the marking area, of course, I can. I can -- you know, I can probably come closer than that.

If it's in the total width of the tooth, I'm not -- I think I could hit it within a millimeter because the lower teeth are only five millimeters. So that gives me one chance in five of hitting it on the button, which is sort of bad percentage-wise. They are good for me and bad the other way.

Here again, unless the entire width of the tooth mark--and I'm saying that very specifically--unless the entire width marked--and most teeth, the entire width does not mark--then can I hit the exact center? And the answer is, no, I probably can't, using that as a parameter. I can come within a millimeter because, here again, when I'm dealing one millimeter as opposed to five, I think I can probably get pretty close to it.

Q. Okay. You recognized the standard I gave you, did you not?

A. I know where you got it, yes.

Q. Yes. And where did I get it?

A. You got it from an article published in the Journal of Forensic Sciences. I believe it was in '84. Main author was Doctor Ray Rawson from Nevada.

Q. Right. And that's statistical study is based upon that crucial measurement of within plus or minus five degrees of rotation of the tooth, is it not?

A. Well, what he's saying in there is to position tooth centers, that you should be able to measure, you know, to within one millimeter. And he gave himself a pretty good leeway in doing that. Here again, it's one to five. Your odds aren't too bad.

Q. But that's the premise that must be established before you can use that as a statistical basis to make any further conclusions.

A. If I was basing it on his study, I absolutely would. And, of course, his study -- I say to a reasonable degree of certainty. You know, I think he even in his study gives a figure of what the probability factor is if you can do that.

Q. Okay. Now, when you were in front of the jury showing the models and the expanded photograph, you kept using the word direct comparison, direct comparison. In reality, the direct comparison is your interpretation of that evidence.

A. Absolutely. Absolutely it's my interpretation.

Q. Right. You can't take that real-life or real-sized model and place it on the expanded model and make a direct comparison.

A. Oh, no, because one's almost three times bigger than the other one.

Q. Right.

A. Here again, it's a direct visual comparison of one to the other as you go up.

Q. Okay. But you used the same word when you go from actual plaster model to wax impression, that's a direct comparison. And then you take the wax comparison and hold it in front of the expanded photograph and used direct comparison.

A. That's quite true.

Q. It's not the same direct comparison.

A. Yes, it is a direct comparison. It's a direct visual comparison between the two. You can see it in all three instances. So it is a direct comparison in my opinion.

Q. Okay. It's a direct comparison by your interpretation of the visually holding it, showing the relationship. Is that what you're talking about?

A. That's quite true.

Q. Okay. And that's because the photographs that you were originally using aren't to scale. They're blown up.

A. That's right. You've got one that's large. But, here again, you're looking at pattern recognition and doesn't matter whether you use one that's three times the size and one that's one time, you know, regular. It's still a visual comparison between the two --

Q. Absolutely.

A. -- a visual and direct comparison.

Q. Okay. Were you able to take any calipers and measure the one-to-one scale on the black-and-whites with the models?

A. They are fairly close. And by fairly close, I am trying to remember did it come out exactly one-to-one. And I believe when I measured it, it came out to 1.001 to 1.

Q. Based on that ruler in there?

A. That's what you compare it to. In other words, I was just measuring different distances across the ruler, and was it -- you know, did it accurately represent one inch. Sometimes it was not ever exactly one because rulers are not going to be exact. I don't care what people say about standardization of rulers and what have you. It depends where you take the points of your calipers and place them. Can there be a slight variation? Sure, there can. That's why I said approximate, and that's exactly what I meant.

Q. Okay. Wouldn't it have been preferable to have millimeter rules in there?

A. Doesn't make the least bit of difference.

Q. You don't think so?

A. No. As long as you use the same measurement all the way through, it doesn't make the least bit of difference. Also, most of your high quality measuring type instruments have the capability which are digital readout or LED and this type of thing, have capability of switching automatically from inches to millimeters, anyway. So if you're curious about how many millimeters, normally it's just a matter of hitting a button and you've got it, whether it's -- you know, no matter what scale it's in.

Q. Well, that's fine for your measuring instrument -- the statement you made is, I'm sure, very accurate to your measuring instrument, but the actual measuring instrument that's placed in the one-to-one, black-and-white photos can't do that. It's just a rule laid there that's in inches.

A. That's right.

Q. And what I asked you: Wouldn't it have been preferable to have a millimeter rule there to make it more accurate because there are more divisions to millimeters?

A. Well, actually if you think about it, between an inch ruler and a millimeter scale, you have got 10 markings in each centimeter is what it's broken down into is 10. Depending upon your inch rule, you know, many of them are broken into eighths, sometimes into sixteenths. And the individual markings don't -- on the ruler itself, it's used to approximately scale the photograph.

In other words, anybody -- and I would be a fool to come up and sit here and try to tell you that that photograph is absolutely one to one. What in the world do you mean by that? Because I don't think you can find anything that would be absolute. You know, is it scaled approximately one to one? Yes, it is.

Q. Okay. It's approximate. In regard to the angling of the rulers, is that very crucial on how you lay them, whether it would have to be absolutely 90 degrees?

A. The reason for the 90 degrees is just -- in my opinion is to give both a height and a length or a two-sided measurement to the thing. Does it have to be, the answer is, no, you could put the ruler in any direction you wanted to and you can get by with using only one. There is the ABOFO at the current time is sponsoring, for lack of a better word, a ruler that they or a scale that they devised which is a right angle type of scale showing both a vertical and horizontal scale. And it would be nice if we could have that used in every instance. I think it's basically a good scale but unfortunately don't have any control over the different investigative agencies throughout the country as far as what they want to use.

Q. Isn't it more desirable also to include a circular reference in addition to the linear scale?

A. There has been some thought given to circular. Here again, the reason for the circular scale in it is to tell are you exactly at 90 degrees? In other words, if you are to the plane of the photograph, you will have a perfect circle. If it's not perfectly round, well, sure, the camera may be a little bit out off of 90 degrees? Are all photographs taken at exactly 90 degrees? Probably not. And in my experience, 99.9 percent of them are not that I get involved with.

Here again, if you do have a circular scale, it could even be a quarter, a dime. It can be set on the tissue, anything else. This does help you to let you at least have an idea of where it came from.

Q. Don't the guidelines for bite mark analysis by the American Board of Forensic Odontology state that it presently appears desirable to include a circular reference in addition to the linear scale?

A. That's exactly what it says in exactly those words.

It's a desirable thing. Like I said, I wish we could have it all, but we don't get it every time.

Q. Okay. The reason it's desirable is it might increase the accuracy of the information to help better provide something for you to base your opinion on.

A. Here again, you know, if you've got a real good scale, if you've got the circulars, you can tell, you know, was everything taken at 90 degrees, is everything oriented just exactly properly. That's true. That's the ideal situation, and it's too bad we don't have it most of the time.

That still does not negate being able to use something that, we'll say, was taken slightly off of 90 degrees because, here again, we're talking about pattern recognition. Is the pattern there? And the pattern will be there, you know, even though it's not at just exactly perfectly 90 degrees.

THE COURT: I'm going to interrupt you, sir. It's time for our 3:00 o'clock break.

Take 15, ladies and gentlemen of the jury. Don't discuss anything you have heard among yourselves nor let anyone else discuss anything with you.

(The jury was retired,
and a recess was taken.)

THE COURT: It's become apparent to everybody here we're probably not going to get to your testimony today. So come on in, let me get everybody's name, and let me send you all home. I'm sorry to do this to you, but I think you'd rather go now than wait until 5:00 o'clock and go, hit that traffic.

All right. Now, ladies and gentlemen, I have got to have everybody's name. I have got to have the spelling of everybody's name. Come on in so we can see you. I'm going to point to you. I want you to give me your name. I want you to spell it so I can hear it, so this lady can hear it. Okay?

Start on my far left, you, sir?

A WITNESS: Charles Currier, C-U-R-R-I-E-R.

THE COURT: C-U-R-R-I-E-R. Sir?

A WITNESS: Larry Gavlick, G-A-V-L-I-C-K.

THE COURT: Sir?

A WITNESS: John Hooper, Jr., H-O-O-P-E-R.

THE COURT: Ma'am?

A WITNESS: Lenora Murley.

THE COURT: L-E-N-O-R-A.

A WITNESS: L-E-N-O-R-A.

THE COURT: And your last name, ma'am?

A WITNESS: Murley, M-U-R-L-E-Y.

THE COURT: Ma'am?

A WITNESS: Rebecca Edwards.

THE COURT: Rebecca?

A WITNESS: Rebecca Edwards.

THE COURT: E-D-W-A-R-D-S?

A WITNESS: Uh-huh.

A WITNESS: Bryan Edwards.

THE COURT: B-R-Y-A-N?

A WITNESS: Yes.

A WITNESS: Bobby Hunter, H-U-N-T-E-R.

THE COURT: Yes, sir?

A WITNESS: John Hooper, Sr.

A WITNESS: Dora Hooper.

THE COURT: First name?

A WITNESS: Dora, D-O-R-A, Hooper.

THE COURT: Sir?

A WITNESS: Barry Hines.

THE COURT: B-A-R-R-Y?

A WITNESS: H-I-N-E-S.

THE COURT: Everybody please raise your right hand.

(The witnesses were duly sworn by the Court.)

THE COURT: Thank you. Now, lower your hands. Let me explain to you that the Rule of Evidence has been invoked in this case. Now, that means that every one of you sworn as witnesses must now remain outside the presence and hearing of the courtroom except while you are testifying. Please do not discuss your testimony with any other witnesses. Do not talk to another witness or any other person about this case except by permission of the Court. Do not read any report of or comment upon any testimony that's been taken in this case. You may, of course, speak with the attorneys. But when you do so, be sure that no one else is around. Okay?

Now, let me tell you I want you all back at about a quarter of 9:00 in the morning. I am going to send you home now; and if you will be back at a quarter of 9:00, I'd really appreciate it. And I'll see you then. Thank you very much.

(The witnesses were excused from the courtroom.)

THE COURT: I believe if the doctor will take the stand. Are we ready to gear up and go?

You may seat the jury, ma'am.

(The jury returned into open court, and the following proceedings were had.)

THE COURT: You may be seated, ladies and gentlemen.

Mr. Tatum, you may continue.

MR. TATUM: Thank you, Judge.

Q. (BY MR. TATUM) Isn't it true, Doctor, that everything you have been talking about is basically an approximate thing?

A. Yes. It's no -- no definitive measurements in this case.

Q. As part of the guidelines for making an analysis, isn't it, when it's possible, good to have salivary trace evidence done?

A. Ideally that's true. Unfortunately, many times it isn't done.

Q. Okay. Is there any other technique in making analysis of bite marks involving impressions from the surface of the bite mark?

A. Sometimes impressions really will give you information. In my experience, sometimes they do. More often than not, they are not worth the trouble because you end up with nothing or you end up with a lot of care.

Q. Okay. But this is another technique to at least show a three-dimensional part of the marking itself; is that right?

A. I really don't like the word three-dimensional. Really, the only time I feel that bite marks will give you really a three-dimensional type of impression is if these indentations are deep enough to where they'll really show and show clearly, number one, or will give you a very accurate two-dimensional representation of where the wound is in size. In other words, the skin tissue is broken. But, here again, most bite marks are not of either of those two types.

Q. Okay. There is a lot of damage or bruising into the bite mark area of these photographs, is there not?

A. Well, you're looking at two things: Is there bruising beneath the skin? Absolutely, there is. Is there some post mortem drying? Absolutely, there is. So, you know, you're looking at both.

Q. Okay. You mentioned post mortem drying. Is that consistent with tissue shrinking?

A. What you see in post mortem drying really isn't a tissue shrinking as the surface becoming sort of similar to a scab on a scrape, this type of thing. So initially it's not that at all.

Q. Okay. Did you put these -- any of these photographs under any type of microscope?

A. I happen to have in my office a four-times enlarger lens with a light under it which I used to look at all the photographs with.

Q. Okay. Is that just something you hold and move around like that?

A. No. It's on a big arm with a light in it, and it's a fancy magnifying glass. Okay?

Q. Okay.

A. All right.

Q. But you didn't actually get down and compare it microscopically beyond the power that you're talking about?

A. No. I did not look at it under a microscope at all.

Q. Okay. Are there other techniques for bite mark comparison using these electron microscope and things like that?

A. Some people have used electron microscopy, that's true. Photographic enhancement is used, also. There are many techniques that have been used and are useful depending upon the particular case. They are not used in all of them by any stretch of the imagination, and each case must be handled pretty much on an individual case-by-case basis because a lot of times you'll have a lot of information. A lot of times you won't.

Q. Okay. But you don't know unless you try, unless you make that effort to examine the photograph or the actual impressions or the actual tissue samples with those types of special devices. Right?

A. Not necessarily. That's not true. Here again, the proponents of electron microscopy have a point in does it help them see a little better? Sometimes, yes; sometimes, no. I can give you all the faults of each technique and the benefits, too. So is it necessary? No, not really. It all depends on the case.

Q. Okay. It may not be necessary, but it certainly could aid in defining the evidence.

A. In some cases, it may.

Q. Okay. In this case, could it have?

A. I don't know.

Q. Okay. You made the statement in looking and showing the photographs to the jury that you have to look for it real hard. Do you remember making that statement?

A. That's right.

Q. Okay. And you said it takes a trained eye to spot what you were talking about.

A. It sure does.

Q. Okay. That really puts it into somewhat of a subjective realm as to your interpreting the evidence, right?

A. Of course it is. It's very, very similar to your people that work for NASA and the people that work for the military, the photo interpreters. It's definitely a trained eye.

Q. Would you consider this bite mark a class C type bite mark?

A. What is a class C type bite mark? I don't know your classification. If you'd just tell me what you mean, I'll answer your question.

Q. I don't know. Maybe you can ask Doctor Hales.

MR. TATUM: I'll pass the witness.

REDIRECT EXAMINATION

BY MR. PASK:

Q. Is there anything the defense attorney asked you that has caused you to change your opinion?

A. No, sir.

Q. How many bite marks have you actually viewed?

A. Oh, well over -- well over 300. I don't know the exact number.

Q. Based on the photos you have seen, had the bite mark changed or decomposed to the extent that it would have any effect on your comparison and your ability to render an opinion?

A. I don't believe so, no, sir.

Q. Mr. Tatum cited an article to you, I believe, that you are aware of. Does that article give any odds as to what the odds would be when you're reasonably dental certain what odds there would be for someone else in the world to make that bite mark?

A. Well, that particular article dealt with if you could find the center of a mark within one millimeter and there are six adjacent teeth, what the odds would be. It gives that figure, yes.

Q. Do you have the capacity for photo enhancement?

A. Yes, I do.

Q. Have you explored that possibility in this case?

A. In this case, no, and there's a reason for it.

Q. And what is that reason?

A. In the photograph itself when it was photographed, the hair was not removed from the surface of the injury. And consequently as a result, if you would run photo enhancement on an area, it comes up and really looks like a forest because the hairs stand out tremendously, and it becomes very hard to distinguish sometimes once that overlies it at extreme magnification what it would really look like.

MR. PASK: I'll pass the witness.

THE COURT: Sir?

MR. TATUM: I have nothing further.

THE COURT: Thank you, sir. You may step down.

THE WITNESS: May I be excused, Judge?

THE COURT: Any objection to this witness being

Exhibit

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The Washington Post

The Watch

How the flawed ‘science’ of bite mark analysis has sent innocent people to prison

By Radley Balko February 13

This is part one in a four-part series. The rest of the series will be posted next week.

Before he left the courtroom, Gerard Richardson made his mother a promise. “I told her that one day she’d see me walk out of that building a free man,” he says.

Her response nearly broke him. “She said, ‘Gerard, I’ll be dead by then.’”

Richardson, then 30, had just been convicted for the murder of 19-year-old Monica Reyes, whose half-naked body was found in a roadside ditch in Bernards Township, N.J. The year was 1995, and Richardson had just been sentenced to 30 years in prison.

There were only two pieces of evidence implicating him. One was a statement from Reyes’s boyfriend, who claimed to have heard Richardson threaten to kill her. But that statement was made only after police had shown the boyfriend the second piece of evidence: a finding from a forensic odontologist that a bite mark found on Reyes’s body was a match to Richardson’s teeth. Dr. Ira Titunik, the bite mark expert for the prosecution, would later tell jurors there was “no question in my mind” that Richardson had bitten Reyes.

“I thought it was crazy,” Richardson says. “There was no way it was possible. The FBI looked at hairs, fibers, blood, everything the police found at the crime scene. None of it came from me. Just this bite mark.”

Despite his certainty, Titunik’s analysis consisted of little more than a one-page report identifying Richardson as the culprit. “There were only two things on that sheet. It said there was a bite mark on the victim, and that I had made it.”

In fact, when questioned at trial about his methodology — about why he was able to single out Richardson as the biter — Titunik relied on a more detailed report offered by Richardson’s own expert witness, Norman Sperber, also a bite mark analyst. But Sperber, also going off his own report, told jurors there was no way the bite mark could have been left by Gerard Richardson. Two witnesses who called themselves experts relied on the same report and came to diametrically opposing conclusions.

“I thought that was the very definition of reasonable doubt,” Richardson says. “The only physical evidence against me was Dr. Titunik’s testimony. But my own expert was just as qualified as he was and was saying the very opposite. And they were both using the same report. How could that not be reasonable doubt?”

In 1998, three years after Richardson’s conviction, a handyman named Edmund Burke was arrested for the brutal murder of a 75-year-old woman near her home in Massachusetts. Burke became a suspect after a police dog led officers to the house where Burke lived with his mother, about a quarter-mile from the crime scene. As with Richardson, the only physical evidence against Burke was the testimony of a bite mark expert who claimed to match Burke’s teeth to marks found on the victim. That expert, Dr. Lowell Levine, hadn’t actually examined the body, only photos of it. Nevertheless, he claimed he could match a dental mold of Burke’s teeth to the bite marks in the photos with “a reasonable degree of scientific certainty.” Prosecutors then turned to a second odontologist to verify Levine’s match: Ira Titunik. He did.

Burke was held in jail for 41 days. He was released when DNA testing on saliva recovered from the bite mark excluded him. Five years later, DNA from the saliva around bite mark hit a match in the FBI's Combined Index DNA System (CODIS). The match was to a man already convicted of murder. Prosecutor William Keating, who took office after Burke's arrest, told the Chicago Tribune he had "no question" that Burke was innocent.

Gerard Richardson wasn't quite as lucky as Edmund Burke. Though saliva was also collected from the bite mark left on Monica Reyes, the DNA technology available at the time wasn't able to produce a profile. It would take nearly two decades for the technology to improve to the point where enough useful DNA could be extracted from the small amount of saliva. When that finally happened, it showed that Richardson wasn't Reyes's killer.

Richardson was finally released in December 2013. He says that when his attorneys told him he could be released, he was elated and relieved. But he also didn't want his vindication to be validated in a stack of papers.

"I wanted it done in a courtroom," he says. "I wanted to hear it from a judge. I wanted my family and friends to hear a judge declare my innocence."

Most important, he says, he wanted to keep his promise to his mother. "She saw me walk out of the courtroom. A free man."

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The field of forensics has reached an important moment. In 2009, the National Academy of Sciences published a congressionally commissioned report on the state of forensic science in the courtroom. The report was highly critical of a wide range of forensic specialties, from fingerprints to hair and fiber analysis to blood spatter analysis. It found that many of the claims forensic analysts have been making in courtrooms for decades lacked any scientific foundation to back them up. Yet judges and juries have taken and continue to take those claims as foolproof science, often because the experts themselves frame them that way.

The report was particularly critical of an area of forensics loosely known as pattern matching. That area encompasses a group of largely subjective specialties in which an analyst looks at two pieces of evidence, such carpet fibers, hair fibers or marks made by tools, and simply declares based on his or her experience and expertise whether the two are a match.

Bite mark analysis is also part of this group. But even within the pattern matching disciplines, the NAS report singled out bite mark matching for some especially harsh criticism. The report found “no evidence of an existing scientific basis for identifying an individual to the exclusion of all others.” The problem is that this is precisely what bite mark analysts do — and what they have been doing for decades.

Bite mark matching has been around since the 1970s. Generally speaking, bite mark analysts look at indentations found in human skin thought to be caused by human teeth. They first confirm the marks are actually a human bite. They then compare those marks to plaster molds taken of the teeth of one or more suspects. In some cases, analysts will make a mold of the bite itself. In others, they’ll perform their analysis from a photograph of the bite, sometimes with the aid of software like Adobe Photoshop.

But this is just a generalization of the practice. It’s difficult to lay out the standard procedure of a bite mark analysis because it varies from analyst to analyst. Professional organizations claim to have established best practices and procedures, but there is little to no self-policing within the field. The discipline has been evolving on the fly, not usually in response to scientific research but ahead of it, often as a defensive move after the exonerations of people convicted by the testimony of its practitioners.

Bite mark analysis is most commonly used in criminal rape, murder and child abuse cases. It also sometimes comes into play in child custody disputes. The field has always had its critics. As with other flawed forensic specialties, those critics found some vindication in the 1990s when DNA testing started uncovering wrongful convictions won primarily on bite mark testimony. According to the Innocence Project, 24 people — including Gerard Richardson — have been exonerated after they were either convicted or arrested because of the assertions of a bite mark analyst. (A 25th, Douglas Prade, was initially cleared in Ohio, but that decision was overturned by an appeals court last March.) Chris Fabricant, a director of special litigation for the Innocence Project who specializes in bite mark evidence, estimates that there are still hundreds of people in prison today due to bite mark testimony, including at least 15 awaiting execution.

The NAS report generated a lot of media coverage. It spawned congressional hearings, think pieces, and legal conferences. It also spurred the White House to turn to the classic Washington response to a pressing problem: the blue ribbon panel. The National Commission on Forensic Science has been given the mission to "enhance the practice and improve the reliability of forensic science" and to "promote scientific validity" in the courtroom. The NAS report also elicited promises from large forensic professional organizations to establish best practices, take ethics more seriously and do a better job of policing their members.

There is no better example of the pitfalls of allowing junk science into the criminal justice system than bite mark analysis: The field has helped convict a disturbingly high number of people later proven to be innocent. The National Academy of Sciences found it to be lacking of any basis in science. And its members have a poor track record of policing themselves. Yet this particular forensic discipline is not only still going strong; it may be as strong as ever.

The community of bite mark analysts wields considerable influence. The field's foremost advocacy group and certifying organization, the American Board of Forensic Odontology (ABFO), is aggressive, dogged and holds a lot of sway within the American Academy of Forensic Sciences (AAFS), one of America's largest professional forensics organizations. And while bite mark matching and the ABFO may be looked upon with some suspicion by other forensic specialists (and certainly by the scientific community), the AAFS is generally seen as an innocuous, credible umbrella organization. As one advocate for forensic reform put it in an interview for this series, "The ABFO needs AAFS for legitimacy. The AAFS doesn't really need the ABFO."

(Not all forensic dentistry is this controversial. The ABFO also represents practitioners who use dental records to identify human remains, a field that is well established and well regarded by both the scientific and forensic communities.)

The AAFS and its leadership have been active in the forensics reform movement that has arisen in the wake of the NAS report. The problem is that the AAFS has also been aiding bite mark analysts and their supporters, lending some of its legitimacy to the cause. That's in part because the ABFO has been persistent and successful in promoting its own membership for leadership positions within AAFS. Four bite mark analysts have served as president of the AAFS, most recently in 2012. And so even as the influential AAFS and its leadership pay lip service to forensics reform and the problems addressed in the NAS report, the group is actively working to push bite mark analysis, for which — again — the NAS report reserved some of its harshest criticism. This narrative was confirmed by several prominent advocates for forensics reform, though it's worth noting that most of these outspoken advocates were unwilling to criticize the AAFS for attribution. The organization is still that influential.

Much of the NAS report's bite mark section was based on the research of Michael Bowers, a 65-year-old dentist, college professor and deputy medical examiner in Ventura County, Calif. Bowers has seen lots of cases like Richardson's. He has personally assisted in seven exonerations of people convicted because of bite mark evidence. For about a quarter-century, Bowers has been basically trying to eradicate bite mark matching from the courtroom.

"I've watched over and over as these people take the witness stand and give testimony that isn't just false and misleading, but that has put innocent people in prison," Bowers says. "It's such a corruption of justice. But for a long time people just didn't want to hear about it."

Bowers fought his battle from within as a member of the ABFO, where he once served on committees and held leadership positions. When that didn't work, he resigned from the organization and began criticizing it from the outside. That's when he became a target.

Two months after Gerard Richardson was released from prison, Peter Loomis, then president of the ABFO, filed an ethics complaint with the AAFS. It was the first time the president of the ABFO had ever filed such a complaint. But Loomis's complaint wasn't against Ira Titunik, the man whose testimony sealed Richardson's conviction. Nor was it against any of the bite mark analysts who have contributed to other false arrests or convictions over the years.

Instead, Loomis's complaint was against Michael Bowers. If successful, the complaint could get Bowers expelled from the AAFS and effectively destroy his credibility as an expert witness. It would remove an important critic from the courtroom. (I'll have more on the specifics of the complaint in Part 3.) **UPDATE (Monday): At its annual meeting, the AAFS's board dismissed the complaint against Bowers.**

The 2009 NAS report also expressed the need for more scientific research on the underlying assumptions of bite mark analysis — that human dentition is unique and that human skin is capable of registering bite marks in a way that makes them identifiable and distinguishable. Just as the NAS report was being published, a research team at the University of Buffalo led by the husband-and-wife team of Peter and Mary Bush was preparing to publish the results of a series of studies they had designed to probe exactly those questions. The results so far have been damning for the field of bite mark analysis. Bite mark analysts and their supporters have since subjected the Bushes to vicious, sometimes highly personal attacks.

This past fall the Justice Department announced the members of the National Forensic Science Commission subcommittee that will study the scientific validity of bite mark matching. This is part of the reform process put in motion by the NAS report. Incredibly, a majority of the members of the subcommittee are people who either practice or have openly defended the very sort of bite mark matching that the NAS report criticized. Robert Barsley, the chairman of the committee, is not only a practicing bite mark analyst, but his testimony also helped put an innocent man in prison for 17 years.

Meanwhile, every time someone has challenged the science of bite mark matching in court since 2009, the court has ruled the other way. In short, the scientific community has declared that bite mark matching isn't reliable and has no scientific foundation for its underlying premises, and that until and unless further testing indicates otherwise, it shouldn't be used in the courtroom. And so far, the criminal justice system has said it doesn't care. If bite mark matching is a bellwether issue for meaningful forensics reform, the prospects for meaningful reform appear to be dim.

Radley Balko blogs about criminal justice, the drug war and civil liberties for The Washington Post. He is the author of the book "Rise of the Warrior Cop: The Militarization of America's Police Forces."

The Washington Post

The Watch

It literally started with a witch hunt: A history of bite mark evidence

By Radley Balko February 17

This is part two in a four-part series. Read part one here.

On May 4, 1692, the Rev. George Burroughs was arrested in Salem, Massachusetts on suspicion of witchcraft. The only physical evidence against Burroughs were bite marks found on some of the girls he was accused of recruiting to join him. Summarizing the research of historians on the ordeal in an article for the February 2014 newsletter of the New York State Dental Association, William James Maloney writes that at trial, “the defendant’s mouth was pried open and the prosecution compared his teeth with the teeth marks left on the bodies of several injured girls present in the courtroom.”

At the urging of notorious witch hunter Cotton Mather, Burroughs was convicted, sentenced to death and hanged. Two months later, the governor of Massachusetts called for an end to the witchcraft trials. He also prohibited the use of “spectral and intangible evidence” in criminal trials. Two decades later, Burroughs was declared innocent, and the colony of Massachusetts compensated his children for their father’s wrongful execution.

Nearly three hundred years later, in 1974, Walter Edgar Marx was convicted of voluntary manslaughter due in part to bite marks found on the nose of his alleged victim. The marks were found during an exhumation of the victim’s body more than six weeks after she had been autopsied, embalmed and buried. Three dentists testified for the state that they could match an impression made of the marks to Marx's teeth. In 1975, a California appeals court upheld the conviction. That ruling has become enormously influential. In a 2000 article for the Albany Law Review, Seton Hall law professor and evidence expert Michael Risinger wrote that the *Marx* ruling "came to be read as a global warrant" for courts to admit bite mark evidence.

The *Marx* case effectively went around the prevailing standard for admitting forensic evidence: the 1923 case *Frye v. United States,* in which the U.S. Court of Appeals for the D.C. Circuit rejected testimony from a polygraph instructor who claimed that a rise in systolic blood pressure indicated that a suspect was lying. The appeals court ruled that in order to be admissible in federal court, scientific evidence or testimony must have "gained general acceptance in the particular field in which it belongs." For the next 70 years, *Frye* was the model in federal court, and was subsequently adopted by nearly every state in the country. (The Supreme Court didn't address the standard until 1993, with three rulings now known as the *Daubert* cases. The *Daubert* standard instructs judges to assess both the relevance of expert testimony and whether the testimony itself is reliable.)

In *Marx*, the judges actually accepted that there was no scientific research to support bite mark matching. There is "no established science of identifying persons from bite marks" and "no evidence of systemic, orderly experimentation in the area," the court wrote. But the judges' reasoning then took a peculiar turn. Because there was no science to analyze, the court declined to hold a *Frye* hearing. Instead, the judges simply invented their own test for evidence that wasn't scientific, but was nevertheless presented with a science-like veneer. They found that because the trial judge saw the bite mark evidence and concurred that it seemed sound, that was good enough for them. (Marx was convicted at a bench trial, not a jury trial.) The appeals court judges wrote that the evidence was admissible because to not admit it would be to "abandon common sense."

Three years later, another California appeals court relied on *Marx* to uphold bite mark evidence again . Bizarrely, that court explicitly referenced the "superior trustworthiness of the scientific bitemark approach," despite the fact that the *Marx* opinion specifically acknowledged a *lack* of scientific research in support of the practice. From there, bite mark evidence began to get accepted simply by virtue of the fact that it had been accepted in other courts in previous cases. Thus began an established record of precedents. It also began an established record of wrongful convictions.

Bite mark matching then gained national notoriety in 1979 during the trial of serial killer Ted Bundy. The high profile nature of the case, the brutality of the crime and Bundy's obvious guilt cast a public image of bite mark analysis as an emerging science that could put away serial killers and sex offenders, and the analysts themselves as heroic scientists who help put dangerous people behind bars. One of the analysts who testified in Bundy's case was Lowell Levine. Bundy's conviction launched Levine's career. He became one of the most visible bite mark evangelists in the United States. In 1977, he wrote that a bite mark match "is as good as a fingerprint." It was 20 years later that Levine's analysis would lead to the wrongful arrest of Edmund Burke discussed in part one of this series.

Levine later served terms as president of both the American Board of Forensic Odontology (ABFO) and the American Academy of Forensic Sciences (AAFS), and became one of just a few dentists to make a full-time career of bite mark analysis. In a 2011 interview with CNN's Anderson Cooper, Levine continued to defend bite mark analysis as "important and viable." But when Cooper asked if there's any way bite mark analysis can be reconciled with the scientific method, Levine replied with some candor: "I sure can't think of it." Yet Levine has testified countless times in court about his "level of scientific certainty" with respect to bite marks.

In a forthcoming law review article, Chris Fabricant of the Innocence Project and Tucker Carrington of the Mississippi Innocence Project look at how the *Marx* ruling affected bite mark admissibility. They found 16 court opinions from 12 states over the following 13 years after *Marx* that either relied on the decision, or adopted what Fabricant and

Carrington call "the eyeball test." All but three of those rulings noted the "scientific" nature of bite mark analysis, despite the fact that, again, not only is there no science to back up the claims of bite mark analysts, but the *Marx* decision explicitly acknowledges as much. One such ruling came in 1978 after the Arizona Supreme Court heard arguments to overturn a conviction based on bite mark testimony from Homer Richardson Campbell Jr., a ABFO-certified forensic odontologist. Campbell told the jury that that the odds of anyone other than the defendant leaving the marks he found on the victim's breast were "eight on one million." On cross examination, Campbell conceded that he didn't compute those odds personally. Rather, they were a rough estimate of his memory of "articles written in the journals of the American Academy of Forensic Sciences." In truth, there was no scientific basis for his estimation whatsoever. The court nevertheless found his testimony admissible, and upheld the conviction.

In 1987, Campbell's testimony helped convict Joe Sidney Williams of a rape and murder in Texas. Williams was exonerated by DNA testing in 2001. Campbell's bite mark matching also helped convict David Wayne Spence for the 1984 murders of three teenagers near Lake Waco, Tex. In fact, his testimony was the only evidence linking Spence to the scene of the crime. During Spence's appeal, his attorneys showed the crime scene photos Campbell used to make his match to five other ABFO-certified forensic odontologists, along with dental molds from five people, including Spence. Only two matched the photographed bite marks to any of the dental molds, and both matched them to the mold of an uninvolved patient of the dentist who ran the test. The lead homicide investigator in the case told New York Times columnist Bob Herbert in 1997, "'My opinion is that David Spence was innocent. Nothing from the investigation ever led us to any evidence that he was involved." Spence was executed by the state of Texas in 1997.

Campbell, now deceased, would go on to become a prominent advocate for bite mark matching. He also served as president of the American Academy of Forensic Sciences.

One particularly striking example of how bite mark matching was back-ended into the criminal justice system came in a 1986 ruling by the Court of Appeals of Wisconsin. The case was the first time bite mark evidence had been introduced in the state. The court's ruling was one of "first impression," meaning that there was no precedent, and that its ruling in the case would likely establish one. In 1983, Robert Lee Stinson had been convicted of raping and murdering an elderly woman. The only physical evidence linking him to the crime was the testimony of two bite mark specialists: Lowell Thomas Johnson and Raymond Rawson.

Rawson at the time was on the ABFO's Bite Mark Standards Committee. He had also co-authored the organization's original guidelines for bite mark matching. Johnson performed the initial analysis in the Stinson case by placing a mold of the suspect's teeth over photographs taken of some marks on the victim's body. Johnson concluded that the marks "had to have been made by teeth identical in all of these characteristics" to the teeth of Robert Lee Stinson. Rawson went next, and confirmed that the marks matched Stinson's teeth "to a reasonable degree of scientific certainty."

Stinson appealed the admission of bite mark evidence in his trial. The Wisconsin Court of Appeals ruled against him. The court's opinion was forceful and authoritative.

> A total of fourteen upper and lower jaw impressions were made from the bite marks found on Cychosz's body. Because of the opportunity to examine so many bites, and the fact that some of the bites were so deep as to be three-dimensional, Dr. Johnson testified he was able to detect a repetition of some particularly unique features in several of the bites.
>
> Dr. Johnson later performed a forensic odontological examination of Stinson. Following the examination, Dr. Johnson noted the following unique features: one of the central incisors was fractured and decayed almost to the gum line; the lateral incisor in the upper jaw was set back from the other teeth; all of the upper front teeth were flared; the lower right lateral incisor

> was worn to a pointed edge; the right incisor was set out from the other teeth on the lower jaw. Dr. Johnson used these features along with the arch of the mouth and the spacing, width, and alignment of the teeth to make comparisons with the bite marks found on the victim. After an exhaustive examination of the photos, models and tissue samples taken from Stinson and the victim, Dr. Johnson concluded, to a reasonable degree of scientific certainty, that the bite marks on the victim were made by Stinson.
>
> The jury also heard from Dr. Rawson who concluded, based on the workup Dr. Johnson performed on both the victim and Stinson, that Stinson had inflicted the bite marks on the victim. In Dr. Rawson's opinion the evidence in the case was overwhelming and he stated that "if we have four or five teeth that we are able to examine, then we can say that there is no other set of dentition like that." In this case, Dr. Johnson was able to identify seventy-five individual tooth marks in various combinations of between five and eleven teeth.

In the end, the Wisconsin Court of Appeals concluded that the reliability of the bite mark evidence in the case was sufficient "to exclude to a moral certainty every reasonable hypothesis of innocence."

And yet the court was wrong. Stinson spent 23 years in prison before DNA testing exonerated him. Stinson never bit the victim. All of the argumentation about set-back incisors, flared teeth and the arch of the mouth, all of that evidence that screamed guilt — *to a moral certainty* no less — it was all nonsense. Yet the court never made any effort to correct its mistake. As Fabricant and Carrington point out in their article, *State v. Stinson* is still the controlling precedent for bite mark evidence in Wisconsin. That the man whose name appears in the case was actually innocent doesn't seem to matter.

Six years later, after the ruling in the *Stinson* case, Raymond Rawson helped convict another innocent man. In 1992, Ray Krone was convicted of murdering Phoenix waitress Kim Ancona. The only physical evidence linking Krone to the crime scene were bite marks left on the victim that two forensic odontologists, one of them Rawson, said could only have been inflicted by Krone. The highly-publicized trial and the nature of the bite mark testimony earned Krone the nickname, "the Snaggletooth Killer."

In 1995, Krone was awarded a new trial due to a legal technicality. The following year he was convicted a second time, again due to testimony from Rawson, who declared a pattern on the victim's bra to be a "scientific match" to Krone's teeth. Krone spent 10 years in prison, including some time on death row, before he was exonerated by DNA evidence in 2002.

By 1988, the West Virginia Supreme Court noted in an opinion that bite mark matching had been so "generally accepted" in American courtrooms that a *Frye* analysis was no longer necessary. (In that particular case, a bite mark analyst had determine that a tooth mark in a roll of paper towels was a "perfect match" to the defendant "to the exclusion of all other individuals.") By the time that ruling came down, 21 state appellate courts had accepted bite mark analysis, without a single dissenting opinion. There still wasn't a shred of scientific evidence to back any of it it up. Instead, all of these courts had relied on the rulings of prior courts, going all the way back to *Marx*. In some instances, these state courts adopted what Fabricant and Carrington call the *Marx* court's "eyeball test." In others, the state courts falsely claimed that *Marx* had already validated the science of bite mark matching, or they cited opinions that had falsely stated the same, thus relieving them of the need to do an analysis themselves — a phenomenon Fabricant and Carrington call the "echo chamber effect."

"Most of the time when doing one of these analyses, the only thing a judge will ask is, 'Have other courts allowed this?'" says Michael Saks, a law professor at Arizona State University who has written extensively on the intersection of law and science. "If the answer is yes, then they'll figure out a way to let it in. Or they'll decide that if the government is paying a person to do this analysis, it must be legitimate. That's a far cry from an analysis of its scientific merit. But it doesn't seem to matter."

More state courts followed West Virginia's lead, accepting bite mark matching based solely on the fact that other courts had already accepted it.

By the early 1990s, the bite mark matching business was booming. One of the most prolific expert witnesses of that era was a Hattiesburg, Miss., dentist named Michael West. Using yellow goggles and ultraviolet light, West claimed to have pioneered a new method of bite mark analysis that allowed him to find and analyze bites that no one else could see, not even other trained forensic odontologists. Conveniently, West said that his process couldn't be duplicated or recorded. He called it "the West Phenomenon."

West struck the right balance of brash arrogance and aw-shucks charm to win the trust of Mississippi jurors. That made him hugely popular with prosecutors. His services were in ever-increasing demand, particularly in Mississippi and Louisiana, even as his claims grew more preposterous.

In one case, West claimed to have matched the bite marks in a half-eaten bologna sandwich to the defendant. The jury convicted. (The conviction was overturned on appeal when defense lawyers discovered that the autopsy report recorded a partial bologna sandwich in the stomach of the victim.) In 1991, West claimed to have found bite marks in an exhumed body that had been buried months earlier, even though police and investigators never noticed the marks when the body was fresh. He then said he could match the bite marks to the woman's husband, Anthony Keko. West and (the also controversial) Mississippi medical examiner Steven Hayne didn't photograph or preserve the incriminating marks. They claimed to have tried to preserve one of them, but say they inadvertently destroyed the sample by storing it in the wrong type of solution. So West was testifying from memory. The jury still convicted.

Despite these incidents, by 1994 West had testified in several states, was testifying frequently in Mississippi and had been elected coroner of Forest County, Miss. In 1996, West told the American Bar Association Journal that he had testified in 55 cases. He had also recently been certified by an Ohio court as an expert in "splash patterns." That ABA Journal profile was critical, and noted the mounting skepticism in the legal community about West's claimed expertise.

Yet judges continued to certify West, and prosecutors continued to utilize him. One Louisiana prosecutor told the publication, "I'm quite confident in the guy . . . I think he makes one heck of a witness."

In September 1990, 3-year-old Courtney Smith was abducted from her bedroom in Noxubee County, Miss. She was then raped and murdered. Michael West was called in to perform a bite mark analysis, and he claimed to match marks he found on the child's body to Levon Brooks, the boyfriend of the girl's mother. In January 1992, Brooks was convicted of murder and sentenced to life in prison.

Four months later, in May of 1992, 3-year-old Christine Jackson was abducted from her room, raped, and murdered. Jackson lived just a few miles from where Smith had been murdered. Local law enforcement officials again focused their investigation on the boyfriend of the victim's mother, in this case Kennedy Brewer. West again claimed to have found bite marks on the victim, and again claimed he could match the marks to the prosecution's main suspect, to the exclusion of anyone else. Brewer was convicted in 1995 and sentenced to death.

Today, the ABFO disclaims Michael West, calling him a rogue whose methods were never embraced by mainstream analysts. “Things have changed since the 1990s,” says Peter Loomis, the ABFO president. “This is an evolving field.We want to do the right thing.”

It’s true that in 1995, the ABFO gave West a one-year suspension. To date, it is the only time the ABFO has ever disciplined one of its members. (West protested by resigning from the organization.) But though that suspension was in effect during Kennedy Brewer’s trial, it still didn’t prevent West from testifying. And up until that point, West was an ABFO-certified forensic odontologist, despite the fact that he was already regularly giving testimony well outside the constraints of reality.

By the time the Brewer case made its way to the Mississippi Supreme Court in 1998, the problems with West were well-known. Yet the court still upheld his testimony, explicitly writing that West “clearly” had the “knowledge, skill, experience, training, and education necessary” to testify as an expert witness. The next year, the same court also upheld the conviction of Levon Brooks. This time, the court explicitly took judicial notice of bite mark analysis, writing, “We now take the opportunity to state affirmatively that bite mark identification evidence is admissible in Mississippi.” Just one justice dissented. Among the authorities the court cited in that opinion: the Wisconsin Supreme Court’s *Stinson* decision.

Also in 1992, West’s testimony helped convict Eddie Lee Howard of killing 84-year-old Georgia Kemp. In his closing argument, Mississippi District Attorney Forrest Allgood made reference to the growing criticism of West, but he told the jurors that this was merely a testament to West’s brilliance. West, Allgood said, was a great mind of science who was merely ahead of his time. “Whether we like to think so or not, the progress of mankind has been carried forward on the backs of people like Michael West,” Allgood said. “The church threatened to burn Copernicus because he dared to say that the planets didn’t revolve around the earth. So it was with Michael West.” (Allgood also seems to have mistaken Copernicus for Galileo.) The jury convicted Eddie Lee Howard, and sentenced him to death.

In 2001, West was further exposed, this time by Christopher Plourd, the attorney for Ray Krone, the Arizona man convicted by Ray Rawson. Angered by what had happened to his client, Plourd set out to demonstrate the illegitimacy of bite mark analysis. Plourd had a private investigator send West photos of the bite marks on the woman Krone was wrongly convicted of killing. The investigator also sent West a dental mold of his own teeth, a retainer check and a made-up cover story. He asked West if he could match the crime scene photos to the dental mold he had enclosed. West not only confirmed the match, he sent back a 20-minute video in which he confidently explained why only the person whose teeth were represented in the dental mold could have left the marks on the victim. That of course was impossible.

Five years later, the Mississippi Supreme Court heard the appeal of Eddie Lee Howard. The court was now aware of all of West's exploits, including Plourd's "proficiency test." Incredibly, the court still upheld West's testimony, explaining that "just because Dr. West has been wrong a lot, does not mean, without something more, that he was wrong here."

Since then, videos have emerged of some of West's bite mark examinations. In them, he is shown repeatedly jamming suspects' dental molds into the skin of the alleged victims. Forensics specialists have said that at minimum, the videos depict gross malpractice and reveal West to be tampering with evidence. But some experts, like Michael Bowers (see part one for more on him), say the videos show West actually creating the bite marks he would later claim in testimony were inflicted by the suspect.

In 2007, two years after that Mississippi Supreme Court's ruling in the Howard case, Kennedy Brewer and Levon Brooks were exonerated. DNA taken from the young girls' bodies in both cases were finally run through the state database. The DNA profile from both cases was the same; it matched Justin Albert Johnson, a man who lived near the scene of both crimes. He later confessed.

Johnson was initially a suspect in the first murder before West matched the bite marks to Levon Brooks. Not only did West's bite mark matching wrongly imprison two innocent men for 15-plus years, he may well have allowed Johnson to remain free to rape and murder Christine Jackson.

Recently, even West himself said he no longer believes in the validity of bite mark matching. (Though in typically odd fashion, he still defended his own bite mark testimony.) But that doesn't mean the state's courts and prosecutors are overturning convictions that West was a part of. In the summer of 2011, Mississippi Attorney General Jim Hood claimed he had opened an investigation into West. Months later the assistant district attorney in charge of that investigation said it had consisted of no more than a "Westlaw search" of relevant cases – the legal equivalent of a Google search. Three-and-a-half years later, nothing else has come of that investigation. Instead, Hood and his subordinates continue to argue that the defendants still in prison due to West have already used up their opportunities to challenge his credibility. That is, they either tried to challenge West or bite mark evidence in general and lost, or they never tried to challenge, and now it's too late.

Just last month, Hood's office filed another brief in the Eddie Lee Howard case which astonishingly cites the Mississippi Supreme Court's rulings in the *Brooks* and *Brewer* decisions. The brief points out that the state's supreme court has "unequivocally held on direct appeal that Dr. West was qualified to testify as an expert in forensic odontology," and that "bite-mark evidence is admissible in Mississippi." Legally speaking, Hood's office is correct. Brewer and Brooks may have been innocent, but they weren't exonerated by a precedent-setting court opinion. So just as *Stinson* is still the law in Wisconsin, the Mississippi Supreme Court's rulings in *Brewer* and *Brooks* are still good law in Mississippi — and the state's controlling law on bite mark evidence.

If he wanted, Hood could release Howard tomorrow, or even agree to a new trial without using West's testimony. Instead, Hood's office is essentially arguing that the people convicted based on the testimony of a man Hood himself has said is untrustworthy should be kept in prison on a technicality. Or possibly even executed. Currently, two men are still on death row due primarily due to bite mark analysis performed by Michael West — Howard in Mississippi, and Jimmie Duncan in Louisiana.

Though bite mark analysts like West and Rawson are now either disclaimed or quietly ignored by the ABFO and the community of bite mark analysts, their impact on the field is hard to overstate. Rawson, as noted, was a former president of ABFO who helped write the first guidelines for bite mark analysis. And both West and Rawson were as prolific at authoring articles on their methods for forensic journals and odontology textbooks as they were at testifying in court.

The ABFO may now try to distance today's bite mark analysts from men like Rawson, Campbell and West, but those figures wielded enormous influence in the field during the era when the courts were issuing precedent-setting opinions about admissibility. (Rawson is still a member in good standing.) And that influence persists. As noted earlier, West is still considered a reliable expert by the Mississippi Supreme Court and the office of Mississippi Attorney General Jim Hood. And it isn't just in Mississippi. In 1994, John Kunco was convicted of rape due to bite mark analysis that was based on the methods first pioneered by West. That conviction was upheld by a Pennsylvania judge in 2011.

More to the point, the ABFO still embraces members who have participated in more recent wrongful arrests or convictions. Some of them hold or have held leadership positions within the organization. The ABFO has never sought to discipline or file ethics complaints against those members. Instead, as this series will explore tomorrow, the group's leadership has focused on ruining the people who have helped expose those wrongful arrests and convictions. Bite mark matching in America began with a literal witch hunt. Its proponents are engaged in a figurative one today.

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The Washington Post

The Watch

Attack of the bite mark matchers

By Radley Balko February 18

This is part three in a four-part series. Read part one here and part two here.

There were red flags that bite mark analysis was flawed even as the first cases in the 1970s secured its use in the courtroom. For example, a 1975 study asked bite mark analysts to match bite marks made in pig skins under optimal laboratory conditions to the teeth that were used to make the marks. The error rate was 24 percent. When the analysts were asked to make their matches from photos of the marks taken 24 hours later — as is often done in criminal cases — they were wrong nine out of 10 times.

But neither proficiency test results nor a lack of scientific research to support the field seemed to bother America's courts. By the early 1990s, judges were welcoming bite mark testimony into courts across the country. In 1990, the Supreme Court in Arizona — the state where Ray Krone would soon be wrongly convicted because of bite mark evidence — ruled that so long as a bite mark expert has been accredited, the state's courts no longer needed to submit their opinions to a *Frye* test. (See part two for more about the *Frye* standard.) A 1995 article in the Santa Clara High Technology Law Journal found that as of 1992, bite mark matching had been admitted as evidence in 193 criminal cases across the country and had been accepted by appellate courts in more than half the states.

There had been a few critics in the 1970s and 1980s, but the practice wasn't yet widespread enough for anyone to care. But by the early 1990s, bite mark analysts were testifying often enough to begin to raise some alarms.

Michael Bowers was one of those early critics. Bowers is a practicing dentist in Ventura County, Calif. He also has a law degree and serves as a consultant with the Ventura County Sheriff's Office and the Ventura County Medical Examiner. Bowers joined the American Board of Forensic Odontology in 1989. While he was a member of ABFO, Bowers wrote articles for the organization's newsletter and served on its board of directors and its credentialing committee.

But Bowers grew increasingly blunt in voicing his concerns about bite mark matching. In a 1996 article for the newsletter of the American Society of Forensic Odontologists (ASFO is an educational organization, and while there are many overlapping members between the ABFO and the ASFO, the ASFO doesn't offer board certification), Bowers didn't mince his words. He wrote that the "physical matching of bite marks is a non-science which was developed with little testing and no published error rate. It is supported by anecdotalism and a minuscule number of inadequate population studies."

In another article for the ABFO newsletter the same year, Bowers encouraged the group to rein in its experts. He urged more cautious testimony, at least until the underlying assumptions behind bite mark matching could be verified or disproved with science-based research.

> There is no reliable way of saying, other than colloquially, that one or more tooth marks seen in a wound are conclusively unique to just one person in the population. Because of this vacuum, value judgements abound in our discipline. Proffering the testifying expert's years of experience is a popular means of "proving" uniqueness." He or she has seen more bitemarks. This misses the scientific point and is misleading to a lay jury that is given the responsibility of filtering good science from bad. The confidence level of

> expert testimony must be based on data available to BOTH the dentist and the court. This scientific data does not exist. Until this changes, the admissibility of bitemark analysis should be limited to a "possible" determination. The odontologist doesn't have a basis to expand an opinion beyond that.
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> . . . Research must progress to raise the current anecdotal level of individuation in contemporary bitemark analysis. A concerted effort to find funding and research facilities has to be done by this organization. It will be the cheapest assurance that our future in court will be positive, rather than controversial. After the research is done, the "possible" might then become "unique."

That research didn't happen. In the early 1990s, the FBI set up more than 20 scientific working groups to study and improve the practice of more than two dozen forensic disciplines. Some of those groups uncovered the flaws in forensic analyses that inspired a National Academy of Sciences (NAS) report in 2009. Others weren't as successful. But notably, forensic odontology is the only widely used forensic discipline that wasn't subjected to the scrutiny of a working group at all.

As Bowers watched the ABFO and its membership duck serious scientific scrutiny, his criticism grew stronger, and his relationship with the organization began to sour. In 1999, he conducted a bite mark "workshop" at an American Academy of Forensic Sciences (AAFS) conference. Bite mark analysts were asked to match bite marks with the teeth that made them. More than 60 percent made an incorrect identification. Bowers then published the results of his test, further agitating the bite mark community. To this day, ABFO officials refer to that 1999 test as a "workshop," not a competency test, and insist that the results were meaningless.

"That criticism might have some validity if ABFO administered its own competency tests," says Chris Fabricant, director of strategic litigation for the Innocence Project. “But the organization has shown no interest in testing to see if two or more of its own certified experts can look at the same set of bite marks and independently come to the same conclusion. There’s no reliability in these methods. Therefore, there’s no way to test for accuracy. That means this isn’t science. And if it isn’t science, it doesn’t belong in the courtroom.”

Increasingly frustrated with ABFO’s disinterest in keeping unscientific testimony out of criminal cases, Bowers resigned from the group in 2011. Since then, he has continued his criticisms in journal articles, presentations at conferences, a textbook, court testimony and a blog he runs with fellow dentist and bite mark matching critic David Averill.

But the pro-bite mark matching community began to fight back.

The first shot at Bowers came from Carl Hagstrom and Russell Schneider, two bite mark specialists who testified for prosecutors in the 1986 trial of Bennie Starks, an Illinois man found guilty of raping a 69-year-old woman. The testimony from Hagstrom and Schneider was the primary evidence against Starks. In 2000, DNA testing on semen found in the woman’s underwear excluded Starks as the source of the semen. But citing the bite mark testimony, Lake County, Ill., assistant state’s attorney Michael Mermel insisted that Starks was guilty and prevented the DNA profile created from the semen from being run through CODIS, the federal DNA database. Mermel added that if the semen had been taken from the woman’s vagina instead of her underwear, he’d be advocating for Starks’s release himself.

Mermel's promise was put to the test in 2006, when a vaginal swab previously thought to have been lost was found and tested. Again the DNA profile excluded Starks. This time, Starks's conviction was overturned by an appeals court. But despite his earlier statement, Mermel again insisted that Starks was still guilty, and again he cited the bite mark testimony from Hagstrom and Schneider. He kept Starks in prison pending another trial, positing that Starks must have bitten the woman while someone else raped her, or alternately, that the victim must have had consensual sex shortly before the incident. (The victim, who survived the attack, insisted that she hadn't.)

Mermel was forced to resign in 2011 after an unflattering New York Times Magazine feature cited Starks's conviction among other cases in which Mermel had concocted implausible theories after DNA testing revealed a likely wrongful conviction. Meremel's boss was defeated in the 2012 election and shortly after taking office the following January, the new Lake County district attorney finally dropped the charges against Starks.

Bowers cited the Starks case in a presentation at the 2011 AAFS conference in Chicago. Hagstrom and Schneider sued Bowers in 2011, claiming that his presentation caused them "ridicule and a loss of business." The two dentists argued that the appellate court never explicitly ruled that their bite mark testimony was flawed, only that Starks deserved a new trial. This was true. But given the DNA evidence, it didn't need to. The men's lawsuit against Bowers implicitly relied on the discredited Mermel's still-unlikely theory: Starks must have bitten the woman while someone else raped her. Bowers settled the suit for $1,250 with each dentist, an amount significantly lower than what it would have cost him to litigate.

In October 2013, Bowers published the book "Forensic Testimony: Science, Law and Expert Evidence," which includes essays by Bowers and other critics of modern forensics. The essays are meticulously researched and generally skeptical of a wide array of forensic disciplines. It comes down especially hard on pattern matching analysis and on bite mark matching in particular. The book was an honorable mention for a PROSE Award in law and legal studies.

Four months after the book was published, Bowers was dropped from the editorial board of the Journal of Forensic Sciences, the AAFS flagship publication. In an e-mail, editor Michael Peat told Bowers he had been "termed out" of his position due to the "need to bring on new members." Peat did not respond to a request for comment, but other forensic specialists said in interviews for this article that the timing of Bowers's ouster is suspicious. They point out that another member of the editorial board, Robert Barsley, is a bite mark analyst who has held numerous leadership positions at both the ABFO and the AAFS. The editorial board also includes Ken Melson, chair of the ethics committee that would later recommend Bowers's ouster from AAFS. The board does include at least one other bite mark skeptic. So it's at least plausible that dropping Bowers from the board wasn't related to his criticisms of pattern-matching forensic specialties. Others speculated that with the building tension between Bowers and the ABFO, the journal may have just wanted to avoid controversy.

But then came the ethics complaint. In November 2013, two weeks after Bowers's book was published and a month after Gerard Richardson became the latest bite mark exoneree, recently elected ABFO President Peter Loomis filed a six-page complaint against Bowers with the AAFS ethics committee. Loomis cited three cases in which he claimed Bowers had violated AAFS ethical regulations, one in 2008 and two in 2010. Loomis wasn't present at any of the proceedings where the alleged ethical violations occurred, nor were there any complaints filed against Bowers by any of the attorneys or judges in those cases. The complaint also came as Bowers has been preparing to testify as an expert witness in two lawsuits against bite mark analysts brought by people who had been convicted by bite mark testimony and were exonerated after serving long terms in prison.

"There's no doubt in my mind that the ethics complaint was retaliation," says Fabricant. "Look at the timing. The complaint came a month after the high-profile exoneration of Gerard Richardson. Of all the exonerations in bite mark cases, of all the perversions of justice caused by bite mark analysts over the years, the first ethics complaint an ABFO officer ever files with the AAFS is against one of the most effective critics of bite mark analysis. This was an attempt to silence a critic."

Michael Saks, an Arizona State University law professor and expert on forensic evidence, agrees. "It's a beautiful example of the adversarial process in action. When you first read it, the complaint sounds as if it could have some merit. Then you read Bowers' response. You get the context, and you realize that there's no there there. The complaint is either badly mistaken, or it's a transparent attempt to purge someone who has been a problem for them."

"Bowers has been a thorn in the ABFO's side for forever," says Michael Risinger, a Seton Hall University law professor who specializes in law, science and expert testimony. "This certainly looks like an attempt to purge a critic. "

To understand the significance of the complaint, it's important to understand that the AAFS is the largest forensics organization in the country. It is the main professional body of the forensics community. While they're technically private organizations, groups such as the AAFS and the ABFO have enormous influence over who does and doesn't get to testify in court. "An AAFS finding that Bowers committed ethical violations would render him useless as an expert witness," Saks says. Even if Bowers could persuade judges to continue certifying him, an opposing attorney could use the finding to discredit him to the jury.

At the time Loomis filed his complaint, the chairman of the AAFS ethics committee was Haskell Pitluck, a retired Illinois state court judge. As it turns out, Pitluck is also the legal counsel for the ABFO and a nonvoting member of the ABFO's ethics committee. One year before Loomis's complaint, the ABFO established the "Haskell Pitluck Award," which the organization presents annually to someone who has "served the ABFO community in an exemplary fashion." The first ABFO Haskell Pitluck Award was given in February 2012. The first recipient: Haskell Pitluck. And the person who would determine whether there was any merit to the complaint filed by the ABFO president against the ABFO's biggest critic? Haskell Pitluck.

"It was such an obvious conflict of interest, all I could do was laugh," Bowers says. He and his attorney requested that Pitluck recuse himself and that the AAFS bring in a neutral arbiter. Pitluck refused. He then found probable cause for Loomis's complaint. The AAFS would proceed with an ethics investigation of Bowers.

Loomis's complaint alleges 13 ethical violations committed by Bowers over 13 years. But a close look at the accusations reveals them to be rather thin. For example, Loomis alleges that in the 2008 case *California v. Frimpong*, Bowers first claimed he could not exclude the defendant as the source of a bite mark, then, after the defense paid him, claimed he could exclude the defendant. Loomis is alleging that Bowers is a "hired gun" willing to change his mind in exchange for pay.

In his response, Bowers explains that his initial opinion was based on no more than a photo of a bite mark that he felt lacked enough detail to draw any conclusions at all. He wasn't sent the dentition evidence taken from the defendant until the night before the trial. Because he didn't have sufficient time to properly analyze the new evidence, he "could not exclude" the defendant as the source of the bite mark. Consequently, he didn't testify. After the trial, Bowers had time to do a more thorough analysis with more evidence and came to the conclusion that the defendant could be excluded.

To say a defendant "can't be excluded" is another way of saying that the available evidence doesn't say much either way. It doesn't indicate guilt, but it doesn't exonerate either. Bowers explains in his response that he didn't "change" his opinion; he went from "no opinion" to "having an opinion," but only after he was presented with more evidence and given time to analyze it properly. This would seem to be exactly what we'd want from a conscientious expert witness.

Loomis also alleged an ethics violation because a judge once found Bowers's testimony to be "not credible." But this is hardly evidence of an ethical violation. In fact, because of the very subjectivity of bite mark evidence, these cases will often feature two expert witnesses offering two diametrically opposed opinions. During a bench trial or a hearing on admissibility of bite mark evidence, the judge will naturally have to rule for one side or the other. Judicial opinions aren't scientific pronouncements, and in fact, as previously noted in this series, they're often ignorant of or oblivious to the prevailing science. On many occasions, judges have vouched for the credibility of bite mark experts in upholding the convictions of defendants who were later proved innocent by DNA testing.

But even this is beside the point. Even if the judge had been correct about Bowers's credibility, this sort of ruling isn't proof — and doesn't claim to be proof — that the expert who testified for the losing side was unethical. It really only means that he failed to persuade the judge. And as Fabricant points out, it also magnifies the selectivity of Loomis's complaint: "You have two-dozen cases where a judge or a prosecutor found a bite mark analyst to be 'credible,' after which the suspect was completely exonerated of the crime. Some of these people spent decades in prison. Where are the ethics complaints against them? Michael Bowers helped exonerate many of those people. But he's the one hit with a complaint, because a judge in one case didn't find him credible? It's just brazen."

The most serious allegation in Loomis's complaint is that Bowers altered or fabricated evidence in the *Frimpong* case. Loomis's evidence for this charge is Bowers's testimony during a hearing for the 2010 case *Alabama v. Ramirez-Vitae*. In that case, Bowers told the judge that in the *Frimpong* case he had reversed the orientation of the suspect's teeth. Bowers's testimony to the judge about why he did this is somewhat ambiguous, and Loomis's complaint alleges that Bowers reversed the orientation in order to deceive. But to believe that, you'd have to believe that Bowers, a reputable expert witness with no prior allegations of ethical misconduct, not only deceptively and intentionally distorted evidence, but also openly boasted about doing so, directly to a judge, in a case two years later.

Bowers says he was open about what he was doing. He thought the state's experts had the orientation wrong themselves — that they had mistaken the upper teeth for the lower teeth. And in fact, during post-conviction, one of the state's own experts actually agreed with Bowers. The new expert, Greg Golden, disagreed with Bowers that when properly aligned, the marks excluded the defendant as a suspect. But he agreed with Bowers that the state's expert at trial (a different analyst) had misaligned the teeth and the bite marks.

In other words, the prosecution offered up two ABFO-certified bite mark analysts as experts, one at trial and one during post-conviction. The analyst at trial said the bite marks implicated the defendant. During post-conviction, the second analyst analyzed the same bite marks, only with the upper and lower teeth of the defendant switched. But he, too, said they implicated the defendant.

Bowers says he brought the case up at the Alabama hearing because it illustrated the absurdity of the entire field of bite mark matching. “I told the judge in the Alabama case that this was an example of how ambiguous bite marks can be. How you can have multiple theories with multiple conflicting assumptions and opinions, but all of them within the ABFO guidelines,” Bowers says.

Obviously, an individual’s lower teeth are going to leave different marks than his or her upper teeth. One might think that the president of the organization that sets the standards for bite mark analysis would be concerned about the fact that two of its members implicated the same defendant despite the fact that their analyses were done with opposing orientations of the defendant’s teeth. Yet it’s Bowers that Loomis has targeted, for calling attention to the problem.

I asked Loomis about his complaint against Bowers in a phone interview last year. He said that AAFS bylaws prohibited him from discussing any ethics proceedings, so he could neither confirm nor deny the existence of any complaint. He also expressed concern about the fact that I had obtained a copy of his complaint and cautioned me about publishing it. Later in the conversation he added that if, in theory, he had filed a complaint against Bowers, anyone who read it would be thoroughly convinced of Bowers’s guilt.

“Dr. Bowers is not credible,” Loomis said. “I can’t confirm the existence of any complaint, but if there was one, and I could talk about it, I would change the minds of Bowers’ supporters.”

Loomis is right about the AAFS bylaws requiring confidentiality. But those bylaws are intended to protect the accused. Bowers stands as the accused and has asked for complete transparency. In his initial response to Loomis’s complaint, Bowers stated: “I waive all rights to confidentiality and hereby request a public hearing to adjudicate this matter . . . Moreover, I request the proceeding be videotaped, transcribed, and made available to the public."

Pitluck eventually found probable cause for the complaint against Bowers to move forward. A hearing was scheduled for July 8, 2014, in a conference room at a Chicago hotel. By the time of the hearing, Pitluck's term on the AAFS ethics committee had ended. He was replaced by Melson, a former federal prosecutor for 24 years who had most recently served as acting director of the federal Bureau of Alcohol, Tobacco, Firearms and Explosives. Melson was reassigned from his position in 2011 in the wake of the "Fast and Furious" scandal.

Despite the controversy surrounding his previous position, two forensics experts and advocates for forensics reform interviewed for this article say they considered Melson to be reputable and fair and initially considered him a good choice to chair the ethics committee. (Neither wished to be named.) In fact, Melson was also a president of AAFS in 2003-2004. In his "President's Message" in the organization's newsletter, he repeatedly emphasized the need for forensics reform, better certification and taking ethical obligations seriously.

When I first interviewed Risinger about the complaint last summer, he seemed confident that the AAFS would dismiss it. He said the organization had to treat the complaint seriously because there was a national spotlight on forensics at the moment. To disregard an ethics complaint — even one that appears to be retaliation against a whistleblower — would send the wrong message.

"In my opinion, the ethics complaint filed against Mr. Bowers is thin on its face, and without merit when viewed in the light of the responsive filing," he said. "I know the AAFS is committed to being a reliable agency of self-regulation in forensic science, and, as in other contexts, that means not only reliably convicting the guilty, but also reliably acquitting the innocent. Under these circumstances, I believe their process will come to the right conclusion in this case."

But Melson would surprise Risinger and other forensic watchdogs with an astonishing proceeding that fell far short of any reasonable conception of fairness or due process.

It actually began before the hearing, when according to Bowers, Melson turned down all of Bowers's discovery requests. When the hearing was just a couple of months away, Bowers's attorney Gabriel Fuentes wrote to Melson to complain that he he and his client still hadn't been informed of what format the hearing would take, what evidence would be used against Bowers or who would be sitting in judgment of him. In fact, Fuentes wrote, Melson had turned over "absolutely no documents or information whatsoever." From the time he first received notice of the complaint, Bowers had asked for an explanation of how each allegation against him violated AAFS ethical guidelines. Again, Melson refused. (Melson declined to be interviewed for this article, citing AAFS bylaws about confidentiality in ethics investigations.)

Fuentes was most concerned about Melson's role in the hearing. In his letter, he complained that Melson had yet to make it clear whether he'd be acting as a prosecutor, as a representative of AAFS or as a judge in his position as chair of the ethics panel. The answer would turn out to be all three.

On the morning of the hearing, Bowers learned that Melson had actually met with Loomis the previous night. Not only that, but the purpose of the meeting was so that Melson could help Loomis prepare. Later, during the hearing, it was revealed that Loomis got the idea for the complaint after a conversation at a dinner party hosted by Golden — the same analyst who agreed with Bowers about the proper orientation of the bite marks in *Frimpong*. Golden also preceded Loomis as ABFO president and now sits on the group's executive committee. In addition, Loomis revealed that it was Golden who brought up the *Frimpong* case, the heart of Loomis's complaint. (Golden was the opposing expert in that case.) None of this had previously been disclosed to Bowers.

Paula Brumit, also a member of the ABFO executive committee, was also one of the ethics committee members who was sitting in judgment of Bowers last July. Brumit had also met with Melson and Loomis the night before the hearing — also to help Loomis prepare his testimony. None of this was disclosed to Bowers or his attorney until the morning of the hearing.

"So two of the people on this supposedly unbiased committee, including the chairman, had met with my accuser the night before to help him prepare his case," Bowers says. He adds, wryly, "And they're aghast that anyone would dare suggest they're on a witch hunt."

The proceedings only got more absurd from there. Melson ran the hearing, acting as both judge and prosecutor. There are surreal passages in the transcript in which Bowers's attorney objects to a question Melson asks as Melson is playing the role of prosecutor. At that point, Melson takes on the role of the "neutral fact-finder," or judge, and overrules the objection. It also includes passages in which Melson the prosecutor objects to questions by Bowers's attorney — then slips into the role of Melson the judge to sustain his own objections.

"It was a Star Chamber," says Fabricant, who attended the hearing. "I've never seen anything like it. At every turn, they failed to afford Bowers even minimal due process. It was outrageous."

On Sept. 6, Melson sent Fuentes a letter informing him that the committee had ruled against Bowers on one count. It had determined that Bowers had "committed a fraud on the court" in the *Frimpong* case. The ethics committee recommended that Bowers be expelled from AAFS. Melson told Fuentes that he would forward a copy of the committee's report to the AAFS president and board of directors.

Under AAFS bylaws, Bowers is permitted to make his own appeal to the board. The problem is that Melson has refused to let Bowers see a copy of his committee's report. In other words, Bowers is allowed to make an appeal, but he doesn't get to see what exactly it is that he's appealing.

Moreover, Melson didn't specify on which of the allegations the committee ruled against Bowers. He still hasn't. So Bowers must not only appeal without seeing the committee's reasons for ruling against him, but he also must do so without knowing for certain exactly what the ethics committee thinks he did wrong. (Through the process of elimination, Bowers and his attorney are fairly certain that it's the complaint alleging Bowers altered evidence in the *Frimpong* case.)

Brandon Garrett, a law professor at the University of Virginia who specializes in criminal procedure and innocence cases, reviewed the transcripts of the hearing and found them astounding. He submitted a declaration on Bowers's behalf. In his declaration, Garrett wrote that the entire adjudicative process "failed to satisfy minimal, but fundamental, due process protections."

The AAFS convenes for its annual conference this month in Orlando. During the conference, the AAFS board will consider the charge against Bowers. If the board votes to uphold it and expel him, Bowers can appeal and ask the entire AAFS membership to vote on the matter.

(Note: After the first of installment of this series ran on Feb. 13, the AAFS board voted on

Monday to dismiss the charge against Bowers, against the recommendation of the ethics committee.)

After the ethics committee issued its recommendation, I spoke again with Risinger, the forensic evidence expert and law professor who initially seemed confident that Melson and his committee would do the right thing. He, too, was taken aback by what transpired during the hearing.

"Assuming that what I've heard about the hearing is correct, I was wrong to have as much faith as I did in the ethics process," he said.

Tussles with the Bushes

By 2009, just as the ABFO was battling Bowers's increasingly vocal criticisms and the fallout from the NAS report, the organization ran into another problem. In 2007 Mary and Peter Bush, a married couple who head up a team of researchers at the State University of New York at Buffalo, began a project to do what no one had done in the three decades — conduct tests to see whether there's any scientific validity to the bite mark evidence presented in courts across the United States.

The Bushes sought to test the two main underlying premises of bite mark matching — that human dentition is unique and that human skin can record and preserve bite marks in a way that allows for analysts to reliably match the marks to a suspect's teeth. The Bush team was the first to apply sophisticated statistical modeling to both questions. It was also the first to perform such tests using dental molds with human cadavers. Previous tests had used animal skins.

When they first set out on the project, the Bushes received preliminary support from some people in the bite mark analyst community. "Franklin Wright was the ABFO president at the time," says Mary Bush. "He visited our lab, and then put up a message praising our work on the ABFO website." They also received a small grant from the ASFO, the discipline's non-accrediting advocacy and research organization.

"There was a lot enthusiasm at the outset," says Fabricant. "I think some analysts were excited about the possibility of getting some scientific validation for their field."

But when the Bushes began to come back with results that called the entire discipline into question, that support quickly dried up.

The Bushes' research found no scientific basis for the premise that human dentition is unique. They also found no support for the premise that human skin is capable of recording and preserving bite marks in a useful way. The evidence all pointed to what critics such as Bowers had always suspected: Bite mark matching is entirely subjective. The Bushes' first article appeared in the January 2009 issue of the Journal of Forensic Sciences. The couple have since published a dozen more, all in peer-reviewed journals.

Outside of ABFO and their supporters, the Bushes' research has been lauded. "I think there's a chance that because of the Bushes' research, five years from now we aren't going to be talking about bite mark evidence anymore," says Risinger. "It's that good. Their data is solid. Their methodology is solid. And it's conclusive."

Other legal scholars and experts on law and scientific evidence interviewed for this article shared Risinger's praise for the Bushes' research but were less optimistic about its implications, in part because the criminal justice system so far hasn't recognized the significance of their work.

But from a scientific standpoint, the Bushes' research was a direct and severe blow to the credibility of bite mark analysis. At least initially, it threatened to send the entire field the way of voice print matching and bullet lead analysis, both of which have now been discredited. And so when defense attorneys began asking the couple to testify in court, the bite mark analysts fought back with a nasty campaign to undermine the Bushes' credibility. In a letter to the editor of the Journal of Forensic Sciences, seven bite mark specialists joined up to attack the Bushes in unusually harsh terms for a professional journal. When that letter was rejected for publication, five of the same analysts wrote another. That, too, was rejected. A toned-down but still cutting third letter was finally published.

In the unpublished letter dated November 2012, the authors — all bite mark analysts who hold or have held positions within ABFO — declared it "outrageous that any of these authors would go into courts of law and give sworn testimony citing this research as the basis for conclusions or opinions related to actual bite mark casework, especially considering that no independent research has validated or confirmed their methods or findings."

Of course, critics would say this was a bit of rhetorical jujitsu — that the last clause could describe exactly what bite mark analysts have been doing for 35 years. For emphasis they added, "This violates important principles of both science and justice." In the other letter, the authors referred to the Bushes' testimony in an Ohio case, which was based upon their research, as "influenced by bias" and "reprehensible and inexcusable."

The primary criticism of the Bushes' research is that they used vice clamps to make direct bites into cadavers that were stationary through the entire process. This is quite a different scenario than the way a bite would be administered during an attack. During an assault, the victim would probably be pulling away, causing the teeth to drag across the skin. For the Bush tests, the clamp they used to make the bites moved only up and down. A human jaw also moves side to side. A biter might also twist his head or grind his teeth. A live body will also fight the bite at the source to prevent infection, causing bruising, clotting and various other defenses that would alter the appearance of the bite.

“We acknowledge that our lab tests are different from how bites are made in the real world,” says Mary Bush. “But to the extent that our tests differed, they should have made for better preserved samples.”

In other words, the tests that the Bushes conducted made for cleaner, clearer bites that could be easily analyzed. If they were in error, they were in error to the benefit of the claims of bite mark analysts. And they still found no evidence to support the field’s two basic principles.

“That’s exactly right,” says Risinger. “If there was any validity to bite mark analysis at all, these tests would have found it. They gave the field the benefit of the doubt. The evidence just wasn’t there. Their data is very, very strong.”

To argue that the Bushes’ experiments should be disregarded because they weren’t able to replicate real-world bites is also an implicit acknowledgment that real-world bites aren’t replicable in a lab, and therefore aren’t testable. You won’t find many people volunteering to allow someone else to violently bite them for the purposes of lab research. Even if you could, a volunteer won’t react the same way to a bite that an unwitting recipient might.

The Bushes’ research not only failed to find any scientific support for bite mark matching, but it also exposed the fact that for four decades the bite mark community neglected to conduct or pursue any testing of its own. It put the ABFO and its members on the defensive. The bite mark analysts responded by intensifying their attacks on the couple and making the attacks more personal.

At the February 2014 AAFS conference in Seattle, the ABFO hosted a dinner for its members. The keynote speaker was Melissa Mourges, an assistant district attorney in

Manhattan, one of the most outspoken defenders of bite mark matching in law enforcement.

Mourges already had a high profile. The combative, media-savvy prosecutor was part of the prosecution team featured in the HBO documentary "Sex Crimes Unit," which followed the similarly named section of the Manhattan DA's office, the oldest of its kind in the country. Mourges herself founded a cold-case team within that unit. At the 2012 AAFS conference she spoke on a panel called "How to Write Bestselling Novels and Screenplays in Your Spare Time: Tips From the Pros." At this year's conference, she'll be on a panel that's titled "Bitemarks From the Emergency Room to the Courtroom: The Importance of the Expert in Forensic Odontology." She'll be co-presenting with Franklin Wright, the former ABFO president who initially supported the Bushes' research.

Mourges was also the lead prosecutor in *State v. Dean*, a New York City murder case in which the defense challenged the validity of the state's bite mark testimony. In 2013, Manhattan state Supreme Court Judge Maxwell Wiley held a hearing on the scientific validity of bite mark evidence. Mary Bush testified about the couple's research for the defense. It was the first (and so far the only) such hearing since the NAS report was released, and both sides of the bite mark debate watched with anticipation. In September 2014, Wiley ruled for the prosecution, once again allowing bite mark evidence to be used at trial. (I'll have more on the *Dean* case in part four of the series.) Mourges's talk at the ABFO dinner was basically a victory lap.

There's no transcript of Mourges's speech, but those in attendance say it was basically a no-holds-barred attack on Mary Bush. Cynthia Brzozowski has been practicing dentistry in Long Island for 28 years and sits on the ABFO Board of Directors. She practices the widely accepted form of forensic dentistry that uses dental records to identify human remains, but she doesn't do bite mark matching, and she won't testify in bite mark cases.

Brzozowski was at the dinner in Seattle and says she still can't believe what she heard from Mourges.

"Her tone was demeaning," Brzozowski says. "It would be one thing if she had just come out and presented the facts of the case, but this was personal vitriol against the Bushes because of their research."

According to Brzozowski, Mourges even went after Mary Bush's physical appearance. "At one point, she put up an unflattering photo of Mary Bush on the overhead. I don't know where she got it, or if it had been altered. Mary Bush is not an unattractive person. But it was unnecessary. You could hear gasps in the audience. It was clear that she had chosen the least flattering image she could find. Then she said, 'And she looks better here than she does in person.' It was mean. I had to turn my back. I was mortified."

Other ABFO members — including two other members of the board of directors — also complained, to both the ABFO and the AAFS. The complainants described Mourges's attack on Bush as "malicious," "bullying" and "degrading." According to accounts of those in attendance, other members were also upset by Mourges's remarks but didn't file formal complaints for fear of professional retaliation.

A few weeks later, Loomis sent an e-mail to the ABFO Board of Directors to address the complaints. Loomis defended Mourges and her presentation. He described the dinner as a "convivial affair" where members can socialize, have a libation and "be entertained" by the invited speaker. He argued that "anyone who understands litigation" should not have been unsettled by the talk and described the presentation as "sarcastic, serious, and even light-hearted." He stood by the decision of his predecessor, Greg Golden, to invite Mourges, calling it "a good decision," adding, "I apologize to those who were offended. However, I do not apologize for the message."

"'Bullying' is exactly what it is," says Peter Bush. "We're scientists. We're used to collegial disagreement. But we had no idea our research would inspire this kind of anger."

Loomis had good reason to know exactly what he'd be getting in Mourges. At the previous AAFS conference in Washington, D.C., Mourges heckled the Bushes during a panel in which they tried to explain their research. According to those in attendance, she brought a printout of Mary Bush's testimony from the *Dean* case and essentially tried to continue her cross-examination in a public forum.

Even in her brief in the *Dean* case, Mourges went well beyond standard legal arguments to launch personal attacks at the critics of bite mark matching. At one point in the brief, she implies that Bowers is cut from the same cloth as the notorious bite mark charlatan Michael West. She notes that both have resigned from the ABFO and that she finds it "a relief" that neither plans to testify in court again. (Note: Bowers says he doesn't know where Mourges got this — he's still testifying presently and plans to do so in the future.) She also references Bowers's testimony in the *Frimpong* case, falsely stating that he "admitted publicly and under oath that he manipulated evidence," a good indication that the attacks on Bowers and the Bushes have been well coordinated.

Mourges's attempt to conflate the most notorious fraud in the annals of bite mark analysis with a man who has spent the past two decades trying to expose the field's shortcomings is certainly audacious. Multiple advocates for forensics reform said it's also completely unmoored from reality.

"It's patently absurd," says the Innocence Project's Fabricant. "Michael Bowers is well-regarded and well-respected. His work was cited in the NAS report. To my knowledge, the only people who have ever questioned his ethics are the people he's been trying to expose."

(The Manhattan DA’s office did not respond to my requests to interview Mourges for this series.)

This is the way it has been for critics of bite mark matching. Despite the trail of innocents put behind bars — some of whom were nearly executed — it’s the critics who have been put on the defensive. They’re heckled and belittled at forensics conferences, are subjected to lawsuits and ethics complaints, are attacked in court briefs and can expect their professional reputations to be called into question.

Ian Pretty testified for Bowers at the AAFS hearing. Pretty is a professor of public health dentistry at the University of Manchester in the United Kingdom. He’s somewhat critical of bite mark matching but less vocal about his objections than someone like Bowers. He also chairs the AAFS odontology section. At the hearing, Pretty alluded to the treatment of Bowers and the Bushes and said he feared that the attacks on them would chill critics and stifle an open debate.

“One thing that I have noticed and I’ve become increasingly concerned about is the tone in which . . . certain [individuals'] research has been received,” Pretty said. “I’ve found that the discourse around our scientific sessions has become more aggressive than I would like to have seen.” He added that “there’s been somewhat of an attack on the ability for people to speak freely. ” He also worried that the hearing would create a new method of attacking critics through the ethics process, “that we will have situations where people are concerned about what they say, be it in court, be it in depositions, be it in an Academy meeting, [they'll] fear that they will be brought in front of this Ethics Committee for expressing an opinion.”

“We were naive going into it all,” says Mary Bush. “We thought we were providing research that would help prevent innocent people from getting convicted. We expected disagreement, but we expected polite, academic disagreement. We never expected the response to be so vitriolic.”

That vitriol has been persistent. In June 2013, Fabricant moderated a panel on forensics at a New York City conference hosted by the American Bar Association. Mary and Peter Bush were on the panel. During the question-and-answer period, the Bushes were once again subjected to some pointed criticism from a member of the audience. He derided the Bushes' research and defended bite mark matching.

That audience member was Ira Titunik. The following month, DNA testing exonerated Gerard Richardson, the man Titunik's bite mark testimony had put in prison for 20 years.

Addendum: After this post was published, the office of Manhattan District Attorney Cyrus Vance sent the following statement:

> Melissa Mourges is a veteran prosecutor and a nationally recognized leader in her field. As Chief of the Manhattan District Attorney's Forensic Science/Cold Case Unit, she has solved dozens of cold case homicides, including two recently attributed to "Dating Game" serial killer Rodney Alcala. In addition to being a Fellow at the American Academy of Forensic Sciences, ADA Mourges has also served as co-chief of the DNA Cold Case Project, which uses DNA technology to investigate and prosecute unsolved sexual assaults. As part of that work, she pioneered the use of John Doe indictments to stop the clock on statutes of limitation and bring decades-old sexual assaults to trial. Her work and reputation are impeccable, and her record speaks for itself.

Radley Balko blogs about criminal justice, the drug war and civil liberties for The Washington Post. He is the author of the book "Rise of the Warrior Cop: The Militarization of America's Police Forces."

The Washington Post

The Watch

The path forward on bite mark matching — and the rearview mirror

By Radley Balko February 20

This is the last part of a four-part series. The first three parts can be found here, here and here.

The 2009 National Academy of Sciences report that was highly critical of the way forensics is used in the courtroom was entitled “A Path Forward.” The words expressed the hope of the report’s authors that it would serve as a catalyst to spur scientific testing of forensic specialties, more vigorous policing of what expert witnesses say on the stand and the development of uniform standards and procedures, all pointing toward an ultimate goal of preventing more wrongful convictions caused by unsupported expert testimony.

Reform, of course, is a long process, but in the field of bite mark matching — which again was the forensics specialty the NAS report singled out for some of its harshest criticism — the “path forward” looks to be obstructed. That’s probably because with bite mark matching, the debate isn’t just about adopting better standards or practices, but also about whether the field should exist at all.

“Most people in forensic odontology are practicing dentists, or academics. They don’t make their living doing bite mark analysis,” says Michael Saks, an Arizona State University law professor who studies the role of science in criminal law. “They do it on the side. Many of these cases involve sex crimes and crimes against children. So they see themselves as avenging angels. They're protecting the weak. They're putting away the bad guys. Then along come critics like Michael Bowers or the Bushes, calling their good work into question. You can see why they'd be angry, even though Bowers and the Bushes are right."

Perhaps that's why courts and prosecutors have been so reluctant to acknowledge the field's shortcomings as well. Since the NAS report was released, there have been several court challenges to the validity of bite mark evidence. So far, every challenge has been struck down.

In 2011, for example, a Pennsylvania judge upheld the 1994 conviction of John Kunco, who had been convicted of rape due in part to the testimony of bite mark analysts Michael N. Sobel and Thomas J. David. (David is a previous president of the American Board of Forensic Odontology.) In his closing argument, the prosecutor emphasized the importance of the testimony:

> [T]here's no way, no way on this earth, for Mr. Kunco to explain how his tooth marks got on Donna Seaman's shoulder unless you accept the fact that he's the one who attacked and brutalized Mrs. Seaman. That's the only explanation, ladies and gentlemen. That's why the evidence is better than fingerprints or hair samples … [T]he bite mark on Donna Seaman's shoulder was as good as a fingerprint. And I submit to you it was that, ladies and gentlemen, for all intents and purposes. Ladies and gentlemen, I'd submit to you that John Kunco should have just signed his name on Donna Seaman's back, because the bite mark on Donna Seaman's shoulder belongs to John Kunco.

The alleged bite marks on the victim's shoulder weren't actually examined by Sobel and David until five months after the rape, a length of time long enough for most wounds to heal. In a 1994 article for the Journal of Forensic Sciences, Sobel and David explained they were able to "recapture" a bite after so much time had passed. They wrote that they employed a technique using ultraviolet light to find, isolate and photograph the mark. They then used the photograph to match the marks to Kunco. The article included a footnote to cite the bite mark analyst who had pioneered the technique. That bite mark analyst: the discredited Michael West.

(Thomas David is also quoted at length in Melissa Mourges's brief in the *Dean* case, discussed below.)

To win a new trial after conviction, an inmate must show that he or she has discovered new evidence, that the new evidence was not discoverable at the time of trial and that if the evidence had been available, the jury would probably have acquitted. The inmate must also file his or her petition within a year of when the new evidence was discovered or should have been discovered. Kunco's petition hinged on the NAS report and its findings on bite mark evidence. In denying Kunco's petition for a new trial, Judge Rita Donovan Hathaway acknowledged that there are problems with bite mark analysis, but she found that the NAS report wasn't new evidence. Rather, it was based on older research for which Kunco had already missed his deadline to file.

Hathaway's ruling may have been correct on the law, but it underscores just how difficult it can be to get a conviction based on bad science overturned. Many, many defendants in fact *had* challenged bite mark evidence based on the prior research and criticisms Hathaway ruled that Kunco should have discovered earlier. They, too, were denied. At this point, even the ABFO may disclaim Michael West. But his legacy in bite mark analysis continues to keep people in prison.

In the 2012 case *Coronado v. Texas*, a state appeals court upheld bite mark evidence on the grounds that forensic odontology is a "soft science" and thus does not need to be subject to a more rigorous analysis. Under a 1998 state appeals court decision, "soft" sciences are admissible if they come from a credible field and if the expert is practicing the principles of that field. In determining that bite mark analysis is a credible field, the court cites the 1990 state appeals court decision upholding the conviction of David Wayne Spence. As noted previously in this series, Spence was convicted primarily due to bite testimony from Homer Campbell, a forensic odontologist who had participated in another wrongful conviction and had given preposterous probability statistics to the Arizona Supreme Court. There were also significant doubts about Spence's conviction. He was executed in 1998. In upholding that conviction, the Texas appeals court upheld bite mark evidence, in part because "our research has not yet led us to a reported case where bite mark evidence has been ruled not to be admissible evidence."

Here again a court upheld bite mark evidence in large part because it has always done so in the past. And it has always done so in the past because other courts had done so before that. As previously noted in this series, many of those precedent-setting cases were supposed to be limited in scope, were misinterpreted by later courts or actually involved suspects who were later exonerated. These opinions aren't scientific analysis so much as a jurisprudential version of the childhood game of Telephone.

The California Supreme Court then took things to new heights of absurdity in the case of William Richards. In 1997, Richards was convicted of killing his wife, Pamela, due in large part to testimony from bite mark analyst Norman Sperber. He had looked at an autopsy photo of Pamela Richards's body and found a mark he thought was a bite. Sperber testified that a gap in the alleged bite was a match to William Richards's unusual dentition. More than a decade later, Sperber recanted his testimony, calling the gap a flaw in the photo. He added that he no longer even thought the bite was made by a human. Four other forensic odontologists said that the photo did not offer enough detail to provide a match to William Richards.

This was still not enough for the California Supreme Court to overturn Richards's conviction. In what the publication California Lawyer called "the worst opinion of the year," the majority ruled in 2012 that once he was in post-conviction, Richards had to prove that the evidence against him was false, not merely overstated. The bite mark analysts who advocated for him after his conviction could not rule him out as the source of the bite (if it was a bite at all); they could only say that the photo from which Sperber originally drew his conclusions was too blurry to prove that Richards was a match.

In other words, a bite mark analyst making grand claims from a blurry photo was good enough to convict Richards, but other analysts — including that same analyst who helped convict him — stating after the fact that the photo was inconclusive was not enough to free him. (At this week's American Academy of Forensic Sciences conference in Orlando, Sperber, who kept a man in prison for more than a decade before changing his mind, received three lifetime achievement awards, one from the AAFS, one from the ABFO and one from the American Society of Forensic Odontology. The latter is a new award called the Norman D. Sperber Award for Forensic Dental Excellence.)

The most significant challenge to bite mark evidence since the NAS report was released came in *State v. Dean*, the New York case mentioned in part three of this series. In 2013, attorneys for defendant Clarence Dean challenged the prosecution's plan to use bite mark evidence against their client. Manhattan state Supreme Court Judge Maxwell Wiley granted a hearing to assess the validity of bite mark matching. It was the first such hearing since the NAS report was published, and both sides of the bite mark debate watched closely. Mary Bush testified for the defense, as did Karen Kafadar, chair of the statistics department at the University of Virginia and a member of the National Institute of Standards and Technology's Forensic Science Standards Board.

The prosecutor in that case was Manhattan assistant district attorney Melissa Mourges, an aggressive 30-year prosecutor with a high profile. Mourges was featured in a 2011 HBO documentary and holds the title of chief of the District Attorney's Forensic Science/Cold Case Unit in what is arguably the most influential DA's office in the country. So her advocacy for bite mark matching is significant.

As reported in part three, Mourges has not only defended bite mark evidence but also seems to be on a campaign to denigrate its critics, going so far as to heckle scientific researchers Mary and Peter Bush at a panel, and then to personally attack Mary Bush during a dinner talk at a forensics conference. Her bite mark brief in the *Dean* case compared bite mark evidence critic Michael Bowers to the notorious bite mark charlatan Michael West. It was a particularly egregious comparison because Bowers had helped expose West back when he was still embraced by the ABFO.

In her brief, Mourges first encouraged Wiley to embrace the “soft science” approach to bite mark analysis used by the Texas court in *Coronado*. Conveniently, doing so would allow bite mark specialists to testify to jurors as experts with almost no scrutiny of their claims at all.

Mourges next argued that if the court must do an analysis of the validity of bite mark testimony, it do so on the narrowest grounds possible. When it comes to assessing the validity of scientific evidence, New York still goes by the older Frye standard, which states that evidence must be “generally accepted” by the relevant scientific community. The question then becomes: *What is the relevant scientific community?*

In her brief, Mourges urged Wiley to limit that community to analysts who “have actually done real-world cases.” In other words, when assessing whether bite mark matching is generally accepted within the scientific community, Mourges says the only relevant “community” is other bite mark analysts.

Saks offers a metaphor to illustrate what Mourges is asking. “Imagine if the court were trying to assess the scientific validity of astrology. She’s saying that in doing so, the court should only consult with other astrologers,” he says. ”She’s saying the court shouldn’t consult with astronomers or cosmologists or astrophysicists. Only astrologers. It’s preposterous."

Saks, who submitted a brief in the case on behalf of Dean, also offers a real-world example: the now-discredited forensic field of voiceprint identification. The FBI had used voiceprinting in criminal cases in the 1970s but discontinued the practice after an NAS report found no scientific support for the idea that an expert could definitively match a recording of a human voice to the person who said it.

"If you look at the Frye hearings on voiceprint identification, when judges limited the relevant scientific community to other voiceprint analysts, they upheld the testimony every time," Saks said. "When they defined the relevant scientific community more broadly, they rejected it every time. It really is all about how you define it."

In urging Wiley to only consider other bite mark analysts, Mourges also casts aspersions on the scientists, academics and legal advocates urging forensics reform. She writes:

> The make-up of the relevant scientific community is and should be those who have the knowledge, training and experience in bitemark analysis and who have actually done real world cases. We enter a looking-glass world when the defense urges that the Court ignore the opinions of working men and women who make up the ranks of board-certified forensic odontologists, who respond to emergency rooms and morgues, who retrieve, preserve, analyze and compare evidence, who make the reports and who stand by their reasoned opinions under oath. The defense would instead have this Court rely on the opinions of statisticians, law professors and other academics who do not and could not do the work in question.

Of course, one needn't practice astrology or palm reading to know that they aren't grounded in science. And if police and prosecutors were to consult with either in a case, we wouldn't dismiss critics of either practice by pointing out that the critics themselves have never read a palm or charted a horoscope.

Mourges also attempts to both discredit the NAS report and claim that it isn't actually all that critical of bite mark analysis. For example, she laments that the report was written by scientists and academics, not bite mark analysts themselves. This, again, was entirely the point. The purpose of the NAS report was to research the scientific validity of entire fields. If it were written by active practitioners within those fields, every field of forensics would have been deemed valid, authoritative and scientifically sound.

Mourges also misstates and mischaracterizes what the report actually says. She writes in one part of her brief that "the NAS report does not state that forensic odontology as a field should be discredited." That's true. But bite mark matching is only one part of forensic odontology. The other part, the use of dental records to identify human remains, is widely accepted. What the report makes abundantly clear is that there is zero scientific research to support bite mark analysis in the manner it is widely practiced and used in courtrooms.

In another portion of the brief, Mourges selectively quotes part of the the report, cutting out some critical language. She writes:

> When Dr. Kafadar and her NAS committee created the NAS report, they wrote a summary assessment of forensic odontology. In it they said that "the majority of forensic odontologists are satisfied that bite marks can demonstrate sufficient detail or positive identification …

That ellipsis is important, as is the word that comes before the quote. Here's the passage quoted in full:

> *Although* the majority of forensic odontologists are satisfied that bite marks can demonstrate sufficient detail for positive identification, *no scientific studies support this assessment, and no large population studies have been*

> *conducted*. In numerous instances, experts diverge widely in their evaluations of the same bite mark evidence, which has led to questioning of the value and scientific objectivity of such evidence.
>
> Bite mark testimony has been criticized basically on the same grounds as testimony by questioned document examiners and microscopic hair examiners. The committee received no evidence of an existing scientific basis for identifying an individual to the exclusion of all others.

The report only acknowledges the near consensus within the community of bite mark analysts for the purpose of criticizing them. Mourges's selective quotation implies that the report says the relevant scientific community accepts bite mark matching. The full passage reveals that the report is essentially pointing out just the opposite: The insular community of bite mark analysts may believe in what they do, but the larger scientific community is far more skeptical.

One common tactic that shows up in Mourges's brief and has also shown up in defenses of bite mark analysis across multiple forums — court opinions, forensic odontology journals and public debates — is a sort of meticulous recounting of the care and precision into which bite mark analysts collect and preserve evidence as well as the scientific-sounding nomenclature used by the field's practitioners. Mourges devotes more than 10 pages to laying out the procedures, methods and jargon of bite mark matching.

In any field of forensics it's of course important that evidence be carefully handled, properly preserved and guarded against contamination. But to go back to the astrology metaphor, even the most careful, conscientious, detail-oriented astrologer . . . is still practicing astrology. If the field of bite mark analysis cannot guarantee reliable and predictable conclusions from multiple practitioners looking at the same piece of evidence, if it cannot produce a margin for error, if its central premises cannot be proved with testing, then it doesn't matter how pristine the bite mark specimens are when they're analyzed or what the mean number of syllables may be in each word of a bite mark analyst's report.

But ultimately, Mourges was effective. In September 2013, Wiley rejected the defense challenge to bite mark evidence in the *Dean* case. He never provided a written explanation for his ruling. In an e-mail, Joan Vollero, director of communications for the Manhattan District Attorney's Office, wrote of the ruling: "Following the months-long Frye hearing, Judge Wiley denied the defendant's motion to preclude the bite mark evidence, finding that the field of bite mark analysis and comparison comports with New York State law."

Moving on, but without looking back

Generally speaking, since the NAS report came out, the courts have treated other pattern-matching disciplines in the same way they've treated bite mark matching — they haven't really factored in the NAS report at all. There have been some exceptions, but by and large even with the exceptions, the courts have merely limited the degree to which an analyst can declare a "match." That is, a court may rule that an expert witness can say a bite mark or hair fiber is consistent with the defendant, but they can't say it could only have come from the defendant.

In some cases, the courts (and defenders of the forensic disciplines under fire) have noted that the NAS report itself doesn't explicitly call on the courts to invalidate any field of forensics. That's true, but that wasn't the report's intent. The intent was to draw attention to the lack of scientific research to support what many forensic analysts have been claiming in court — its purpose was to review the science, not to change existing law. The fact that the NAS didn't explicitly tell the courts to invalidate fields such as bite mark analysis doesn't mean that the NAS report was validating them. Nor does it mean that judges weren't to take the report into consideration when conducting analyses on admissibility.

But Mourges made that very argument in her *Dean* brief. Other prosecutors have made it as well. To support it, they often cite congressional testimony given by Harry T. Edwards, a federal judge with the U.S. Court of Appeals for the D.C. Circuit and the chairman of the NAS committee that wrote the report. In a speech at a Yale conference on technology and law, Edwards thoroughly refuted this argument.

> I recently had an opportunity to read several briefs filed by various U.S. Attorneys' offices in which my name has been invoked in support of the Government's assertion that the Committee's findings should not be taken into account in judicial assessments of the admissibility of certain forensic evidence . . .
>
> This is a blatant misstatement of the truth. I have never said that the Committee's Report is "not intended to affect the admissibility of forensic evidence . . . To the degree that I have commented on the effect of the Report on admissibility determinations, I have said something quite close to the opposite of what these briefs assert.

What Edwards did say was that judges will continue to follow the law — that they'll continue to use the Daubert and Frye analyses. His point was that he hoped the NAS report would inform those analyses.

> [T]here is a critical difference between saying that judges will continue to apply existing legal standards . . . and saying that the Report should have no effect on how judges apply those standards. I most certainly never said, or even suggested, that judges should not take into account the new

> information provided by the Report in assessing the validity and reliability of forensic evidence while making admissibility determinations. Claims to the contrary are without basis in fact and utterly absurd.

That speech was in 2010. Mourges filed her brief in *Dean* in 2013.

There are at least a few hopeful signs that some policymakers are taking notice of the effects of bad forensics. After the California Supreme Court ruling in the Richards case, the state's legislature passed a law that makes it easier for inmates to challenge convictions based on bad science. William Richards is now mounting another challenge to his conviction under the new law.

Texas also recently passed a "junk science" law, mostly in response to the faux-arson science used to convict and execute Cameron Todd Willingham. And a federal judge in Wisconsin recently issued a well-informed opinion striking down a conviction based on handwriting analysis.

But these instances have been few and far between, especially in the courts. Michael Saks says it all goes back to asking judges to be the gatekeepers of science. He suggests a sort of national forensics panel that would evaluate new and existing forensic specialties and decide which have sufficient scientific support to be allowed in the courtroom. "We need to move outside the courts," he says. "Look at these forensic areas that even the government now admits have been discredited. Bullet lead composition, voice print analysis, and so on. The courts had been letting this stuff in for years. It took declarations from the scientific community to put at an end to it. What does that tell us? It tells us that these decision shouldn't be made by judges." Edwards seems to agree. In a speech last year, he cautioned that "Judicial review, by itself, will not cure the infirmities of the forensic community."

While the courts have been slow to embrace the NAS conclusions, there are some indications that the ABFO is at least aware of the heightened public scrutiny. The organization now discourages members from using terms such as “scientific certainty,” “the only person in the world” or Michael West’s trademark phrase “indeed, and without a doubt.” Last year, the ABFO issued a “decision tree,” essentially a flow chart for bite mark analysts, and encouraged its members to use phrases such as “included,” “excluded,” “not excluded” and “the probable biter.”

The problem is that the flow chart still provides no objective criteria for making those assessments. It’s still an entirely subjective process. It’s still an “eyeball test.”

Moreover, according to Brandon Garrett, a University of Virginia law professor who studies innocence cases, it’s far from clear that such changes in language have much of an effect on jurors. “What we’ve found in jury studies is the precise phrasing an expert witness uses doesn’t really matter,” Garrett says. “Whether they say something careful like ‘this is consistent with the suspect’ or something more definitive like ‘this is a scientific match,’ all the jurors hear is an expert witness saying ‘this guy did it.’ ”

In our interview, ABFO President Peter Loomis also said that the ABFO no longer recommends that analysts claim they can match a biter to the exclusion of everyone else on the planet. Instead, it recommends only making positive identifications in what they call “closed populations” — that is, the police or prosecutor give the analyst a list of suspects, and the analyst then determines who is the “probable biter.”

“It’s a meaningless distinction,” says Chris Fabricant, director of strategic litigation for the Innocence Project. “It all depends on who is defining the closed population. The Kennedy Brewer and Levon Brooks cases were both closed populations. And they still identified and convicted the wrong men.”

What troubles critics such as Fabricant most is that all this talk about moving forward cavalierly glosses over what has already happened. Even if you believe the current promises from the forensics communities that things are better now, if you don't change the structural failures that allowed bad science to convict innocent people in the first place, it's almost certain to happen again.

But there's also plenty of reason to question those assurances that things are better now. "The ABFO just dismisses these innocence cases as rogue examiners, or artifacts from a bygone era," Fabricant says. "But they did immeasurable damage, not just to human lives, but to our jurisprudence. Where is the accounting for that? Where is the acknowledgment? Where is the reckoning?"

With the exception of West, the ABFO has never suspended or disciplined one of its members, even when their analysis contributed to a wrongful arrest or conviction. Several who have participated in such injustices are today outspoken advocates or hold leadership positions within the organization. For example, in 1998, bite mark matching by Franklin Wright helped convict Ohio police officer Douglass Prade of killing his wife. But in 2010, DNA testing on saliva taken from the bite mark excluded Prade. An Ohio judge gave Prade a new trial and released him before an appeals court overruled her and ordered Prade back to prison. Today, Wright serves on several ABFO committees, including the ethics, bite mark evidence and proficiency testing committees.

And the larger forensics community isn't exactly showing bite mark analysts the door. The absurd AAFS ethics hearing on Michael Bowers is a pretty good indication of that. (Note: After this series began on Friday, the AAFS board of directors voted to dismiss the ethics complaint against Bowers, overriding the recommendation of the organization's ethics committee. Bowers says the cost of his legal defense topped $100,000.)

The theme of this year's AAFS conference is "Celebrating the Forensic Science Family," which feels like a plea for unity in a field under criticism. The event features at least eight panels focusing on bite mark evidence, plus the annual "Bitemark Breakfast," with remarks by ABFO Vice President Adam Freeman and Jeffrey Ashton, prosecutor in the Casey Anthony case. (In conjunction with the conference, for $700 the ABFO is also offering a one-day course in bite mark analysis. Completion of the course will get you one credit in bite mark analysis toward qualification to take the group's certification exam.)

Of the 20-plus speakers panels specifically related to bite mark analysis, all but three include practitioners in or proponents of the field. One session in defense of bite mark matching will feature Melissa Mourges and Franklin Wright. Neither Mary nor Peter Bush will be speaking, nor will Michael Bowers.

More troubling is that the federal reform apparatus put in place in the wake of the NAS report may have already been captured by the bite mark practitioners. Last October, the National Institute of Standards and Technology (NIST) announced the members of the subcommittee working group that would be studying the scientific validity of forensic odontology. Ten of the 16 members are either practicing bite mark analysts or people who have openly advocated the practice.

The committee includes ABFO president Peter Loomis, ABFO vice president Adam Freeman and ABFO general counsel Haskell Pitluck. It also includes Franklin Wright and David Senn, who testified for the prosecution in the *Dean* case. The chair of the committee is Robert Barsley, the former ABFO president, former AAFS president and bite mark analyst who helped put an innocent man in prison in the 1990s. The committee does also include a few bite mark skeptics, including Mary Bush. But they're vastly outnumbered. In fact, the committee includes all five authors of the vitriolic letter to the editor of the Journal of Forensic Sciences that castigated Bush.

After the announcement of the subcommittee, Loomis sent out a celebratory e-mail to the

ABFO membership. “It is quite an honor for the ABFO to be so well represented in the Odontology Subcommittee,” Loomis wrote. “Nine (9) of its sixteen (16) members are ABFO Diplomates with Dr. Robert Barsley as its chairman. Even the ABFO legal advisor, the Honorable Judge Haskell Pitluck was appointed as a member . . . Congratulations to all of you!”

If the subcommittee collectively approves of bite mark matching, then the ABFO and its supporters will be able to say that the field survived scrutiny even by the government committee put together to address forensics in the criminal justice system. What was supposed to be a process to rid the courts of dubious expert testimony will have become an official government imprimatur for that very sort of testimony. If it was already difficult to get judges to understand the limits of bite mark matching, de facto approval from a subcommittee put together by a government agency as reputable as NIST will make it nearly impossible. That the subcommittee was stacked from the start probably won’t matter.

The move toward forensics reform was spurred by the revelations unveiled by DNA testing. The hard science of DNA analysis, which was born of the scientific method and extensively peer-reviewed, has shown time and time again that practitioners of the “soft sciences” of forensics were wrong, and have probably been wrong for decades. But DNA testing is only applicable in a small percentage of criminal cases, and the flaws in forensic analysis likely produce unjust outcomes just as often in non-DNA cases as they do in DNA cases. DNA testing was a wake-up call that the system is in need of repair. There probably won’t be another one. So it’s important that we learn the correct lessons, and that reform is done right.

Unfortunately, if bite mark matching is indicative of the larger reform process, the ultimate result of the wake-up call may end up being fairer, more just DNA cases — only because of DNA testing — but business as usual everywhere else. That not only calls into question the fairness and integrity of the criminal justice system, but also brings up the far more fundamental question of whether the system even *aspires* to be fair.

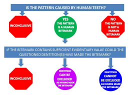
“We can’t let go of the past, because the past is still the present,” says Fabricant. “You still have people in prison because of bite mark analysis. Some are on death row. There has been no accounting for the damage done. It sounds nice to talk about the path forward. But it would be foolish to embark on a long journey forward without a rearview mirror.”

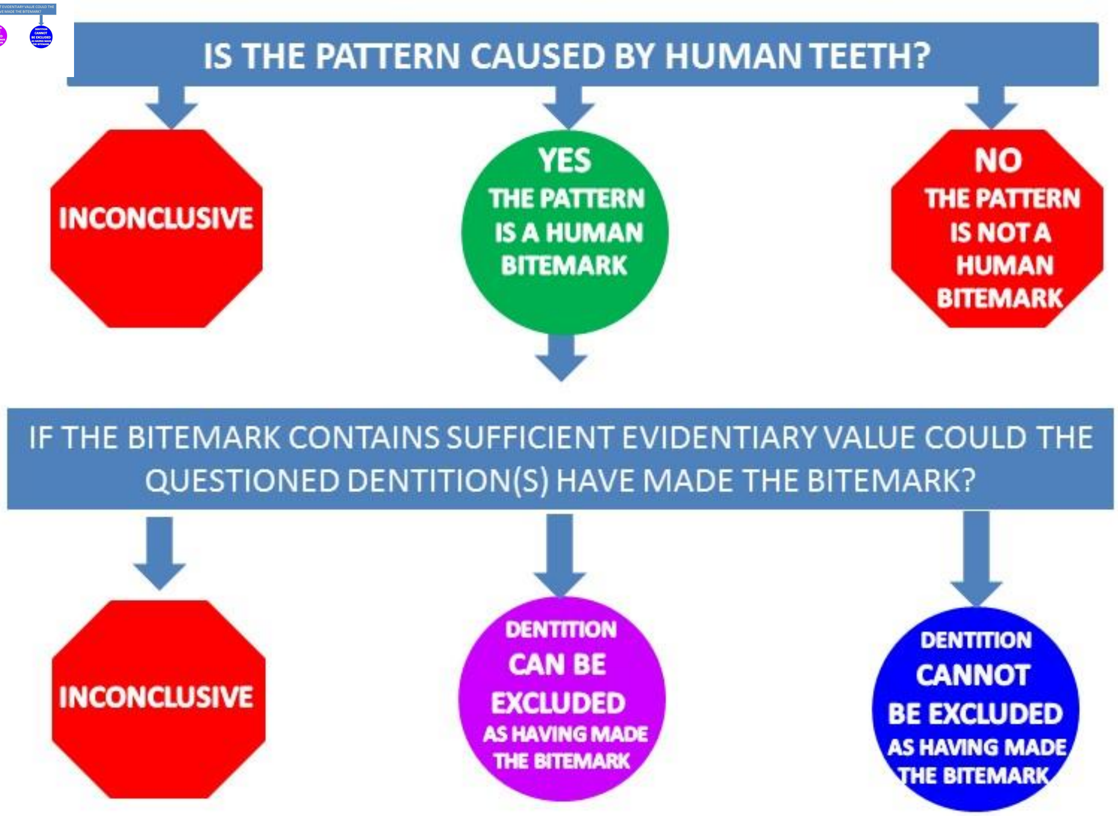
Addendum: After the third installment in this series, the office of Manhattan District Attorney Cyrus Vance sent the following statement:

> Melissa Mourges is a veteran prosecutor and a nationally recognized leader in her field. As Chief of the Manhattan District Attorney’s Forensic Science/Cold Case Unit, she has solved dozens of cold case homicides, including two recently attributed to “Dating Game” serial killer Rodney Alcala. In addition to being a Fellow at the American Academy of Forensic Sciences, ADA Mourges has also served as co-chief of the DNA Cold Case Project, which uses DNA technology to investigate and prosecute unsolved sexual assaults. As part of that work, she pioneered the use of John Doe indictments to stop the clock on statutes of limitation and bring decades-old sexual assaults to trial. Her work and reputation are impeccable, and her record speaks for itself.

Radley Balko blogs about criminal justice, the drug war and civil liberties for The Washington Post. He is the author of the book "Rise of the Warrior Cop: The Militarization of America's Police Forces."

EXHIBIT J

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