RDT&E IWG Human Bitemark Analysis Question List

1. What is the literature on bitemark production and the factors that affect it, including but not limited to body location, elasticity and contour, age, health factors, coagulation status, intermediate material (i.e. clothing), time and force?

1972 - Raekallio, J; Determination of the age of wounds by histochemical and biochemical methods. *Forensic Science, 1*, 3-16.
Abstract Methods of enzyme histochemistry can reveal vital changes around skin wounds and burns inflicted about one hour before death. This is about 8 times earlier than was possible before, when only histological methods were used. Histochemical methods act further as a guide to estimate the approximate age of wounds, especially of those inflicted 1–16 hours before death. However, conditions like senility, cachexia and severe brain injuries may impair the local reactions and thus complicate the dating of wounds.

The determination of the age of wounds becomes more reliable when several independent methods are used simultaneously. The techniques of enzyme biochemistry seem to provide an experimental basis of new methods for the distinction between ante-mortem and post-mortem wounds. Isoelectric focusing in polyacrylamide gel has revealed qualitative differences between the enzymes (arylaminopeptidases and esterases) from ante-mortem and post-mortem wounds, respectively. Autopsy studies on the applicability of enzyme biochemical methods are in progress.

By contrast, biochemical histamine and serotonin determinations, as well as enzyme histochemistry, are applicable even in forensic practice. According to our autopsy studies, a distinct increase (twofold, at least, in regard to serotonin, and 1.5-fold or more, concerning histamine) in the serotonin and free histamine content, as compared to a control sample of neighbouring intact skin, indicates the ante-mortem origin of an injury. The increases in serotonin and histamine are the earliest vital reactions so far known, becoming demonstrable after a survival time of as little as some minutes.

1972 - Robertson, I, Hodge, PR; Histopathology of healing abrasions. *Forensic Science, 1*, 17-25.
Abstract The histological examination of abrasions is of value in determining their age and the age of associated underlying subcutaneous bruises, provided multiple sections are examined and special stains (commonly used in routine histological laboratories) are employed.

1974 - Barbenel, JC, Evans, JH; Bite marks in skin—mechanical factors. *Journal of the Forensic Science Society, 14*, 3, 235-38.
Abstract: The mechanical factors concerned in bite marks involve firstly the forces applied to skin. These may be direct biting pressure from the teeth but in addition suction and tongue thrusting may be involved. The properties of the particular area of skin bitten may affect the appearances of a bite mark. A clear and concise coverage of the topic that has not been addressed since.

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

1974 - Millington, PF; Histological studies of skin carrying bitemarks. *Journal of Forensic Science Society, 14,* 239-40.
Abstract Histological examination has been carried out on biopsy material taken from sites of bite marks in both experimental studies and forensic cases. Superficial evidence from macro-photography of the skin surface showed dramatic changes in the quality of the marks with time. Serial sectioning of specimens revealed that a correlation between collagen staining and the site of the teeth marks was possible. Return to normal staining by dermal collagen was evident even after 4 or 5 days although complete recovery may not occur for 2 or 3 weeks. In non-living tissue the load-induced changes in collagen staining appear to be permanent.

1980 - Glass RT, Andrews EE, Jones K; Bitemark evidence: a case report using accepted and new techniques, J Forens Sci; 25(3):638-45
Abstract: 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.

1981 - Jakobsen, JR, Keiser-Nelson, S; Bite mark lesion in human skin. *Forensic Science International,* 18(1):41-55.
Abstract: Bite marks in human skin may be found to have been so forcefully made that the skin surface has been disrupted; the marks have become skin lesions. In the following, a case is reported in which such lesions were found on the back of a victim of assault. The dental examiners found it necessary to arrange for a series of simulated bites to be made in order to obtain adequate material for comparison.

1983 - Vale, J, Noguchi, TT; Anatomical distribution of human bitemarks in a series of 67 cases. *Journal of Forensic Sciences, 28 (1),* 61-9.
Abstract: A study was made of the anatomical distribution of human bite marks, as well as their distribution by age of victim and type of crime involved. Bite marks in this study occurred primarily in sex-related crimes, child abuse cases, and cases involving other types of physical altercations. Bite marks were found on virtually all areas of the body, with more than one bite mark on 40% of the victims. Female victims were most commonly bitten on the breasts, arms, and legs, while male victims were most commonly bitten on the arms and shoulders.

1984 - Elliot TR. Rogers AH. Haverkamp JR. Groothuis D; Analytical pyrolysis of Streptococcus salivarius as an aid to identification in bitemark investigation, *Forens Sci Int*; 26(2):131-7
Abstract: 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.

1986 – Sperber, N; Identification of children and adults through federal and state dental identification systems: recognition of human bite marks, *Forensic Sci In,* 30(2-3):187-93.
Abstract: Forensic pathologists are often involved in the identification of unknown bodies. It is imperative, therefore, that they become aware of a national computerized identification system (NCIC) administered by the FBI. There is also a state system in California which has

resulted in the identification of 59 individuals. This article describes the current methods available for dental identification and indicates the reasons pathologists must rely on odontologists. A brief description of human bite marks and their usual locations is also included, since forensic pathologists often encounter such important evidence during an autopsy.

1990 – Allison, RT, Whittaker, DK; Use of benzidine for histological demonstration of haemoglobin in human bite marks, *J Clin Pathol*, 43: 600-603
Abstract: Describes use of a prohibited carcinogen to stain for haemoglobin.

1995 - Dailey, JC, Bowers, CM; Aging of bitemarks: a literature review. In *Manual of forensic odontology, 3rd Ed.*
Dailey, J.C. and C.M. Bowers; Aging of bitemarks: a literature review. *Journal of Forensic Sciences, 42 (5),* 792-95, (1997)
Abstract: The aging of bitemarks through the subjective interpretation of visual signs has created an area of controversy in the forensic science community. The healing dynamics of these bite wounds has been insufficiently studied and is poorly understood. A review of the literature related to bitemark aging was undertaken in an effort to summarize the currently published information on this misunderstood subject.

1996 – West, MA, Barsley RE; Wound patterns: detection, documentation and analysis; *J Clin Foren Med,* 3(1):21-27
Abstract: Bruises and other injuries located in skin can play a valuable role in the forensic investigation of a crime. This paper presents details outlining how forensic odontology can be useful in detecting, documenting and analyzing such patterned injuries. In addition, four illustrated case histories are included.

1998 - Sweet D, Parhar M, Wood RE, Computer-based production of bite mark comparison overlays. *J Forensic Sci*, 1998 Sep; 43(5):1050-5.
Abstract: Bite mark comparison protocols include measurement and analysis of the pattern, size, and shape of teeth against similar characteristics observed in an injury on skin or a mark on an object. The physical comparison of tooth position often depends upon transparent acetate overlays to detect similarities or differences between the teeth and the bite mark. Several methods are used to produce life-sized comparison overlays. The perimeter of the biting edges of the anterior teeth is usually recorded to produce facsimile images called hollow volume overlays. Some investigators hand-trace these outlines from dental study casts, or from bite exemplars produced in wax, styrofoam, or similar materials. Some use hand-traced outlines from xerographic images produced with office photocopiers that are calibrated to produce life-sized final images. Others use radiographic images and toneline photography of wax exemplars filled with radio-opaque materials, such as metal filings or barium sulfate. Dependence upon subjective input by the odontologist to trace these images manually is considered problematic. This is because the errors incorporated at any production stage are increased in the final product. The authors have developed a method to generate accurate hollow volume overlays using computer-based techniques. A PowerPC Macintosh computer, flatbed scanner, and Adobe Photoshop (a popular graphical interface application) are used to acquire, select, arrange and export detailed data from class and individual characteristics of a suspect's teeth to acetate film loaded in a high-resolution laser printer. This paper describes

this technique to enable the odontologist to produce high-quality, accurate comparison overlays without subjective input.

2000 - Pretty IA, Sweet D., Anatomical location of bitemarks and associated findings in 101 cases from the United States, *J Forensic Sci*, 2000 Jul; 45(4):812-4.
Abstract: The purpose of this paper is to update and confirm previous studies that examined the anatomical location of human bitemarks. This information is useful to forensic odontologists and pathologists, physicians, and coroners who must be familiar with the most likely locations of bitemarks. The data are also useful for those involved in bitemark research. Using the legal database "Lexis," 101 bitemark cases were identified from the United States Courts of Appeal. Cases were included in the study if they provided details concerning the bitemark, such as anatomical location, number of injuries, and information concerning the victim. Information on 148 bites was collated. These data are presented in tabular and graphical form to allow comparisons between males and females, victims and perpetrators, adults and children, and the crime types associated with human bites.

2001 – Pretty, IA, Sweet,D; Adherence of forensic odontologists to the ABFO bite mark guidelines for suspect evidence collection, *J Forensic Sci*, 46(5):1152-8.
Abstract: Boards and associations within forensic science have long been accepted as vehicles for the development and dissemination of protocols and recommendations for practice. Recent controversies surrounding bite mark analyses have brought the methods and practices of forensic dentists to the attention of both the courts and the media. In the mid-eighties the American Board of Forensic Odontology developed guidelines for bite mark analysis in response to unfavorable commentaries on the discipline by legal observers. The purpose of this study is to examine the adherence of board certified and noncertified forensic dentists to the guidelines for collection of evidence from bite mark suspects. A questionnaire was employed during an American Academy of Forensic Sciences meeting. Results showed that, in general, when the odontologists collected evidence they did adhere to the guidelines, although collection of salivary samples was not common. Of concern is the large number of odontologists who do not collect their own evidence from suspects. Police officers or other individuals often perform this task and therefore the guidelines must be disseminated to these groups to ensure that the maximum yield is obtained from bite mark evidence. A review of the materials used to collect evidence is also included with details of applications in forensic science.

2001 - Vanezis, P; Interpreting bruises at necropsy, *J Clin Pathology*, 54:348-55.
Abstract: The accurate interpretation of bruising at necropsy is essential to understanding how a victim has been injured and assists the pathologist in a reliable reconstruction of the events leading to death. It is essential not only to assess the mechanism of production of a bruise, taking into account the type of impacting surface and the magnitude of force used, but also to estimate when the injury was caused. An account is given of the various methods used in the examination of bruises, particularly with respect to aging, as well as the factors that may affect their appearance. Differentiation from artifacts resulting from postmortem changes is also discussed in some detail.

2001 - Sheasby, DR, MacDonald, DG; A forensic classification of distortion in human bite marks, *Forensic Science International*, 122(1):75-8.

Abstract The occurrence of distortion in human bite marks is well recognised. A forensic classification of distortion is suggested which is based upon the causative factors and their inter-relationships. The terms primary distortion and secondary distortion are introduced and described. The objective of this classification is to emphasise the need for a scientific approach to the recognition and interpretation of the types of distortion found in human bite marks. The relationships between distortion, distinctive features and superimposition techniques in bite mark analysis are discussed.

2004 - Broder B, Jerrard, D, Olshaker, J, Witting, J; **Low risk of infection in selected human bites treated without antibiotics;** ***Amer J Emergency Medicine,*** **22(1):10-13.**
Abstract: To assess the need for antibiotics in low-risk human bite wounds, a prospective, double-blind, placebo-controlled study involving 127 patients presenting with low-risk human bite wounds over 2 years to a 40,000 visit per year major academic ED was performed. Low-risk bites penetrated only the epidermis and did not involve hands, feet, skin, overlying joints, or cartilaginous structures. Exclusion criteria included age less than 18 years, puncture wounds, immunocompromise, allergy to penicillin or related compound, or bites greater than 24 hours old. Patients were randomly assigned to receive either a cephalexin/penicillin combination or placebo. One hundred twenty-five patients completed the study. Infection developed in 1 of 62 patients receiving placebo (1.6%, 95% confidence interval CI, 0–7.3%). Infection developed in 0 of 63 patients receiving the cephalexin/penicillin combination (0%, 95% CI, 0–4.6%). Antibiotic treatment of some low-risk human bite wound could be unnecessary. Infection rates appear similar in low-risk human bite wounds whether treated with antibiotics or placebo.

2005 - Freeman, AJ, Senn, DR, Arendt, DM; Seven hundred eight bitemarks: analysis by anatomic location, victim and biter demographics, type of crime, and legal disposition. ***J Forensic Sci,*** **50(6):1436-43.**
Abstract A study of the etiology, anatomic location, victim demographics and legal disposition of bite mark cases was made with the purpose of updating and augmenting previous research in the field. The information may be of interest to a myriad of professional disciplines including Forensic Odontologists, Medical Examiners, Detectives, Profilers, Emergency Room Personnel, Coroners, Psychologists, and Family Service Counselors, as bite marks provide both physical and biological data. While bite marks were found on all anatomic regions of the body some sites are significantly more likely to receive bites, and the frequency that an area is bitten may vary with the type of crime. Sex and age of the victim may also impact the resulting location and frequency of bites. A survey form for bite mark cases was created and mailed to all Diplomates of the American Board of Forensic Odontology. The survey form was also included in the American Society of Forensic Odontology newsletter. The survey requested that the recipient fill out a separate form for each case for which the recipient was the primary investigator of a patterned injury. The data from the resulting surveys were entered into a Microsoft Excel spreadsheet. The responses detailed two hundred thirty two (259) bite mark cases that included seven hundred (778) individual bite marks. Harvey (1976) and Sweet and Pretty (2000) published studies finding the highest percentage of bites to the breasts. In 1983 Vale and Noguchi published the paper indicating that the most frequently bitten area was the upper extremities. The survey forms were sent to approximately 1100 forensic dentist in 26 countries. The forensic experience level of the dentists varied from neophyte to very experienced. The data were analyzed and the results reported and organized in the following categories; Victim Distribution by Gender, Victim Distribution by Age, Child

Abuse Distribution by Age and Gender, Sexual Assault Distribution by age and Gender, Homicide Distribution by Age and Gender, Bite Mark Distribution by Gender and Location, Number of Bite Marks per Victim, Bite mark Distribution Comparison to Previous Research, Child Abuse Suspect Age Distribution by Age and Sex, Homicide Suspect Age Distribution by Age and Sex, Sexual Crimes Suspect Age Distribution by Age and Sex, and Bite Mark Incidence by Anatomical Area and Type of Crime. Fifty-two forensic odontologists from seven countries responded. Nineteen responders were Diplomates of the American Board of Forensic Odontology. The number of cases reported by each responder ranged from one to thirty-three and the average number of cases reported was 4.5. In this broad based study, females were bitten more often than males. The average male victim was younger than the average female victim. Males that were victims tended to be either very young or very old. The youngest victim was a two-month-old boy and the oldest victim a 95-year-old woman. Perpetrators were male more often than female and there was an average of 1.4 suspects per case. The results show that most bites occurred on the arm, followed by the breast. If broken down by gender, males were bitten on the arm more than females, and females were bitten on the breast more often than males. The data show patterns in location and number of bites that seem related to both the type of crime and the age of the victim.

2005 - Wallace, CG, Urso-Baiarda, FG; Human bite injuries.
***Annals of the Royal College of Surgeons of England*, 87(4):295.**

2006 - Murmann, DC, Brumit, PC, Schrader, BA, Senn, DR; Comparison of Animal Jaws and Bite Mark Patterns; Article first published online: 11 JUL 2006
DOI: 10.1111/j.1556-4029.2006.00166.x
Abstract: The purpose of this study was to compare the jaw shapes and bite mark patterns of wild and domestic animals to assist investigators in their analysis of animal bite marks. The analyses were made on 12 species in the Order Carnivora housed in the Mammalian Collection at the Field Museum of Natural History in Chicago, Illinois. In addition to metric analysis, one skull from each species was photographed as a representative sample with an ABFO No. 2 scale in place. Bite patterns of the maxillary and mandibular dentition were documented using foamed polystyrene exemplars, which were also photographed. A total of 486 specimens were examined to analyze the jaw and bite mark patterns. A modified technique for measuring intercanine distances was developed to more accurately reflect the characteristics seen in animal bite marks. In it, three separate areas were measured on the canines, rather than just the cusp tip. This was to maximize the amount of information acquired from each skull, specifically to accommodate variances in the depth of bite injuries.

2007 – Pretty, IA; Development and Validation of a Human Bitemark Severity and Significance Scale, Article first published online: 19 APR 2007 DOI: 10.1111/j.1556-4029.2007.00412.x
ABSTRACT: Numerous efforts have been made to develop a consistent manner to describe bite injuries. Some have been related to the type of injury, others to the manner in which it was caused or simply its anatomical location. Bitemark severity is related to forensic significance and hence the ability to use a common means of injury description would be of benefit to odontologists and those who commission their services. 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. Weighted κ analyses were used to determine the agreement data both between and within groups and individuals. κ demonstrated a high level of intraoperator and interoperator reliability, particularly in the police officer group. The index shows promise as a universal means of describing bite injuries between professionals concerned with their detection and analysis.

2007 - Kouble, RF and Craig, GT; A survey of the incidence of missing anterior teeth: Potential value in bite mark analysis, *Science & Justice*, 47(1):19-23.
Abstract: Bite mark analysis involves comparison of individual dental characteristics between a dentition and the bite injury. A bite mark injury may result from sexual assault, or physical assault, and defensive injuries, and as such can be used to link a suspect to a victim or vice versa. Missing teeth are one of the characteristics that could implicate or exclude a suspected biter. However frequency data for use by forensic odontologists can only be collated from epidemiological studies. Therefore an audit was undertaken of missing anterior teeth in adult patients (n = 1010) attending for treatment, gathering data that could be more relevant to odontology. One in five of the sample presented with missing teeth that were either replaced with a denture (11%), not replaced (6%) or missing with the gap closed (2%).

2008 - Bernitz, O, Heerden, J, van Willie, FP, Solheim, T; An Integrated Technique for the Analysis of Skin Bite Marks; *J Forensic Sci*, 53(1):194-198.

2008 - Brouwer, IG; Medical legal Importance of the correct Interpretation of traumatic skin injuries, Continuing Medical Education

2008 - Bush, MA, Miller, RG, Bush, PJ; Biomechanical Factors in Human Dermal Bitemarks in a Cadaver Model, Article first published online: 24 NOV 2008
DOI: 10.1111/j.1556-4029.2008.00908.x; *J of Forensic Sci*, 54(1):167-76 (2009).
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.

2009 - 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*, 1(1-3):33-7.
Abstract The infliction of a bite is a four-dimensional space–time event that is ideally analyzed with three-dimensional (3-D) technology. Comparison of 2-D images (photographs) of a bitemark with a 3-D replica of a suspect's dentition is challenging. The authors present a

technique that produces 3-D images of indented marks and dentitions for comparisons. Study models and corresponding dental-wax bites were digitized by 3-D scanning, and comparison overlays were generated using DentalPrint© software. The effectiveness of the method was analyzed by determining the area under receiver operating characteristic (ROC) curve and the sensitivity, specificity and 95% confidence interval (CI) for each cut-off point. An area under the ROC curve of 0.953 (SE = 0.029; 95% CI = 0.893–0.985) and high sensitivity and specificity values were obtained for 104 comparisons made by an expert examiner, who correctly identified 92.3% of matching dentitions and 98.7% of non-matching dentitions. This technique can be considered a highly accurate method of bitemark analysis, although indentations must be present in the injury, limiting the cases that can be resolved. A comparative study of the same dentitions using 2-D bitemark photography confirmed the superiority of the new approach.

2009 - Miller, RG, Bush, PG, Dorion, RBJ, Bush, MJ; Uniqueness of the dentition as impressed in human skin: a cadaver model, Article first published online: 26 May 2009, *J Forensic Sci,* 54(4):909-14.

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.

2009 - Radford, G, Kieser, G, Bernal, JA, Waddell, V, Forrest, JN; Bitemark Reconstruction; *J Forensic Odontostomatol,* 27(1):33-36.

Abstract: his paper investigates the changes in upper and lower dental bite records that occur when the anterior teeth occlude into a three-dimensional rather than a flat object. Methods: anterior bite registrations were obtained from 20 volunteers with full and unrestored dentitions. As a three-dimensional, life-like bite target we cast a silicone replica from the impression of an actual arm, fitted with a rigid bony interior. Each participant was asked to bite into a single layer of softened bite registration wax wrapped around the same location on the fake arm, as well as into a flat wafer of the same material. Upper and lower bite registrations were then scanned in the same location on a flat bed scanner. We analysed the sizes of the different bite marks by means of landmark- and semi-landmark analysis to calculate Procrustes distances between tooth outlines. In order to analyse shape variation between the two types of bite registration we carried out principal components analyses on the partial warp scores. These were derived from
partial Procrustes coordinates aligned by means of thin-plate spline decomposition based on a bending energy matrix. Our results show that there are significant differences in the shape of the upper or lower teeth when they occlude into a flat or three-dimensional target. We conclude that the use of a traditional flat bite registration in human bitemark reconstruction and analysis has to be seriously questioned.

2010 - Bush, MA, Thorsrud, K, Miller, RJ, Dorion, RBJ, Bush, PJ; The response of skin to applied stress: investigation of bitemark distortion in a cadaver model. *J Forensic Sci*, 55(1):71-6.

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.

2010 – Bush, MA, Cooper, HI, Dorion, RBJ; Inquiry into the Scientific Basis for Bitemark Profiling and Arbitrary Distortion Compensation*, Forensic Sci,* 55(4):976-983, July 2010.

2011 - Hinchliffe J; Forensic odontology, part 4. Human bite marks; *British Dental J*, 210(8):363-8, 2011 Apr 23.

Abstract: The aim of this paper is to give a brief overview of bite mark analysis: its usefulness and limitations. The study and analysis of such injuries is challenging and complex. The correct protocols for collection, management, preservation, analysis and interpretation of this evidence should be employed if useful information is to be obtained for the courts. It is now possible, with advances in digital technology, to produce more accurate and reproducible comparison techniques which go some way to preventing and reducing problems such as photographic distortions. Research needs to be continued to increase our knowledge of the behaviour of skin when bitten. However, when presented with a high quality bite mark showing good dental detail, and a limited, accessible number of potential biters, it can be extremely useful in establishing a link between the bitten person and the biter or excluding the innocent.

2011 - Kaushal, N.; Human Bite Marks In Skin: A Review, *The Internet Journal of Biological Anthropology.* 2011 Vol 4

Abstract: Human identification is the mainstay of civilization. Identification by teeth is not new. Bite marks may be found at a number of crime scenes. Human bite mark analysis is one of the most complicated and demanding part of forensic dentistry. The individuality of human dentition allows the forensic odontologists to reach to a strong opinion of association in cases of identification and bite mark analysis. In the cases of physical assault having skin injuries, the anatomy and physiology of skin and the position of the victim affect the detail and the shape of the bite mark and hence not all bite marks have the level of forensic value necessary to identify just one individual. Advanced techniques using digital overlays have been suggested. However the advent of DNA and its recovery from bite marks has offered an objective method of bite mark analysis. The issues within the bite mark analysis are discussed in this paper.

2. What is the literature on the experimental and computational models of bitemark analysis and what validation studies have been conducted to support these?

1976 - Dorion, RBJ, Conclusions to research projects in forensic odontology: Preservation and transportation of foodstuff with bite mark evidence. AAFS, Washington, Feb 20, 1976

1981 - Dorion, RBJ, Preliminary research on the preservation of traumatic injury patterns. Canadian Soc. Forens Sci, Hamilton, ON, Aug 1981

1982 - Dorion, RBJ, Preliminary research on the preservation of traumatic injury patterns, AAFS, Orlando, Feb 1982

1985 - Dorion, RBJ, Preservation in bite mark evidence: Inanimate objects, foodstuff and human tissues. AAFS, Las Vegas, Feb 12, 1985

1987 - Dorion, RBJ, Experimental three dimensional ruler for use in bite mark evidence. AAFS, San Diego, Feb 20, 1987

1992 - Dorion RBJ, Lifting, preserving, storing and transporting skin: an eleven year study. AAFS, New Orleans, Feb 21, 1992

2001 - Dorion RBJ, Bitemark project 2000- Objectivity. AAFS, Seattle, Feb 23, 2001

2005 - *Bitemark Evidence*, edited by Dorion, RBJ. Dekker:New York, NY; Research Projects and Recent Developments, Chapter 29, 573-575, 4.7, 4.8.
Abstract: Discussion of the success rates of preorthodontic models to postorthodontic models in bitemark comparison and the amount of time in comparing these models.

2006 - Al-Talabani N, Al-Moussawy ND, Baker FA, Mohammed HA: Digital analysis of experimental human bitemarks: Application of two new methods, *J Forensic Sci*, 51(6):1372-75.
Abstract: Investigated the suitability of two new different methods for identification of bitemarks by digital analysis.

2006 - Dorion RBJ, Perron MJ, Laforte S, Nielsen ML. Bitemark research – Antemortem and postmortem bitemarks, AAFS, Seattle, Feb 24, 2006

2006 - Dorion RBJ, Factors affecting bitemark analysis, AAFS, Seattle, Feb 24, 2006

2007 - Dorion RBJ, Beehler R, Gromling T, Meza E, Perron MJ, Laforte S, Bitemark research – Antemortem and postmortem bitemarks - Part 2. AAFS, San Antonio, Feb 22, 200

2007 - Dorion, RBJ, Bitemark analysis – Part 1 and 2 results, AAFS, San Antonio, Feb 22, 2

2008 - Miller RG, Bush PJ, Dorion RBJ, Bush MA, The role of the skin in bite marks, part II: macroscopic analysis. AAFS, Washington, Feb 21, 2008

2008 - Bush PJ, Miller RG, Dorion RBJ, Bush MA, The role of the skin in bite marks, part III: microscopic analysis. AAFS, Washington, Feb 21, 2008

2008 - Phillips BG, Bush PJ, Miller RG, Dorion RBJ, Bush MA, The role of the skin in bite marks, part IV: clothing weave transfer. AAFS, Washington, Feb 21, 2008

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: Bites inflicted with the same dentition produced patterns that were all different, with varying degrees of difference (intra-arch as well interarch) from the original dentition.

2009 - Desranleau S, Dorion RBJ, Bite marks: physical properties of ring adhesion to skin. AAFS, Denver, Feb19, 2009

2009 - Bush PJ, Miller RG, Dorion RBJ, Bush MA, The relationship of uniqueness and resolution in bite mark analysis. AAFS, Denver, Feb 19, 2009

2009 - Bush MA, Miller RG, Dorion RBJ, Bush PJ, The response of skin to applied stress: the influence of force per unit area in bite mark analysis. AAFS, Denver, Feb 19, 2009

2010 -Bush MA, Cooper HI, Dorion RBJ, Inquiry into the scientific basis for bite mark profiling and arbitrary distortion correction. AAFS, Seattle, Feb 25, 2010

2010 - Dorion RBJ, Bite Mark Profiling Based Upon Color, UV, and ALI Photographic Interpretation. AAFS, Seattle, Feb 25, 2010

2010 - Perron MJ, Dorion RBJ, Macroscopic and Microscopic Study of the Effects of Freezing and Thawing on Bite Marks. AAFS, Seattle, Feb 25, 2010

2010 - Perron MJ, Dorion RBJ, Bite marks on a live victim: data collection, healing process, and loss of details. AAFS, Seattle, Feb 25, 2010

2010 - Desranleau S, Dorion RBJ, Bite Marks: Physical properties of ring adhesion to skin - phase two. AAFS, Seattle, Feb 25, 2010

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*, 55(1):71–76.**
Abstract: Laceration is diffcult to effect in human skin even at forces higher than those that the anterior segment of the human dentition is capable of administering.

2011 - *Bitemark Evidence, Second Edition*, edited by Dorion, RBJ. CRC Press:Boca Raton, FL

> **Dorion, Bitemarks, 2000, Chapter 21, 323, 324, 21.4, 21.4.1, 21.4.2, 21.4.3**
> **Abstract:** The author compares the success rates of preorthodontic models to postorthodontic models in bitemark comparison and the amount of time in comparing

these models.

Georget, 2003, Chapter 21, 324, 21.5
Abstract: As part of a thesis results it is claimed that bitemark depressions are specific to each subject, depending on muscular tonicity, elasticity, tissue thickness and type, and the exerted pressure.

Avon, 2007, Chapter 21, 326, 21.7
Abstract: As part of a doctoral thesis it provides information on the clinical observations and histopathological aspects of bitemark injuries in an in vivo pig model.

Chapter 21, 328-432, 21.10.1 to 21.12
Abstract: Discussion of various factors influencing bitemark evidence including: extra cellular fluid expulsion, clothing, hair presence and removal, bite slippage, overlapping/superimposed bites, disproportionate dimensional distortion, bitemark profiling, lingual markings, disappearing teeth, bitemark in the presence of other trauma, autopsy artifacts, ears and cartilage, nipples, complementary information, bites containing fewer than 12 teeth, bitemark orientation, one sided bite, muscle perforation 3-dimensional, contusion within a bitemark, am vs. pm bitemarks, lividity.

Chapter 21, 340-341, 21.10.22; Chapter 22, 436-441, 22.3-22.4.3
Abstract: Discussion of the vitality, age, and effects of lividity and freezing on pigskin macroscopically and microscopically.

2011 - Dorion, RBJ, The gold standard. ABFO bitemark workshop #9. ABFO, Chicago, Feb 26, 2011

3. 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."

4. What is the literature on potential changes in bitemark analysis from orthodontic treatment, other dental treatment and time delays in analysis?

1995 - Bowers, CM, Bell, GL; ABFO Guidelines and Standards, *Manual of Forensic Odontology (Third Edition),* Chapter 11, 339-341.
Abstract: The authors suggest that in the case of a living victim, it's beneficial to obtain serial photographs of the bite mark over a period of time due to changes that will occur. They also stress the relevance of obtaining a thorough history of any dental treatment subsequent to, or in proximity, to the date of the bite mark.

1995 - Sweet, DJ; Bitemark Evidence, *Manual of Forensic Odontology (Third Edition),* Chapter 5, 151-188.
Abstract: This author states that if anterior teeth are missing or badly broken down, it should be determined how long these conditions have existed. Early recognition and subsequent preservation of bite marks is critical since the appearance of the injury may begin to change rapidly especially in a living victim. It's important to ask the suspect if he has had any dental treatment at the time of or after the presumed date of the bite mark. A comparison chart from published studies shows the color changes observed on healing bruises over time on human skin. On occasion the weight of evidence towards a suspect may hinge upon an opinion related to the age of the bite mark, the age relationship of one mark to another or the age relationship of a mark to the time of the assault/death of the victim. During the process of healing, the bruise will go through several definitive color changes before fading from perception by the human eye.

1995 - Kenney, JP, Spencer, DE; Human Abuse and Neglect. *Manual of Forensic Odontology (Third Edition),* Chapter 6, 194.
Abstract: The authors discuss the aging of bruises in relationship to how this can be affected and interpreted when there are delays in analysis.

1995 - Rothwell, BR; Bitemarks in Forensic Dentistry, *J Amer Dent Assoc,* 126:223-232.
Abstract: Discussion of the accuracy of tooth marks in skin stating that pre and postmortem changes such as edema, hemorrhage and lividity can result in radical modifications.

2005 - Bernstein, ML; Nature of Bitemarks, *Bitemark Evidence,* Chapter 5, 74-75.
Abstract: Healed bite marks will change and may persist for a long period of time.

2005 - Golden, G, and Wright, F; Photography, *Bitemark Evidence,* Chapter 7, 87-168.
Abstract: Bite marks in a living victim must be taken with various photographic techniques over a period of many days. Several examples of photographic techniques taken over a long period of time are shown.

2005 - Dorion, RBJ; Nonperishables and Perishables, *Bitemark Evidence,* Chapter 12, 217-224.
Abstract: Bite marks in perishables are adversely affected over time due to dehydration etc. Attempts should be made to preserve bite marks when time delays in analysis will occur.

2005 - Dorion, RBJ; Tissue Specimens, *Bitemark Evidence,* Chapter 13, 225-255

Abstract: Delays in analysis can greatly affect the accuracy of bite mark evidence. Measures should be in place to preserve the evidence as best as possible.

2005 - Davis, JH; Histology and Timing of Injury, *Bitemark Evidence*, Chapter 14, 257-273.
Abstract: Timing and aging of a bruise is considered by the author. The histology and tissue changes in healing bite marks are emphasized.

2005 - Dorion, RBJ; Human Bitemarks, *Bitemark Evidence*, Chapter 17, 356-369.
Abstract: The author discusses healing and old vs. new bite marks.

2005 - Johnson, LT; The Suspect, *Bitemark Evidence,* Chapter 19, 415-416.
Abstract: This author discusses the importance of correctly establishing the condition of the suspect's teeth especially if there's been an extended time elapsed since the infliction of the bite mark.

2005 - Dorion, RBJ; Research Projects and Recent Developments, *Bitemark Evidence,* Chapter 29, 573-575, 4.7, 4.8.
Abstract: The author compares the success rates of preorthodontic models to postorthodontic models in bitemark comparison. The author also discusses the amount of time in comparisons of these models.

2005 - Friedich RE, Scheur HA, Schulz, F; Assignment of a Bitemark on a Victim Skin to the Dentition of the Perpetrator by Means of Anomalies in the Number and Position of the Frontal Teeth. *Arch Kriminol,* 215 (1-2):11-7.
Abstract: This abstract discusses a bitemark on a female homicide victim, 76 years of age, and the investigation of a suspect with anomalies in the dentition and orthodontic variations.

2006 - Lassig R, Wenzel V, Weber M; Bitemark Analysis in Forensic Routine Case Work, *Excli Journal,* 93-102
Abstract: The authors, in analyzing forensic routine bite marks, found that if the perpetrator of the crime has removable partial dentures, additional specific tooth marks may be expected. These marks differ between bridges, crowns, and dentures. Crowns & bridges may have metal or ceramic tooth surfaces while partial dentures have certain design elements like clasps and rest seats to attach to the teeth. These peculiarities can be responsible for specific wounds and additional markers for identification. Some distortions in a bite mark are related to time-related distortions that occur when a bite changes with time elapsed subsequent to the bite being made. The authors also explain how important it is to obtain a thorough history of any dental treatment carried out after the suspected date of the bite mark.

2007 - Herschaft, E, Alder, M, Ord, D, Rawson, ., Smith, S; Bite Mark Analysis, *Manual of Forensic Odontology (Fourth Edition), Chapter 4, 171-182.*
Abstract: Time delays in analysis affect best evidence collection because bite marks manifest changes over time due to inflammatory tissue response and post mortem changes. Bite marks and bruises change in a living victim due to healing and in a deceased victim due to decomposition. Thus in a living victim it's important to photograph with various techniques over several days.

2009 - Fonseca, F, Orellano-Blaskovich; Bitemark Analysis, *J Forensic Dental Sci*, 1(2):66-72.
Abstract: Bite mark analysis should begin as soon as possible because the clarity and shape of the bite mark may change in a relatively short period in both living and dead victims. Bite marks have a natural tendency to disappear due to tissue regeneration (live victim) or putrefaction (dead body).

2011 - Sheets, D, Bush, PG, Brzozowski, C, Nawrocki, L, 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*, 56(3):621-625.
Abstract: Study indicates that orthodontically treated patients had a very strong effect on dental shape and similarity. Study also stated that these patients had indistinguishable dentitions that made them less unique.

5. 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.

6. 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.

7. What is the literature on frequency statistics of class and subclass dental characteristics in various populations? What is the literature on thresholds or limitations on bitemark analysis (i.e. population pools, size, bitemark quality, etc.)?

1976 - Moyers, RE, Riolo, ML, McNamara, JA; Standards of Human Occlusal Development. Monograph 5, *Craniofacial Growth Series*. Center for Human Growth and Development, The University of Michigan, Ann Arbor.
Abstract: Contains numerous intercanine arch measurements through stages of growth in several subclasses. Classic text Orthodontic training.

1976 - Sognnaes, RF, Rawson, RD, Gratt, BM, Nguyen, NB; Computer comparison of bitemark patterns in identical twins. *J Am Dent* Assoc, 105(3):449-451.
Abstract: Comparison of five sets of identical twins with respect to individual arrangements of the anterior teeth. Found significant differences within each twin set related to occlusal arch form, tooth rotation and individual tooth locations.

1984 - Rawson, RD, Ommen, RK, Kinard, G, Johnson, J., Yfantis, A; Statistical evidence for the individuakity of the human dentition. *J For Sci*, 29(1):245-253.

Abstract: A general population sample of bite marks in wax is used to demonstrate mathematically the individuality of the human dentition. Methodology and statistical model criticized by some investigators.

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.

1987 - Barsley, RE, Lancaster, DM; Measurement of arch widths in a human population: relation of anticipated bite marks. *J For Sci*, 32(4):975-982.
Abstract: Statistical comparison of the maxillary arch width, mandibular arch width, and the mean difference between maxillary and mandibular arch width were performed. Significant differences between the arch width measurements were found to exist between several classes of subjects based on race and sex.

1990 - Kieser, J. A. (1990, first publication). *Human Adult Odontometrics.* Cambridge Sudies in Biological Anthropology, Cambridge University Press. ISBN 0 521 35390 4.
Abstract: Odontometry of different populations with size and shape tooth variants.

2003 - Adams, BJ; The Diversity of Adult Dental Patterns in the United States and the Implications for Personal Identification. *J For Sci*, 48(3):497-503.
Abstract: Two large datasets were used, one composed of U.S. military personnel and one composed of U.S. civilians. Dental patterns were found to be very diverse on a scale that is comparable to mtDNA. Related more to identification than Bitemarks.

2006 - Bernitz, H, van Heerden, WF, Solheim, T, Owen, JH; A technique to capture, analyze, and quantify anterior teeth rotations for application in court cases involving tooth marks. *J For Sci*, 51(3):624-629.
Abstract: This study described a method for capturing and analyzing anterior dental rotations. 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.

2006 - Murmann, DC, Brumit, PC, Schrader, BA, Senn, DR; A comparison of animal jaws and bite mark patterns. *J For Sci*, 51(4):846-860.
Abstract: A modified technique for measuring intercanine distances was developed to more accurately reflect the characteristics seen in animal bite marks. In it, three separate areas were measured on the canines, rather than just the cusp tip. This was to maximize the amount of information acquired from each skull, specifically to accommodate variances in the depth of bite injuries.

2007 - Kieser, JA, Bernal, V, Waddell, J, Raju, S; The uniqueness of the human anterior dentition: a geometric morphometric analysis. *J For Sci* , 52(3):671–677.
Abstract: An investigation of the question of the uniqueness of the anterior dentition evaluating the incisal and canine surfaces of 50 orthodontic casts. The results indicate that there is no sexual dimorphism in the shape of the upper or lower arches. Also, a higher order

of match is accomplished when both size and shape of the anterior teeth are considered together.

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 - Kouble, RF and Craig, GT; A survey of the incidence of missing anterior teeth: Potential value in bite mark analysis, *Science & Justice*, 47(1):19-23.
Abstract: Bite mark analysis involves comparison of individual dental characteristics between a dentition and the bite injury. A bite mark injury may result from sexual assault, or physical assault, and defensive injuries, and as such can be used to link a suspect to a victim or vice versa. Missing teeth are one of the characteristics that could implicate or exclude a suspected biter. However frequency data for use by forensic odontologists can only be collated from epidemiological studies. Therefore an audit was undertaken of missing anterior teeth in adult patients (n = 1010) attending for treatment, gathering data that could be more relevant to odontology. One in five of the sample presented with missing teeth that were either replaced with a denture (11%), not replaced (6%) or missing with the gap closed (2%).

2008 - Johnson, LT, Wirtz, TS, Radmer, TW; The Verdict Is In: Can Dental Characteristics Be Quantified, Parts I & II. *Scientific Sessions*, Annual Meeting of the American Academy of Forensic Sciences, 2008.
Abstract: Imprints of the upper and lower teeth of 419 individuals, representing Caucasian, Asian, Native American, Black and Hispanic, were studied for the frequency distribution of six dental characteristics; arch width, tooth width, angles of rotation, diastemata and missing or supernumerary teeth. The beginnings of a database of class and individual dental findings.

2009 - Radmer, TW, Johnson, LT; The correlation of dental arch width and ethnicity, *J For Ident*, 59(3):270-74.
Abstract: Sample of 400 individuals to correlate arch width demonstrated significant difference between all non-whites vs whites. Pilot study.

2009 - Johnson, LT, Radmer, TW, Wirtz, TS, Pajewski, NM, Cadle, DE, Brozek, J, Blinka, DD; Quantification of the Individual Characteristics of the Human Dentition. *J For Ident*, 5(6):609–25.
Abstract: Data were collected from 419 volunteers who were digitally scanned using 2 computer programs and whose characteristics were measured and frequency calculated. Results established that selected tooth characteristics are quantifiable. Statistics on the rotation of the incisors, especially the inward rotation of the medial surface was shown to be especially significant.

2009 - Radmer TW, Johnson LT, Yang M, Wirtz T; The quantification of tooth displacement, *J For Ident*, 60(1):4-18.
Abstract: The study represents that individual characteristics, such as tooth displacement, can be quantified in a simple, reliable, and repeatable format.

2010 - Lopez, T. T., M. G. H. Biazevic, et al; National survey of the incidence of missing anterior teeth: Potential use in bite mark analysis in the Brazilian context, *Science & Justice*, 50(3):119-122.
Abstract: Survey of missing teeth in Brazilian population.

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.

8. What interpretation guidelines exist for bitemark analysis? What is the literature to support these guidelines? Areas include but are not limited to standardized protocols, standard measurements, imaging procedures, performance, interpretation, reporting, and quality assurance, variations between individual examiners, institutions and by a single examiner over time. Is there literature that describes a numeric threshold for identification? Is there literature that describes what is (or should be) the scientific validation of this threshold?

Guidelines

-American Board of Forensic Odontology *Bitemark Analysis Guidelines* www.abfo.org
-American Board of Forensic Odontology *Bitemark Terminology Guidelines* www.abfo.org

Literature

1974 - MacDonald DG; Bite Mark Recognition and Interpretation, J Forensic Sci Society 14(3):229-33.
Abstract: A classification of bite marks is presented which is based upon consideration of the mechanical factors involved in their causation. The possible value of this suggested classification in the interpretation of bite marks is indicated and an approach to bite mark interpretation is presented.

1974 - Ruddick RF; A technique for recording bitemarks for forensic studies, *Med Biolo Illus*, 24(3):128-9

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

1984 – Rawson RD, Brooks S; Classifiaction of Human Breast Morphology Important to Bite Mark Investigation Am J Forensic Med Path 5(1):19-24.
Abstract: There is a great range of variability in human breast size and resiliancy that may have an effect upon the interpretation of bite marks. A proper understanding of the normal range of breast morphology and a system of classification is necessary for an understanding of distortion effects, as well as the precise communication of those effects to others. A classification is given for the morphology of the female human breast following a review of the literature.

1985 - Krauss TC, Warlen SC; The forensic science use of reflective ultraviolet photography, *J Forens Sci*, 30(1):262-8.

1987 - Dorion RB; Transillumination in bite mark evidence, *J Forens Sci*; 32(3):690-7.

1988 - Hyzer WG, Krauss TC; The Bite Mark Standard Reference Scale--ABFO No. 2, *J Forensic Sci*, 33(2):498-506.

1988 - Benson, B. W., J. A. Cottone, et al. (1988). "Bite Mark Impressions - a Review of Techniques and Materials.

1988 -Summers R, Lewin DA; Photographic Procedures Relating to Bite Mark Evidence, *J Forensic Science Society*, 28(3):211-212.

1990 - Barsley RE, West MH, Fair JA; Forensic photography - Ultraviolet imaging of wounds on skin, *Am J Forensic Med Pathol*, 11(4):300-8.

1994 - Wood RE, Miller PA, Blenkinsop BR; Image editing and computer assisted bitemark analysis: a case report, *J Forensic Odont*, 12(2):30-6.

1994 - Golden, G S; Use of Alternative Light-Source Illumination in Bite Mark Photography, *J Forensic Sci*, 39(3):815-23.

1995 - Rothwell, BR; Bite Marks in Forensic Dentistry: A review of Legal, Scientific Issues, *JADA*, 126(2): 223-232.

1996 - Kahl-Nieke B, Fischbach H, Schwarze CW; Treatment and postretention changes in dental arch width dimensions- a long-term evaluation of influencing cofactors, *Am J Orthod Dentofac Orthop*, 109(4):368-78.

1998 - Wright FD; Photography in Bite Mark and Patterned Injury Documentation, Part 1 and part 2 case study, *J For Sci*, 43(5)871-81.

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.

1998 - Atsu SS, Gokdemi K, Kedici PD, Ikyaz YY; Bitemarks in Forensic Odontology, *J Forensic Odonto*, 16(2): 30-34.

1998 - Dhar V, Tandon S; Bitemark Analysis in child abuse, *J Indian Soc Pedodon & Prevent Dentistry*, 16(3):96-102.

1998 - Williams RG, Porter BE; Documentation of Bite-Mark Evidence Using Multiple Computer-Assisted Techniques, *ODA Journal*, 88(II2):29-30.

1999 - Miyaura K, Matsuka Y, Morita M, Yamshita A, Watanabe T; Comparison of biting forces in different age and sex groups: a study of biting efficiency with mobile and non-mobile teeth, *J Oral Rehab*, 26(3):223-27.

2001 – Sheasby DR, MacDonald DG; A Forensic Classification of Distortion in Human Bite Marks, Forensic Sci International 122(1):75-78.
Abstract: The occurrence of distortion in human bite marks is well recognised. A forensic classification of distortion is suggested which is based upon the causative factors and their inter-relationships. The terms primary distortion and secondary distortion are introduced and described. The objective of this classification is to emphasise the need for a scientific approach to the recognition and interpretation of the types of distortion found in human bite marks. The relationships between distortion, distinctive features and superimposition techniques in bite mark analysis are discussed.

2001 - Wright, F.D., Dailey, J.C.; Human bitemarks in Forensic Dentistry, *Dent Clin North America*, 45(2):365-97.

2003 - McNamee AH, Sweet D; Adherence of forensic odontologists to the ABFO guidelines for victim evidence collection, *J Forensic Sci*, 48(2):382-85.

2006 – Al-Talabani A, Al-Moussawy ND, Baker FA, Mohammed HA; Digital Analysis of Experimental Bitemarks: Applications of Two New Methods, article first published online 30 October 2006 DOI: 10.111/j 1156-4029.2006.00265x, *J Forensic Sci*, 51(6):1372-75.
Abstract: Bitemark determination in forensic odontology is commonly performed by comparing the morphology of the dentition of the suspect with life-sized photographs of injury on the victim's skin using transparent overlays or computers. The purpose of this study is to investigate the suitability of two new different methods for identification of bitemarks by digital analysis. A sample of 50 volunteers was asked to make experimental bitemarks on the arms of each other. Stone study casts were prepared from upper and lower dental arches of each volunteer. The bitemarks and the study casts were photographed; the photos were entered into the computer and Adobe Photoshop software program was applied to analyze the results. Two methods (2D polyline and Painting) of identification were used. In the 2D polyline method, fixed points were chosen on the tips of the canines and a straight line was drawn between the two fixed points in the arch (intercanine line). Straight lines passing between the incisal edges of the incisors were drawn vertically on the intercanine line; the lines and angles created were calculated. In the painting method, identification was based on canine-to-canine distance, tooth width and the thickness, and rotational value of each tooth. The results showed that both methods were applicable. However, the 2D polyline method was more convenient to use and gave prompt computer-read results, whereas the painting method depended on the visual reading of the operator.

2007 – Gianelli PC; Case Legal Studies Research Paper No. 08-06, Criminal Law Bulletin 43:
Abstract: Courts have admitted bite mark comparison evidence in homicide, rape, and child abuse cases. By the 1980s, the technique had gained widespread judicial acceptance. Hundreds of cases have admitted this type of evidence, and no reported case has rejected it. Moreover, some courts speak of bite mark comparison as a "science." Indeed, its acceptance

is so well-established that several courts have taken judicial notice of its reliability, implying that the validity of the technique is not subject to reasonable dispute.

Yet, the scientific foundations for bite mark comparisons has never been demonstrated. Such basic issues as the uniqueness of the human dentition have not been established. Moreover, there is no agreement concerning the accuracy of these comparisons or about the best analytical procedure for making this determination. Recent DNA exonerations of defendants convicted based on bite mark analysis has now undermined the legal status of this method of proof.

2007 - Pretty, IA; Development and validation of a human bitemark severity and significance scale, *J Forensic Sci*, 52(3):687-91.

2008 – Pretty AI; Forensic Dentistry: 2 Bitemarks and Bite Injuries, Dent Update 35:48-61.

Abstract: While the practice of human identification is well established, validated and proven to be accurate, the practice of bitemark analysis is less well accepted. The principle of identifying an injury as a bitemark is complex and, depending on severity and anatomical location, highly subjective. Following the identification of an injury as a bitemark, the comparison of the pattern produced to a suspect's dentition is even more contentious and an area of great debate within contemporary odontological practice. Advanced techniques using digital overlays have been suggested, yet studies have shown that these can be inaccurate and there is no agreement as to the preferred method of comparison. However, the advent of DNA and its recovery from bitemarks has offered an objective method of bitemark analysis. Despite the strengths of DNA, the physical comparison of a suspect's dentition to bitemark injuries is still commonplace. The issues within bitemark analysis are discussed and illustrated with case examples.

2009 - Bowers CM, Pretty IA; Expert Disagreement in Bitemark Casework, *J Forensic Sci*, 54(4):915-18.

2010 - Bush MA, Cooper HI, Dorion RBJ; Inquiry into the Scientific Basis for Bitemark Profiling and Arbitrary Distortion Compensation, *J Forensic Sci*, 55(4):976-83.

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.

2010 - Wright FD, Golden GS; 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.

2011 – Bush MA, Bush PJ, Sheets D; A Study of Multiple Bitemarks inflicted in human skin by a single dentition using geometric morphometric analysis, DOI: 10.1616/j.forsciint.2011.03.028, Forensic Sci International 211(1-3):1-8.

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.

2011 – Stavrianos C, Vasiliadis L, Emmanouil J, Papadopoulos C; *In Vivo* Evaluation of the Accuracy of Two Methods for the Bite Mark Analysis in Foodstuff, DOI 10.3921/rjmsci.2011.25.31, *Res J Med Sci* 5(1):25-31.

Abstract: The aim of this study was to evaluate the accuracy of two methods for the bite mark analysis in foodstuff. For the purposes of this study ten suspects participated as possible perpetrators of a bite mark found in a fresh apple which was seized at a supposed crime scene. The sample was kept in a sealed bag and stored in a fridge. The following day researchers applied the technique of obtaining an impression of the bite mark in the apple using light body vinyl polysiloxane which was injected without pressure from a central point to the bite mark periphery. A ring was constructed as barrier using a heavy body vinyl polysiloxane. The next stage was to pour model from the bite mark impression with the use of dental stone. Next step

was to take dental impressions of the possible suspects using alginate impression material (protesil) and pour dental casts of the dentitions with dental stone. About 2 independent orensic dentists compared the pattern of the bite mark with the dental casts of the suspects using two different methods each time: the docking procedure (direct method) and the computer-assisted overlay production technique with Adobe Photoshop CS4 software (indirect method). The results of this study showed that the computer-based method for bite mark analysis was as accurate as the docking procedure in cases with bite marks in an apple and may be useful in a variety of substrates.

Books:
2004 - Bowers, CM "Recognition, Recovery, and Analysis of Bite Mark Evidence" Chapter 3; Forensic Dental Evidence Elsevier

2006 - Herschaft EE, Alder ME, Ord DK, Rawson RD, Smith ES, Editors; Manual of Forensic Odontology, Fourth Edition, Chapter 4, American Society of Forensic Odontology.

2010 - Senn DR, Stimson PG; Editors; Forensic Dentistry, *Second Edition*, Chapter 11, Chapter 14, Chapter 18; CRC Press:Boca Raton.

2011 - Dorion, RBJ,Editor; Bitemark Analysis A Color Atlas and Text, *Second Edition*, CRC Press:Boca Raton.

Threshold:

-there is no literature that describes a numeric threshold for biter identification

(Note: There exists no ethical research model to experimentally create human bitemarks in living human skin; thus the ability to produce, measure, evaluate and quantify characteristics necessary to formulate a numerical threshold is not possible.)

Validation:

-there is no literature that describes the scientific validation of this threshold

9. What is the literature on the perceptual and cognitive human factors of bitemark examiners and the potential and actual (or empiric) bias involved in bitemark interpretation?

   While there is scant literature specific to perceptual and cognitive factors of bitemark examiners and bias in bitemark interpretation, a limited body of literature exists on the subject related to other forensic disciplines and forensic examinations in general.

1980 - Greenwald, AG; The totalitarian ego: Fabrication and revision of personal history, *American Psychologist*, 35:603-18.

Abstract: Discusses the relationships between the ego and cognitive biases. The discussion includes descriptions of the effect that cognitive biases have on human behavior. Greenwald theorized that egocentricity, beneffectance, and cognitive conservatism combine to negative effect, leading to expectation biases and observer effects especially in “individuals involved in higher level organizations of knowledge, perhaps best exemplified by theoretical paradigms in science.”

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 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. Non-experts had similar performance to experts.

2002 - Risinger DM, Saks MJ, Thompson WC, Rosenthal R; The Daubert/Kumho Implications of Observer Effects in Forensic Science: Hidden Problems of Expectation and Suggestion, *Calif. Law Rev,* 90(1):1-56.
Abstract: Observer effect factors undermine to some degree the reliability of virtually any form of expertise. The extent to which reliability is undermined depends not only on the presence of such factors, but on the characteristics of the expertise at issue, most particularly the degree to which it depends on subjective human judgment.

2005 - Saks MJ, Koehler JJ; The coming paradigm shift in forensic identification science, *Science,* 309(5736):892-5.
Abstract: Converging legal and scientific forces are pushing the traditional forensic identification sciences toward fundamental change. The assumption of discernible uniqueness that resides at the core of these fields is weakened by evidence of errors in proficiency testing and in actual cases. Changes in the law pertaining to the admissibility of expert evidence in court, together with the emergence of DNA typing as a model for a scientifically defensible approach to questions of shared identity, are driving the older forensic sciences toward a new scientific paradigm.

2006 - Dror IE, Charlton D; Why experts make errors, *J Forensic Identif,* 56:600–16.
Abstract: Examiners were provided biasing contextual information in both the individualizations and exclusions of fingerprints. Two-thirds of the experts made inconsistent decisions. The findings are discussed in terms of psychological and cognitive vulnerabilities.

2007 - Hiss J, Freund M, Kahana T; The forensic expert witness -- an issue of competency, *Forensic Sci Int,* 168(2-3):89-94.
Abstract: Scientists submitting expert opinions within the legal system are expected to be knowledgeable in the forensic aspects of their particular science, as well as to be ethical and unbiased. Scientists are seldom able to decline a request to provide an expert opinion in their field, even when their forensic expertise is minimal. The competence of scientists providing expert opinions in forensic cases is reviewed here. Three examples of the perils of uninformed "expertise" in forensic biology, medicine and anthropology are presented.

2007 - Marsh, DM, Hanlon, TJ; Seeing What We Want to See: Confirmation Bias in Animal Behavior Research, *Ethology,* 113:1089-98.
Abstract: Confirmation bias is the tendency of observers to see what they expect to see while conducting scientific research. Although confirmation bias has been well-studied by psychologists in the context of qualitative judgments, it has been much less studied with respect to the kinds of quantitative observations made by behavioral biologists. Confirmation bias never accounted for more than 13% of the observed variation in behavior, and was generally equivalent to <20% of the mean value of each variable.

2007 - Tavris, C, Aronson, E; Mistakes were made (but not by me), 1st ed. 2007, Harcourt:Orlando, FL.
Abstract: Asserts that an integral part of cognitive conservatism and resistance to certain kinds of change is the tendency toward susceptibility to confirmation bias. This is a persistent problem in the identification sciences.

2009 - Bowers, CM, Pretty, IA; Expert Disagreement in Bitemark Casework, *J Forensic Sci*, 54:915-18.
Abstract: Assessment of outcome of 49 cases using the 2007 severity scale. Concludes that expert disagreement is related to the quality of the evidence. Where there is mutual agreement between experts, bitemarks will most likely have a higher forensic value than those where there is disagreement at trial. In those cases in which DNA has provided exoneration, the bitemark evidence may demonstrate similar quality to those in which a conviction was secured. Forensic odontologists should carefully assess bitemark evidence and ensure that it meets certain minimum standards in relation to the presence of class and individual features before undertaking an analysis.

2009 - Budowle B, Bottrell MC, Bunch SG, Fram R, Harrison D, Meagher S, Oien CT, Peterson PE, Seiger DP, Smith MB, Smrz MA, Soltis GL, Stacey RB; A Perspective on Errors, Bias, and Interpretation in the Forensic Sciences and Direction for Continuing Advancement, *J Forensic Sci*, 54:798–809.
Abstract: The issues surrounding measurement error, human error, contextual bias, and confirmatory bias, and interpretation are discussed. A list of recommendations ranging from further documentation to new research and validation to education and to accreditation is provided for consideration.

2010 - Saks MJ; Forensic identification: From a faith-based "Science" to a scientific science, *Forensic Sci Int*, 201(1-3):14-7.
Abstract: This article reviews the fundamental assumptions of forensic identification ("individualization") science and notes the lack of empirical evidence or theory supporting its typical strong claims. The article discusses three general research strategies for placing these fields on firmer scientific ground. It concludes by suggesting what forensic identification science experts can do while awaiting that scientific foundation.

2010 - Senn DR, Stimson PG; *Forensic Dentistry*. 2nd ed., Chapter 14, Bitemarks, 14.4 Scientific Considerations, Bitemark Analysis Issues, and Controversies, CRC Press:Boca Raton.
Abstract: In Section 14.4.5 the authors discuss the role of human behavior, ego, and cognitive bias in the generation of errors in bitemark analysis. The authors conclude that in an effort to minimize these known problems, certifying bodies must modify their standards and guidelines to include steps to minimize expectation bias. They further recommend the adoption and institution of proficiency testing for certified practitioners involved in the analysis of bitemarks.

2011 - Dorion, RBJ, Editor, *Bitemark Evidence*. Chapter X1, Section 28 Science and the Law, CRC Press:Boca Raton.
Abstract: In this chapter the authors discuss the importance of objectivity and impartiality in bitemark analysis and testimony. The concept of justice versus truth is addressed along with

the “hired guns” concept. They briefly discuss the potential for the institution of court appointed experts that, in the authors’ opinion may alleviate some of the concerns related to biased analysis and testimony.

2011 - Page M, Taylor J, Blenkin M; Forensic Identification Science Evidence Since *Daubert:* Part II—Judicial Reasoning in Decisions to Exclude Forensic Identification Evidence on Grounds of Reliability, *J Forensic Sci*, 56:913–917.
Abstract: The citation of unfounded statistics, error rates and certainties, a failure to document the analytical process or follow standardized procedures, and the existence of observe bias represent some of the concerns that have lead to the exclusion or limitation of forensic identification evidence.

10. Is there literature that describes performance differences between certified examiners and examiners that are not certified?

1998 - Whittaker DK, Brickley MR, Evans 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 Sci International*, 92:11-20.
Abstract: The authors, faculty members at the Dental School and Department of Oral Surgery, Medicine and Pathology, University of Wales College of Medicine, compared results of analyses of fifty color prints of human bite marks which were sent to 109 observers divided into different groups. The observers 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 groups of observers included accredited senior forensic dentists, accredited junior forensic dentists, general dental practitioners, final year dental students, police officers and social workers. Comparison of the results among the groups of observers and a “gold standard” (the actual verdict from the case) was made using Receiver Operating Characteristics (ROC) methodology. Results indicated that 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 conclusions derived from the study indicated that training in interpretation of bite marks is important and its effects need to be assessed in more detail in future studies.

2001 - Pretty IA, Sweet D; Digital bite mark overlays - an analysis of effectiveness, *J Forensic Sci*, 46(6):1385-91.
Abstract: In this study the authors, a doctoral student at the Faculty of Medicine, Department of Clinical Dental Sciences, University of Liverpool and the Director, Bureau of Legal Dentistry, Vancouver, British Columbia, define quantifiable variables for transparent digital overlays, the most commonly employed analytical technique in bite injury assessment. Such works did not exist within the field of bite mark analysis prior to this study. Therefore, this paper addresses the issue within U.S. judicial system requiring that expert witnesses be able to identify published works that define operational parameters of any tests or procedures forming the basis for their scientific conclusions. The study created a series of ten simulated, postmortem bites on pigskin and, with accompanying overlays, these were assembled into cases. Using two separate investigations with four examiner groups, the study defined values for intra- and inter-examiner reliability, accuracy, sensitivity, specificity, and error rates for transparent bite mark overlay analysis. 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 results are consistent with other dental diagnostic systems. It was concluded that weak inter-examiner reliability values can explain the divergence of odontologists' stated opinions in court regarding bite mark identifications. The effect of training and experience of the examiners had little effect on the effective use of overlays within this study. The authors conclude that further research is required so that the results this study can be placed into context. However this research represents a significant first step in establishing the scientific basis for this aspect of forensic dentistry.

11. What is the literature on the evolution of bitemarks in living persons (in both persistence and healing changes over time) and in deceased persons (in both persistence and decompositional changes over time)? What is the literature on the variables (i.e., age, health, body location, nutrition, etc.) regarding evolution of bitemarks? What is the literature on the variables (i.e., lividity, tattoos, race, patterns, age, health, body location, nutrition, onset of decomposition, etc.) regarding bitemarks in deceased individuals?

2005 - *Forensic Pathology – Principles and Practice,* Dolinak, Matshes, Lew; Chapter 27- Forensic Odontology, Souviron, Elsevier Academic Press:Waltham, MA pages 615-629.
Abstract: The author discusses bitemarks and pattern injuries on the living in real time (actual) bites. (Pages 621-623) and experimental bites on live volunteers noting changes over time (pages 625-626). On page 624 there is an example of a bite on a non volunteer, living victim showing changes in the pattern over a five day period.

2006 - *Medicolegal Investigation of Death, 4th Edition*, Edited by Spitz WU, Charles C. Thompson, Ltd:Springfield, IL

Chapter VI- part 1- (pages 264-279). Souviron, R.
Abstract: Bitemarks on living victims showing effects of aging of bite over long period of time with scar formation (pages 268). Distortion of the pattern due to positional changes (pages 270-271) – experimental bites on the deceased (cadaver) (Page 274).

Chapter VI- Part 3- (pages 287-291) Golden, G.
Abstract: The author researched with alternate light showing effects of enhancement of the wound and comparison to a potential suspect.

2009 - *Dental Autopsy*, Silver, W and Souviron R CRC Press:Boca Raton, FL, Chapter 13 pages 151-193.
Abstract: The author describes significant cases of modern times (pages 151-155) and variables in bitemarks with a classification system examples of each class (page 158-163).

2009 – Miller, RG et al; Uniqueness of Dentition as impressed in human skin- a cadaver model, *J Forensic Sci*, 54(4): 909-13.
Abstract: This is an article in which experimental bites are created on cadavers using plastic models of teeth on vice grips. The summary of the experiments would indicate that there are

variables in tissue and similarities in dentition. In cadaver specimens using only lower teeth and two dimensional comparison methods, numerous mismatches were produced.

2010 - Bush MA, Cooper H, Dorion RBJ; Inquiring into the scientific basis for bitemark profiling and arbitrary distortion compensation, *J Forensic Sci*, 55:976-983.
Abstract: The authors experiment with cadavers as victims and bitemarks made by plastic teeth models on vice grips and they analyze the effects of the XY Axis of skin. (Langer lines (Pages 976) and the phenomena of anistrophy (distortion of the skin). They were able to demonstrate on cadavers that there is distortion of the skin when the experimental bites are inflicted in the different axes. The x-axis as opposed the y-axis.

2010 - *Forensic Dentistry*, Senn, DR and Stimson, PG, Eds, CRC Press: Boca Raton, FL, Chapter 14 pages 306-365.
Abstract: The author document in condensed form bitemark cases that have been adjudicated. This includes both foreign & domestic cases of historic significance with discussion of errors in actual cases and their prevention (pages 316-326). This chapter further discusses the variables and mathematical analysis relating to bitemarks. (Pages 354-355).

2011 - *Bitemark Evidence, Second Edition*, edited by Dorion, RBJ. CRC Press:Boca Raton, FL

Section IV- Histology and Timing of Injury. By Dr. Joseph Davis, MD. (Pages 195-202). The author documents both gross and microscopic changes of bites and pattern injuries over time. He documents how time, temperature, location and gravity all have effects on the injury (pages 196-205). He reviews the literature and critics it as it relates to the aging of a pattern injury and a bitemark.

12. What is the literature comparing bitemark analysis on the bodies of deceased individuals, analysis of excised tissue with the bitemark and any supplemental testing (i.e., histology, DNA, analysis of dermal components, etc.) available in deceased individuals?

<u>Bitemark analysis and Saliva, DNA studies</u>
1984 - Elliot TR, Rogers AH, Haverkamp JR, Groothuis D; Analytical pyrolysis of Streptococcus salivarius as an aid to identification in bitemark investigation, *Forens Sci Int*, 26(2):131-7
Abstract: Authors describe a technique for "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. Authors state that this technique can be used to provide corroborative evidence in bitemark analysis.

1984 - Brown KA, Elliot TR, Rogers AH, Thonard JC: The survival of oral streptococci on human skin and its implication in bitemark investigation, *Forensic Sci Int*, 26(3):193-7
Abstract: Authors describe their experiments for recovering bacteria from saliva and their implications for identification of bitemarks. Found that after 6.5 hours on skin viable bacteria could still be removed.

1997 - Sweet D; PCR- Based DNA Typing of Saliva Stains Recovered from Human Skin *J Forensic Sci*, 42(3):447-51.
Abstract: Used simulated bitemark situations where saliva was deposited on the skin of cadavers. Results indicated that the concentration of DNA recovered varies with time since the deposition on skin. PCR amplification was found to be independent of the DNA concentration in the saliva sample.

1999 - Sweet D, Shutler G; Analysis of salivary DNA evidence from a bite mark on a body submerged in water, *J Forensic Sci*, 44(5):1069-72
Abstract: A case report of a female body discovered after being submerged in water for 5.5 h. Saliva was recovered from a bitemark on the victim's body. DNA analysis was performed. DNA typing results from the bitemark correlated with the DNA typing results obtained from other biologic trace evidence recovered from other bodily parts. The bitemark and DNA evidence were used to screen suspects.

2005 - Dorion RBJ, ed. ; Bitemark Evidence, 2005 pgs 193-194.
Abstract: Cites 2 cases of bitemark analysis and comparison supported/corroborated with DNA recovered from victim's clothing and skin.

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Bitemark Analysis and Histologic Studies
1974 - Millington PF; Histological Studies of Skin Carrying Bite Marks, *J Forensic Sci Soc*, 14(3):239-240.
Abstract: A histological study of human skin bite marks in living tissue as well as cadaver skin in forensic cases serial sectioning of the injured skin revealed a correlation between increased collagen staining and the sites of the teeth marks. In living tissue, the collagen staining disappeared completely within 21 days but dermal stain changes in cadaver skin remained same over time. Indicates the usefulness of histology in determining time of injury. Also noted that tissue damage due to biting forces was seen not only in the region of the teeth but extended beyond the line of the marks as well as from the tongue. While this study describes its findings it does not include any data or experimental details.

1980 - Glass RT, Andrews EE, Jones K; 3-D Bitemark evidence: a case report using accepted and new techniques, *J Forensic Sci*, 25(3):638-45.
Abstract: A case report of 2 avulsed bitemarks found on a murder victim. A protocol was described of microbiologic and histologic/histochemical techniques used to confirm the timing of the injuries and that they were human bitemarks .

2005 - Dorion, RBJ, Bitemark Evidence,ed. 2005, ch.14 "Histology and Timing of Injury" pgs. 257-273.
Abstract: Discusses types of bruising, aging of bruising, histopathology and histochemical literature reviews. Recommends microscopic documentation of postmortem bitemarks by the pathologist to correlate healing time with the bitemark gross appearance and the circumstances of the injury. Cites numerous case examples of bitemark histology.

Bitemark and Dermal Component Analysis
1973 - Harvey W, Millington PF. Bite-marks—the clinical picture, physical features of skin and tongue, standard and scanning electron microscopy, *Int. J Legal Med*, 8:3-15.

Abstract: Experimental study of bitemarks inflicted on live volunteers. Authors discuss force deformation characteristics on different body sites, microscopic evaluation of skin in relation to clinical appearance and tongue pressure and suction marks. Authors described skin stress-strain curves which were different according to tension direction and expressed concerns of postural distortions of bitemarks.

1974 - Barbanel JC, Evans JH; Bitemarks in skin - mechanical factors, *J Forensic Sci Soc,* 14(3):235-8.
Abstract: Used live volunteers for experimental study of bitemarks. Describes the mechanical factors used to produce a bite, including tongue pressure and suction. Authors report that the appearance of bitemarks are affected by the mechanical properties of the underlying tissue which varies from site to site and tension line variation with postural changes.

2009 - Bush et al. ,Biomechanical Factors in Human Dermal Bitemarks in a Cadaver Model, *J Forensic Sci,* 54(1).
Abstract: A review of the biomechanical properties of the dermis is described and evaluated through 23 bites made on unembalmed cadavers from a single characterized dentition. Bite indentations were photographed and were re-photographed following various bodily positions. Hollow volume overlays of the biting dentition were constructed, and metric analysis of the dentition and all bitemarks was completed. Of the 23 bites made, none were measurably identical and postural distortion was significant in several cases.

2010 - Bush et al., The Response of Skin to Applied Stress: Investigation of Bitemark Distortion in A Cadaver Model, *J Forensic Sci,* 55(1).
Abstract: Controlled bitemarks were created on cadaver skin using a custom biting apparatus. Force per unit area varied during the controlled bites. Bites were made on 7 different tissue types. Results showed that the appearance of the bite varied greatly with the tissue type rather than with the different biting forces applied to the skin.

<u>Bitemark Analysis and Excision of Tissue</u>
1971 - DeVore DT. , Bitemarks for identification? A preliminary report, *Med Sci Law,* 11(3):144-5.
Abstract: Ink models were used 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. Results show there is a large degree of error in using bitemark photographs and unsecured excised skin. Author concludes that the exact position of the victim's body when bitten must be known in order to perform a bitemark analysis and comparison.

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

1979 - Rawson RD, Bell A, Kinard BS, Kinard JG; Radiographic interpretation of contrast-media-enhanced bite marks, *J Forensic Sci,* 24(4):898-901.

Abstract: Describes a technique of soft tissue radiography of postmortem excised bite marks.

1984 - Dorion RBJ. Preservation and fixation of skin for ulterior scientific evaluation and courtroom presentation, *J Can Dent Assoc,* 50(2):129-130.
Abstract: Describes method of stabilization, removal and preservation of postmortem human skin with bitemark injury for scientific evaluation and courtroom presentation. States there was no appreciable changes in excised bitemark tissue after 3 years of fixation. No description of measurement was described nor did article include any of the data to support the technique.

2001 - Rothwell, BR , Thien AV; Analysis of distortion in Preserved Bite Mark Skin, *J Forensic Sci*, 46(3): 573-576.
Abstract: A study evaluating dimensional changes in excised and fixated (deceased) pig skin over a 38 day period. Results show significant dimensional changes and authors caution the use of metric analysis and bitemark comparisons in preserved tissue.

2005 - Dorion,R , Bitemark Evidence, ed. 2005 chapter 13 pgs.225-255.
Abstract: Describes the technique/methodology of excision and preservation of tissue

13. What is the literature on the factors which contribute to distortion of bitemarks (hydration, temperature, location and body contour, dermatoses, bite force and duration, postmortem positioning, etc.)?

1974 - Barbenel JC, Evans JH; Bite marks in skin--mechanical factors, *J Forensic Sciences Soc*., 14(3):235-8.
Abstract: The authors state that the appearance of bitemarks is modified by the mechanical properties of the skin. The variations can be site specific and there are directional variations at any given site. These directional differences form a consistent pattern similar to Langer's lines. They go on to state that "These directional variations or tension lines alter with movements and changes in body position. Distortions in bite marks which are produced by such directional variation will therefore be dependent on the position of the subject during biting." The authors also write that "the influence of such distortions will also depend on the time after biting. Soon after the bite is inflicted, the skin in the area becomes edematous and thus stiffer than the surrounding tissue. This may reduce the distortion of the bite mark subsequent to body movement, but, as the tissue fluid is reabsorbed, the stiffening effect is reduced." They conclude that, " It is therefore likely that the changes in bite mark shape due to body movements will be greater as the bite mark grows older.

2001 – Sheasby DR, McDonald DG; A forensic classification of distortion in human bite marks. *Forensic Sci International,* 122:75-78,
Abstract: The authors summarize types of distortion found in human bitemarks based on causative factors and their inter-relationships. Distortion can occur at different stages in the causation and investigation of bitemarks. Distortion at the time of biting is called primary distortion. Primary distortion is complex and unpredictable and is subdivided into dynamic and tissue distortion. Dynamic distortion is proportional to the degree of movement during the actual biting. Tissue distortion occurs during biting pressure and tissue release. It is affected by age, elasticity, and type of tissue bitten. Secondary distortion occurs after biting has taken place. It is subdivided into time distortion, postural distortion and photographic

distortion. Time distortion is affected by tissue contraction and migration of bruising patterns. Postural distortion occurs when the bitemark is viewed or documented in a position that is different from the initial position. Photographic distortion is caused by off- angulation of the camera to the tissue plane away from 90^0. This type of distortion can be minimized by the use of a scale that includes a circle (ABFO No. 2) to allow correction of off-angulation. Primary distortion cannot be corrected or eliminated, but sometimes secondary distortion can be minimized. Because some degree of distortion is present in all bitemarks, an exact match is fortuitous and unpredictable. Therefore, points of comparison and distinctive features are the most significant criteria in bitemark analysis. As distortion increases, bitemark analysis relies more on distinctive features.

2001 - Rothwell, BR, Thien AV; Analysis of distortion in preserved bite mark skin, *J Forensic Sci,* 46(3):573-6.
Abstract: Deceased Miniature Hanford pigs were used to harvest skin samples for study. Bitemarks imprints were made and then an acrylic ring was superglued and sutured around the bitemark. The bitemarks were dissected out and placed into formalin. Skin samples showed a wide range of type and extent of dimensional distortion in the preserved skin.

2005 - Blackwell SA, Taylor RV, Gordon I, Ogleby CL, Tanjiri T, Yoshino M, Donald MR, Clement JG; 3-D imaging and quantitative comparison of human dentitions and simulated bite marks, *International J Legal Med,* October 2005.
Abstract: The authors sampled 42 study models and corresponding bites made in dental wax. These materials were digitized by laser scanning which allows comparison of a 3-D dentition with a 3-D bitemark. The software used for this analysis was 3D Rugle3, used mostly for facial analysis. Bitemarks produced by a firm substrate like cheese may be more unique with respect to one another than bitemarks inflicted by the same dentitions on a highly deformable substrate like skin. The results indicated that 15% of non-matches could not be distinguished from the true match.
Note: There were a limited number of subjects in this study (42).

2006 - Al-Talabani N, Al-Moussawy ND, Baker FA, Mohammed HA; Digital Analysis of Experimental Human Bitemarks: Application of Two New Methods, *J Forensic Sci,* 51(6):1372-75.
Abstract: The authors propound that a bitemark is not an accurate representation of the teeth that made it. The authors investigated the validity of computer aided digital methods of comparison on experimental human bitemarks made on live human volunteers. The participants were asked to bite the arms of each other with moderate force. The digital methods of analysis used were the polyline method (Adobe Photoshop) and the painting method (Adobe Photoshop). The results of this study showed that the two described methods are applicable and reliable. However, the polyline method was more convenient and gave prompt results. **Note:** The participants in this study were living subjects, not cadaver models.

2006 - Cowan CD, Dewar A; A Comparison between Traditional and 3-dimensional Imaging Techniques for the Identification of Human Bite Marks in Food Substances, *BDS Elective Report,* University of Glasgow 2006.
Abstract: The authors discuss the fact that although CAD scanning has been used as evidence in a court case, its success in identifying bite marks in food has not been proven.

When comparing traditional methods (2-D) with 3-dimensional imaging, traditional methods resulted in 52% of correct answers in 2 different trials, while 3-dimensional imaging resulted in 48% of correct answers. Overall, at this stage, firm conclusions cannot be drawn. Initial results are promising, but more extensive trials need to be conducted.

2007 - Pretty IA; Development and Validation of a Human Bitemark Severity and Significance Scale, *J Forensic Sci* 52(3):687-691.
Abstract: The authors discuss the clear link between the severity of a bite injury at presentation and its forensic significance. For instance, a bitemark that presents as a diffuse non discrete bruise is unlikely to possess distinct characteristics suitable for analysis. On the other hand, very aggressive, avulsive bitemarks are poor candidates for analysis. However, bitemarks that present in the middle of these extremes are considered by odontologists to present the level of significance suitable for inclusion or exclusion of potential suspects. The forensic significance of bite injuries is intimately related to an increasing number of class and individual characteristics that can be observed, measured and compared. Bitemarks limited to only gross characteristics or a few class characteristics can be regarded as having low forensic significance, while those with numerous distinct characteristics having high forensic significance. The scale is rated 1-6, with low numbers (1-2) indicating lower severity and significance. High numbers (5-6) indicate high severity, but lower significance. The middle range of numbers (3-4) indicate moderate severity, but high significance. These cases have the most potential for definitive analyses.

B2008 - Bernitz H, Owen JH, van Heerden WF, Solheim T; An integrated technique for the analysis of skin bite marks, *J Forensic Sci,* 53(1):194-8.
Abstract: The authors state that minimal tissue distortion will not affect the pattern-associated comparison of features in the bitemark. This distortion can be a small degree of warping and shrinkage and will not affect the pattern-associated analysis of the bitemark. The authors conclude that "The expert will never know the exact position of the victim during the biting process, but the relationship of the dental features in a bitemark will remain constant making bitemark analysis possible."

This study contradicts the finding of Sheets & Bush (2011) below.

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):909-914.
Abstract: The authors propound that bitemark comparison is based on 2 fundamental assumptions: 1) the human dentition is unique; 2) skin records these characteristics sufficiently to identify, include or exclude the biter. The dentition can be measured with accuracy, but the uniqueness of the dentition cannot be transferred to the skin perfectly. Similarly aligned dentitions cannot be ruled out as the biter in all cases. This research was not designed as a proficiency test and therefore intra and inter observer effects were not studied. It is acknowledged that cadaver skin differs from living tissue with respect to lack of inflammatory response and subcutaneous bleeding. This was a single arch study and additional information from the other arch may have provided additional data with which to discriminate further. This analysis was 2 dimensional and therefore lacked other potential distinctive information.

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,* 55(1):71-76.

Abstract: The authors believe that distortion in bitemarks comes from 2 sources: the bitemark and the victim. The more complicated factors are associated with the victim, due to the biomechanical properties of skin. Skin is complex due to its nonlinear behavior related to applied stress. Skin is fairly elastic at low stress, but becomes more rigid as stress is increased. Stress is inversely related to surface area and therefore, fewer teeth produce more stress on skin. In general, loose elastic tissue produced greater mesio-distal widths, flattened angles of rotation and greater intercanine widths. The reverse was true with stiffer tissue. Since bites were impressed into cadavers, the level of stress can only be calculated theoretically. Cadaver skin may not replicate living tissue and distortion capabilities may also be different.

2010 - Bush MA, Cooper HI, Dorion RBJ; Inquiry into the Scientific Basis for Bitemark Profiling and Arbitrary Distortion Compensation. *J Forensic Sci,* 54(4):976-83.

Abstract: The authors believe that basic knowledge of human skin and its biomechanical properties is important as it relates to bitemark analysis. One of the properties of skin responsible for distortion is anisotropy. This results in unequal distortion of skin. Skin exists in a state of pre-tension and the direction of pre-tension is best described by Langer lines. Skin also exhibits a nonlinear response to stress as described by stress-strain curves. Because skin deforms, a bitemark may mimic a dentition other than the perpetrators. This is particularly significant in an open population. Although some bite patterns reflected the biters dental arrangement, in many instances, if profiled, other patterns would mislead the investigator.

2010 - Pretty IA, Sweet D; A Paradigm Shift in the Analysis of Bitemarks, *Forensic Sci International,* 201:38-44.

Abstract: This article presents various issues raised by three important groups: 1) advisory bodies, particularly the NAS; 2) The Innocence Movement, in particular, The Innocence Project; 3) research developments. The vast majority of bitemark casework involves the assessment of bitemark injuries on living individuals caused by a human attacker. Bitemarks have been categorized with respect to their forensic significance. High forensic significance relates to injuries that are amenable to analysis and potential comparison, with the ultimate aim of excluding or including potential suspects. Bitemarks that demonstrate high forensic significance are those that feature clear details of distinct features of the biters dentition. Given the present combination of the NAS report, wrongful conviction cases and new research evidence, the bitemark paradigm has changed. A new level of caution, that includes a careful scientific approach and reproducibility of conclusions by independent analysts is essential, along with hypothesis driven research.

2010 - Risinger DM; Whose Fault? – *Daubert,* the NAS Report and the Notion of Error in Forensic Science, *Fordham Urban Law Journal,* 1-22.

Abstract: The author discusses the notion of error and error rates as central to the Daubert opinion and to the recent NAS report as it pertains to forensic science in the United States. However, both fall short of a full consideration of the concept of error. Error in relation to forensic science presents fewer difficulties than a generalized treatment because forensic

science explicitly deals with only conclusions about empirical facts. There are two fundamental approaches to the concept of error that are in tension with one another, normative error and objective error. In the setting of the science of testing, there is no normative charge (error) at all. Saks and Koehler spoke of "the coming paradigm shift" in forensic science. They were envisioning the replacement of the outdated heroic positivist foundational views of forensic science with a set of views about the enterprise of science drawn from more modern approaches. The fact that forensic science is lodged in the legal system as its primary consumer, has not helped to foster change. Today, it can be rightly said that the need for formal validation for many forensic science applications is well established and generally recognized. After the NAS report, most leaders of the forensic science establishment have conceded the necessity of such validation, in order to quiet criticism, if nothing else. Forensic scientists at all levels should embrace the notion that testimony of imperfect, but well validated diagnosticity is much more helpful to the proper ends of the criminal justice system than testimony making unvalidated claims of certainty.

2010 - Stols G, Bernitz H; Reconstruction of deformed bite marks using affine transformations, *J Forensic Sci,* 55(3):784-87.
Abstract: The authors acknowledge that a "a degree of warping, shrinkage, and distortion present in Bite Mark patterns remain one of the biggest stumbling blocks when analyzing evidence for court presentations." In this study, it was tested whether the bitemark matched the dentition of the perpetrator, utilizing affine transformations to reconstruct a bitemark that was distorted. The results of their study concluded that, "The results of the mathematical model applied to the real case study showed that minor deformations did not affect the ability to show positive concordance between the suspect's dentition and the bitemark".
The authors stated, "The difficulties experienced by expert witnesses regarding minimal amounts of warpage, shrinkage, and distortion present in bitemarks can now be scientifically nullified by the numerical explanation".

2011 - Sheets HD, Bush MA; Mathematical matching of a dentition to bitemarks: Use and evaluation of affine methods, *Forensic Sci International,* **207:111-118.**
Abstract: The authors state that "When a bitemark is inflicted, distortion is inevitable. The biomechanical properties of human skin, in particular anisotropy, account for much of the deformation typically seen. The tissue possesses varying degrees of tightness depending on the direction of the skin tension lines. These can vary between different regions of the body. They can also alter with movement." These comments are based on their previous research. In this study they attempt to quantify this distortion mathematically in an attempt of scientifically matching a dentition to a bitemark made on cadaver skin. Several different affine methods of matching dentitions to bitemarks based on landmark data were performed. None of the methods matched the dentition to any of the bitemarks reliably within the measured limits of repeatable measurements, indicating the presence of substantial non-affine (or localized) deformation of bitemarks. The authors conclude "that the distortion found in the laboratory – created bitemarks is principally local (non-global) distortion. This is because of the interaction between the dentition and the anisotropic properties of skin." The results of the study shows that if "local distortion exists in a bitemark and the cause and magnitude of local distortion is unknown, then arbitrary distortion correction using image processing software cannot be performed, nor can a global correction be utilized."

This study contradicts the findings of Stols and Bernitz above (2010).

2011 - Perper JA, Menges DJ; The skin as a repository and masker of evidence, *Amer J Forensic Med Pathology,* 1:56-62.
Abstract: The great elasticity of the skin enables the absorption and inward transmission of large amounts of mechanical energy, leaving minimal or no evidence of external injury. Such a masking effect is more likely to occur in young individuals or in the presence of protective clothing.

2011 - Santoro VA, Lozito P; Experimental Study of Bite Mark Injuries by Digital Analysis, *J Forensic Sci,* 56(1):224-28.
Abstract: This study was carried out in attempting to quantitatively define the anterior teeth of the human dentition and the results obtained support the advantage of morphometric studies and computer-aided programs as an additional aid in the morphological studies of bite marks, with the aim of improving the precision and reliability of the ID of the suspect. This experiment did not take into account the distortion of the soft tissue, and the effects of edema, hemorrhage, and inflammation on the bitemark. The results of the study showed a high correlation coefficient and allowed for positive identification.

Sheets HD, Bush PJ: Dental Shape Match Rates in Selected and Orthodontically Treated Populations in New York State: A Two- dimensional Study, *J Forensic Sci,* 56(3):621-25.
Abstract: The goals of this study were to reexamine the question of sexual dimorphism in a larger population, second to compare match rates between orthodontically treated and non treated sets, and third to understand the dental causes of the principal shape variations. The authors stated that their previous studies showed that "due to distortion, exact metric dimensions of the dentition do not reliably transfer to human skin". (These studies were performed on cadaver skin, and the authors have stated previously that cadaver skin may not replicate living tissue and distortion capabilities may also be different.) The authors conclude that if metric measurements are unreliable, it may be more pertinent to consider the arrangement of teeth in the arch, and their relative arrangement. The study confirmed that the orthodontically treated dentition is not unique, and that in circumstances in which comparison measurements are made on a diffuse bruise, one may expect reduced accuracy and precision.

2011 - Bush MA, Bush PJ; Statistical Evidence for the Similarity of the Human Dentition, *J Forensic Sci,* 56(1):18-23.
Abstract: The authors state that their previous research on cadaver skin suggests that distortion encountered on bitten human cadaver skin limits the resolution of the details transferred. They conclude that this distortion from skin properties effectively reduces the resolution of measurements that can be used to compare the dentition to the bitemark. The results of this study shows that if you consider the distortion of the skin, the match rate between an individual's dentition and the bitemark in cadaver skin will increase, with the possibility of inclusion of false positives in a open population.

14. What is the literature on supplemental and trace evidence (such as DNA, foreign material etc.) that may be a component of bitemark analysis and interpretation?

Oral bacteria as trace evidence

1974 - Clift A, Lamont CM; Saliva in Forensic Odontology, *J Forensic Sci*, 14:241-45.
Abstract: This experiential work is interesting in that, although quite old it provides some context regarding bite marks and trace evidence. The authors state that to one observer a bite mark may be obvious while to others indecipherable and that the presence of trace evidence – namely amylase and blood grouping (this is a pre DNA era paper) provides a measure of corroboration that a suspected bite mark is indeed a bite mark. The authors correctly noted very early on that the deposition of saliva would be associated with the presence of a considerable number of nucleated epithelial cells and substantial amylase activity.

1984 - Brown KA, Elliot TR, Rogers AH, Thonard JC; The survival of oral streptococci on human skin and its implication in bite mark investigations, *Forensic Sci International*, 26:193-197.
Abstract: This study is admittedly an old one however it discusses the detection of known oral microbes (Streptococci total and S. salivarius) can be detected in saliva stains but that the rate of recovery of these bacteria decreases at about 45% per hour. These bacteria can be "semi-individuated" to other persons (see Rahimi et al 2005 below) but this avenue of trace evidence in bite marks is largely over.

1984 - Elliot TR, Rogers AH, Haverkamp JR, Groothuis D; Analytical pyrolysis of streptococcus salivarious as an aid to identification in bite mark investigation, *Forensic Sci International*, 26:131-137.
Abstract: This paper postulates that there is ample evidence that oral bacteria are transferred during a bite mark and that they may not only survive but may cause wound infections. The paper is an elegant dissertation on the subject of salivary subspecies that has been rendered utterly moot by modern DNA recovery techniques.

2005 - Rahimi M, Heng NC, Kieser JA, Tompkins GR; Genotypic comparison of bacteria recovered from human bite marks and teeth using arbitrarily primed PCR, *J Appl Microbiol*, 99(5):1265-70.
Abstract: The authors study undertaken at the University of Otago School of Dentistry New Zealand postulates that attribution of a bite mark to a suspect is feasible based on determining via DNA analysis the subspecies of Streptococci bacteria in the wound and back-matching them to a known group *and* excluding a person who did not do a test bite. The study does prove feasibility of matching bacterial subspecies as a concept however it is under-powered and suffers from its inability to prove uniqueness in a larger population. It also showed that maintenance of the same bacterial species is **not** constant over time thereby limiting its usefulness in criminal investigations where there is a longer time interval between the act of biting and the apprehension of a suspect.

2009 - Nakanishi H, Kido A, Ohmori T, Takada A, Hara M, Adachi N, Saito K; A novel method for the identification of saliva by detecting oral streptococci using PCR, *Forensic Sci International*, 183:20-23.
Abstract: This study by a Japanese police laboratory resulted in the development of sophisticated PCR techniques for isolation of Streptococcus salivarius and S. mutans that were unique to saliva and not in other bodily fluids. The authors found that S. salivarius was a more reliable marker than S. mutans. Although the method has promise it is unlikely to play a role more prominent than that of DNA.

Non-DNA salivary constituents as trace evidence

2000 - Soukos NS, Crowley K, Bamberg MP, Gillies R, Doukas AG, Evans R, Kollias N; A rapid method to detect dried saliva stains swabbed from human skin using fluorescence spectroscopy, *Forensic Sci International*, 114(3):133-138.

Abstract: This study completed at Massachusetts General Hospital showed that in eighty of eighty-two volunteers that had saliva deposited on their skin salivary amylase could be detected using special wavelength fluorescence emission testing with light wavelength in the range of 282nm providing strong presumptive evidence that saliva was present. A weakness of the study was that it implies that the fluorescene could be detected on skin however close reading reveals that the "suspected saliva deposit site" still had to be swabbed which implies ergo that the examiner would still be required to suspect that a bite mark was present, swab it, and then use this tool to detect saliva. Although this appears to be an excellent system *in-vivo* simulated bite marks by subjects onto a substrate such as pig skin or similar would have made this more useful. Additionally another weakness is that in those cases where skin was abraded, as would be seen in bite marks, the test was not as useful.

2009 - Old JB, Schweers BA, Boonlayangoor PW, Reich KA; Developmental validation of RSID-saliva: a lateral flow immunochromatographic strip test for the forensic detection of saliva, *J Forensic Sci*, 54(4):866-73.

Abstract: This study and product development was undertaken at a commercial company in Hillside Illinois. The authors have developed and tested an immunochormatographic strip test that uses monoclonal antibodies directed against amylase. This is in contradistinction to other presumptive tests for amylase that rely on measures of amylase's enzymatic activity. The test strip developed the RSID™-Saliva could detect amylase at very low concentrations and was said to be not cross-reactive with *many but not all* other bodily fluids however it was not specifically tested on amylase on human skin nor on human bite marks *in-vivo.* Although not useful in bitemark analysis currently the technique does show promise at very low concentrations of amylase.

2010 - Akutsu T, Watanabe K, Fujinami Y, Sakurada K; Applicability of ELISA detection of statherin for forensic identification of saliva, *International J Legal Med*, 124(5):493-8.

Abstract: The authors of this Japanese study take a different tack at the issue of detecting saliva that differs from the detection of salivary amylase. The authors developed a test for the detection of Statherin which is a material specific to saliva (amylase is not) and more specifically from the parotid glands. The authors used an unusual experimental approach where they purposely mixed volunteer-associated salivary samples with other biological samples. All samples were from spotted on cloth and air dried for one week at room temperature. Twenty-three of 24 samples tested positive for Statherin. Corresponding tests for amylase resulted in 24/24 detection of saliva however amylase tests were positive in blood, semen, vaginal fluid, sweat and urine. This indicates that Statherin has slightly less sensitivity than tests for amylase when used as a screening test for saliva however it has a much higher specificity for saliva than tests for amylase. This is not surprising since it is only produced in the parotid glands.

2011 - Hedman J, Dalin E, Rasmusson B, Ansell R; Evaluation of amylase testing as a tool for saliva screening of crime scene trace swabs, *Forensic Sci International,* 5(3):194-8.

Abstract: This Swedish study detailed the development of a simple test for salivary amylase on inanimate objects. This study showed that amylase activity levels and DNA concentrations vary greatly between individuals and was not correlated with each other. This simple test has not been used on dermal bite marks nor even on intact skin and the length of time that amylase is detectable in these situations was not the purpose of this study. Additionally amylase is found in other tissues. The technique of demonstrating salivary amylase is a promising one but has not been applied to clinical bite mark situations.

Salivary DNA as Trace Evidence

1992 - Hein PM, Pannenbecker J, Schulz E; Bite injuries upon a newborn, *International Journal of Legal Medicine,* 105(1): 53-55.

Abstract: This case report of a German child who attacked his brother. Both were under the age of 3 years. From a trace evidence standpoint testing for amylase was negative even though the accused was the only one with access to the child, no pets were present and it was a definitive "closed-population" situation. To further buttress the link between the attacker and the victim, the attacker's pajamas contained trace blood evidence of blood group of the victim. This was a case in the pre-DNA era but is interesting from a closed-population and absence of amylase standpoint.

1997 - Sweet D, Lorente JA, Valenzuela A, Lorente M, Villanueva E; PCR-based DNA typing of saliva stains recovered from human skin, *J Forensic Sci,* 42(3):447-51.

Abstract: This paper completed by a Canadian Forensic Odontologist in collaboration with workers in Spain is the seminal paper regarding the quantitation, demonstration of utility, sensitivity and specificity of DNA recovered from cadaver skin. They noted that as little as 1 micro liter of salivary trace evidence recovered from intact skin can yield the same DNA result as 10 micro liters of whole blood. The authors did not in this instance include areas of skin subjected to damage. They showed that the quantity of DNA recovery was less as time passed but that DNA was still recoverable after 48 hours. They postulated that this loss might have been due to donor epithelial cells adhering more tightly to the receiver's skin or degradation of the donor epithelial cells or a combination of both. They opined that in any case the important issue, in this generation of relatively easy amplification of DNA was that the quality of the DNA recovered was likely more important than the quantity. The concluded that salivary trace evidence contains forensically significant quantities of DNA that is stable during the post mortem period over a reasonable amount of time.

1997 - Sweet, D., Lorente M, Lorente JA, Valenzuela A, Villanueva E; An improved method to recover saliva from human skin: The double swab technique, *J Forensic Sci,* 42(2):320-322.

Abstract: This paper completed by a Canadian Forensic Odontologist in collaboration with workers in Spain details a technique by which the yield of DNA recovery from saliva stains on human skin can be improved by as much as 9.3%. The technique detailed (use of a first swab moistened in sterile saline followed thereafter by a sterile dry swab) has become the standard of practice. It is the authors hypothesis that the moistened primary swab loosens the majority of the epithelial cells dried in the saliva stain and causes them to adhere to the cotton fibers of the swab and that when the second dry swab is applied, the newly rehydrated

epithelial cells are more readily picked up on the dry secondary swab. .

1999 - Sweet D, Shutler GG; Analysis of salivary DNA evidence from a bite mark on a body submerged in water, *J Forensic Sci*, 44(5):1069-72.
Abstract: Although this is technically a case report it is a valuable one in that it shows *in vivo* and also in a criminal case that salivary DNA can be isolated and developed such that it may be made useful to the criminal justice system. The authors of the paper present an intriguing case where a combination of metric and pattern analysis of a bite mark to suspect dentitions coupled with biological evidence in the form of a partially-developed DNA profile permitted the exclusion of three police suspects and did not allow exclusion of the suspect that was not known to police, was not a suspect at the time and who was convicted of the crime. The body of the deceased had other types of markings that might reasonable have been mistaken for bite marks (e.g. a marking from the heel of a shoe) but the odontologist correctly recognized that a bite mark was present and since swabs of this suspected bite mark were taken as part of the standard work-up – pattern and biological evidence became an individuating piece of evidence for excluding or not excluding police suspects. The concluded that "…it is clearly advisable for investigators to routinely swab for salivary DNA in bite mark cases, even when the amount of evidence available is thought to be minimal. The value of this paper is that it is analogous to fulfilling Koch's postulates (a renowned mechanistic theory of infection causation by microbes) in the bite mark field.

1999 - Sweet D, Hildebrand D; Saliva from cheese bite yields DNA profile of a burglar: a case report, *International J Legal Med*, 112:201-203.
Abstract: This case report by a recognized expert in the field of recovery of salivary DNA demonstrates that trace evidence of saliva can yield surprising results even in cases where very small quantities of DNA are deposited on sub-optimal substrates such as bacterial-laden cheese; where there is a delay in the time to recognize the substrate as evidence (36 hours); and where the substrate is stored for an extended period of time (10 days) prior to processing. The authors correctly conclude that bite marks in any substrate should be considered both physical and biological (trace) evidence and that DNA recovery should be attempted in any case in which even small quantities of saliva may be present.

2004 - Eichmann C, Berger B, Reinhold M, Lutz M, Parson W; Canine-specific STR typing of saliva traces on dog bite wounds, *International J Legal Med*, 118(6):337-42.
Abstract: This Austrian study is of interest because it examined the ability to discern animal from human DNA in *in-vivo* clinical cases, is one of the few to utilize bandages and swabs from acute wounds, and examined 52 cases. The authors did a pre-test with admixtures of canine and human DNA to validate their test. They determined the best location to gather DNA from the (dog) attacker was around the wound and within it – similar to human bite mark DNA collection. There was only minor bleed-through of human DNA peaks in the pre-trial verification that did not affect the result. The sample in the test cases were from actual dog attacks in Innsbruck over a 2 year period. Dog bite mark cases were sub-categorized into those with some blood, no blood and large amounts of blood. Overall 31% of the samples gave a full canine-specific DNA profile and 9.6% gave a partial profile whereas approximately 60% gave no canine profile. The latter were more likely to be less severe bite. The authors also postulated many people may have washed the wounds prior to this. Overall the report suggests if the location of the bite is known and the bite is severe enough and even using bandages and swabs similar to those used in human bite mark cases, DNA can be found.

This study is important because it shows the sensitivity of DNA for bite marks of known location – and for its ability to discern human from animal DNA in cases where there is either contamination or confusion as to what or whom did a bite. In either case collection of DNA is predicated on knowing in detail where a bite mark is located.

2005 –A nzai-Kanto E, Hirata MH, Hirata RD, Nunes FD, Melani RF, Oliveira RN; DNA extraction from human saliva deposited on skin and its use in forensic identification procedures, *Braz Oral Re,* 19(3):216-22.
Abstract: This study completed in Sao Paulo Brazil is not precisely a study of bite marks per se but rather an investigation as to whether DNA from a salivary source, when placed on the skin of volunteers and then collected after ten minutes and assessed for attribution of a "suspect" based on DNA recovery. The study lacks external validity in that no actual bites were produced. Further, restrictions were placed on activities of the saliva donors prior to their saliva collection that would likely differ from a real scenario. Finally they were able to isolate 4 of 5 donors and they stated that the recovery of DNA from saliva on skins was 10 to 14 times lower than from the saliva alone. This study would be very good if the question at hand was "can you paint saliva from rigidly-controlled donors onto the skin of a person and then recover it within 10 minutes?" Since that is almost never the situation in a bite mark this study is relatively useless.

2006 - Bowers CM; Problem-based analysis of bitemark misidentifications: the role of DNA, *Forensic Sci Int,* 159(Suppl 1):S104-9.
Abstract: This paper is a reflection of a single authors case experience. The author is a self-declared defense witness in bite mark cases and is also a lawyer. The author notes that the gold standard for bite mark analysis is the digital comparison of a dentition to a rectified (corrected) image set. This is not proven and, although it is more difficult to, for lack of a better word "monkey-around" with digital images it is eminently possible to change them with commercially available photo-manipulation software and a modicum of talent. The thrust of this paper is that DNA has exonerated *some* persons in cases where bite mark analysis by reputable experts had inculpated them. This is hardly news since at any trial involving opposing experts of any stripe an error rate of 50 per cent is a given. The author correctly points out that DNA provides a level of individuation not obtainable with traditional, and even advanced bite mark comparison techniques. This is a true statement and applies equally well to virtually all of the comparison sciences. The paper would have been more valuable had the author quoted cases where DNA was recovered from an actual bite mark and subsequently used to either inculpate or exculpate a suspect based on DNA gathered from a suspect bite mark. It is unclear whether the author has personally observed such a case.

2006 - von Wurmb-Schwark N, Mályusz V, Fremdt H, Koch C, Simeoni E, SchwarkFast T; Simple DNA extraction from saliva and sperm cells obtained from the skin or isolated from swabs, *Legal Medicine,* (Tokyo) 8(3):177-181.
Abstract: This German study details another method by which salivary DNA may be isolated by swab techniques. They report an ability to retrieve cells from skin moistened in extraction buffer and increased DNA yields. The study was an *in-vivo* one that utilized 20 micro litres of donated saliva painted on skin. No bite marks were made as part of this study. The study is essentially a technical refinement of other previously reported methods.

2007 - Ellis MA, Song F, Parks ET, Eckert GJ, Dean JA, Windsor J; An evaluation of

DNA yield, DNA quality and bite registration from a dental impression, *JADA*, 138:1234-1240.
Abstract: This American University-based study analyzed the DNA-retaining ability of a wax wafer. A secondary aspect of this study was to assess the ability to record the dimensions of the teeth. Curiously the bite wafers captured enough DNA to permit amplification but the dimensional accuracy – or perhaps the system of analysis of which the wax wafer was a part, was much less accurate.

2011 – Kenna J, Smyth M, McKenna L, Dockery C, McDermott SD; The Recovery and Persistence of Salivary DNA on Human Skin, *J Forensic Sci*, 56 (1):170-75.
Abstract: This experimental study was undertaken with male saliva donors whose saliva was painted on the skin of female volunteers. The authors noted that DNA from saliva is from the cellular component and mention that double swab and single-swab gathering techniques are equal in their ability to allow DNA detection. Specifically they examined the ability to detect and attribute DNA to a "suspect" immediately after painting it on skin, at 24 hours, 48 hours, 72 hours, and 96 hours. The skin was not washed during the collection period. Additionally they examined the ability to detect DNA from saliva transferred from recipient skin to clothing on various clothes. For DNA gathering the authors used both the double swab technique and the minitape recovery method. In eight of nine experimental set-ups salivary DNA from a suspect was recoverable from human skin up to 96 hours after its deposition. The concentration varied with the donor and over time. The tape-lift method was superior to the double-swab technique. The authors did not test whether various washing techniques would result in diminishment of DNA recovery since it was outside the scope of their study. Cotton and polyester were superior to other fabrics (e.g. leather) for recovery of DNA. This study is important because it shows conclusively that saliva deposited on skin is recoverable using conventional techniques up to 4 days following its deposition. From a bite mark standpoint it points to the utility of individuation of DNA samples deposited on skin or through fabric in the commission of a bite mark.

15. What is the literature to support digital image processing of bitemarks for bitemark analysis? What traceable standards exist for digital image processing of bitemarks and the literature to support this?

FROM DORION 1, BITE MARK EVIDENCE, DEKKER 2005

Naru AS, Dykes E. The use of a digital imaging technique to aid bite mark analysis. Sci Justice 1996: 36: 47-50.

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Johansen RJ, Bowers CM, Digital analysis of evidence photographs (bitemark): automated rectification of photographic distortion, resizing to life size, and rotation of images. AAFS, Atlanta, Feb 15, 2002

Dorion, RBJ. Bitemark Evidence, Marcel Dekker, New York; 2005 169-181

FROM DORION 2, BITE MARK EVIDENCE, CRC PRESS 2011

Dorion, RBJ. BM Evidence 2nd Ed., CRC Press, Boca Raton,FL: 2011 "Once digitized, the image can be corrected for rotation, size, and photographic distortion. The entire bitemark comparison and analysis can then be printed, demonstrated on computer, or projected via a laptop computer connected to an LCD projector." p87.
"If one is going to enter an overlay of teeth on a bitemark into court. it matters whether the overlay is the basis for the conclusion that there is or is not a match or if it is to be used merely to show the jury what the investigator has determined using some other technique." p113-114
"in certain circumstances the processed image is the basis for the conclusion. Measurements of tooth position or area of injury may be derived from a processed image and form the basis for a statistical match. In these cases, it will usually be necessary to demonstrate the scientific basis for the conclusion, the error of the measurements, and the validity of the processing method." p115

"While image processing focuses on modifying an image, image analysis focuses on extracting data and drawing conclusions from one." p115

"Image processing may make it easier to see the edge of a bitemark. Determining the distance between teeth or the classification of marks is image analysis. Like medical diagnosis, it is a cognitive function that combines both art and science." p115

"A forensic odontologist may not be allowed to testify about conclusions based on a processed image if he or she cannot demonstrate an understanding of the processing method and how it affects the features he or she uses in analysis. An expert on image processing may not be

allowed to testify about the meaning of the contents of a processed bitemark image if he or she cannot demonstrate competence in forensic odontology." p115

"bitemark analysis involves both objective statistical and cognitive analytical issues." p116
"There are no specific standards for image processing in forensic odontology: in fact, there are few such discipline-wide imaging standards within forensic science in general at the time of this writing." p116

"The fundamental guideline is that the degree of documentation should be sufficient to allow another similarly trained expert to arrive at a similar conclusion." p122Dorion

REFERENCES CITED IN DORION2:

SWGDE/SWGIT digital and multimedia evidence glossary version 2.3 (May 22, 2009) p8. "image processing is defined simply as any activity that transforms an input image into an output image is image ".p112 Dorion

National Policing Improvement Agency.2007. Practical advice on police use of digital images, p28. "Processing images generally involves adjusting the technical properties of the image and modifying the actual content to improve or change some quality of the image." p112 Dorion

Royal Canadian Mounted Police. Integrated forensic identification services standard operating guidelines(SOGs) 10: Enhancement of crime scene images. "The Canadian Royal Mounted Police generally refers to the SWGIT guidelines for definitions, but expands on comments regarding image enhancement for analysis(vie infra)."p112 Dorion. "Enhancements are intended to improve the overall appearance of an image or to extract hidden details within the image. Enhancements are not to hide anything from the courts and should only be performed on a copy of the original." p113 Dorion

Oliver, WR 1998. Image processing in forensic pathology. Clinical Laboratory Medicine 18 (1): 151-180. "While it is not described in the forensic odontology literature, in areas of investigation such as forensic pathology, image processing is often not the basis of the analysis but is instead used to create a collection or "space" of images that are processed using multiple methods and varying parameterizations." p114 Dorion ..."the analyst would be well advised to return to the original image and use it as the basis of his or her conclusions, except in certain circumstances. The image processing is thus used to increase sensitivity, but any analysis based on the processed images alone would also have a much lower specificity." p113-114 Dorion

Scientific Working Group on Imaging Technology. 2007. Section 1. Best practices for forensic image analysis. Version 1.6, p.1. "The SWGIT describe it as 'the application of image science and domain expertise to interpret the content of an image and /or the image itself in legal matters." p115 Dorion

The manual of photogrammetry, 4th ed. 1980. Quoted in SWGIT guidelines, section 12. Best practices for imaging practitioners of image analysis. Version 1.6, 2007. "In general, image-based analysis of bitemark evidence involves all of the tasks

within the general area of image analysis, including photogrammetry, image comparison, and authentication." p115 Dorion

Scientific Working Group on Imaging Technology. 2007. Section 12. Best practices for forensic image analysis. Version 1.6, p.9. "Some conclusions can be based on statistical criteria, while other conclusions are based on subjective criteria. Conclusions derived from photogrammetric analyses can often be reported in terms of statistical criteria. In contract, many conclusions derived from image content analyses are based on subjective criteria. The basis for, and uncertainty of, any conclusion should be reflected in the reporting." p116 Dorion

Marin-de las Heras S, Valenzuela A, Valverde AJ, Torres JC, Luna-del-Castillo JD. 2007. Effectiveness of comparison overlays generated with DentalPrint software in bite mark analysis. Journal of Forensic Sciences 52 (1): 251-156. "The most common use of image processing in bitemark evaluation is the creation of overlay images and image mixing and overlay." p116 Dorion

Kouble RE, Craig GT, 2004. A comparison between direct and indirect methods available for human bite mark analysis. Journal of Forensic Sciences 29 (1): 111-118. "The most common use of image processing in bitemark evaluation is the creation of overlay images and image mixing and overlay." p116 Dorion

McNamee AH, Sweet D, Pretty I. 2005. A comparative reliability analysis of computer-generated bitemark overlays. Journal of Forensic Sciences 50 (2): 400-405. "The most common use of image processing in bitemark evaluation is the creation of overlay images and image mixing and overlay." p116 Dorion

Sweet D, Bowers CM, 1998. Accuracy of bite mark overlays: A comparison of five common methods to produce exemplars from a suspect's dentition. Journal of Forensic Sciences 43 (2): 362-367. p116 Dorion

Miller RG, Bush PJ, Dorion RBJ, Bush MA, 2009. Uniqueness of the dentition as impressed in human skin: A cadaver model. Journal of Forensic Sciences 54 (4): 909-914. Epub May 26, 2009. "Simple Procrustes distances have been found to have limited value." p116 Dorion

Martin-de-las-Heras S, Tafur D, 2009. 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. Epub June 7, 2009. "three-dimensional models were created by the use of laser scanners of casts and impressions, although the comparison was done using two-dimensional projections and overlays." p116 Dorion

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Al-Talabani N, Al-Moussawy ND, Baker FA, Mohammed HA, 2006. Digital analysis of experimental human bitemarks: Application of two new methods. Journal of Forensic Sciences 51 (6): 1372-1375. "measure the relationship of features to a medial axis." p116 Dorion

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Scientific Working Group on Imaging Technology. 2010. Section 11. Best practices for documenting image enhancement. Version 1.3, p.3. " Documenting image enhancement steps should be sufficient to permit a comparably trained person to understand the steps taken, the techniques used, and to extract comparable information from the image. Documenting every change in every pixel value is discourage because it adds nothing of value to the analysis."

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17. What are the research needs in bitemark analysis and what areas of research should receive the highest priority?

    - Research into cognitive issues associated with bitemark analysis
    - Research into cognitive issues associated with "identification" forensics in general
    - Development of a valid model of human skin for bitemark research
    - Measurement of distortion in living human skin (or model) during injury
    - The uniqueness of the human dentition in three dimensions

18. What are the technical needs to advance the science of bitemark analysis?

    - Development of a database for studying the dental arch – shape, size, etc
    - Development of a portable/affordable scanner (laser/visible light) capable of recording the injury pattern from human skin – useful in other types of injuries as well
    - Development of a portable/affordable scanner (laser/visible light) capable of recording in three dimensions the dentition – may useful on other types of structure.

Approved for release by action of the ABFO Executive Committee, October 1, 2011 with the addition of the following statement:

The ABFO wishes to emphasize that the research models utilized to date in most studies mimic human bitemarks only in cadaver skin or in skin of anesthetized animals, no research links these models (and their findings) to human bitemarks in living human skin.