



REVIEW ARTICLE

An evidence-based methodology for the analysis and comparison of human bite marks in skin with teeth

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ABSTRACT

The limited scientific evidence in the analysis and comparison of human bite marks in skin with teeth demonstrates that distortion and cognitive bias are significant factors. The manuscript examines the extensive scientific evidence in the forensic sciences that utilise the visual comparison of crime scene evidence with reference material and how this may be applied to bite mark analysis and comparison. Specifically, the manuscript considers how the effects of distortion and bias may be limited by applying techniques used in comparative forensic science. A feature based analysis and comparison methodology is described and proposed that relies on an evidence-based rationale for the management of distortion and bias. The concept of the forensic significance of a bite mark determining whether or not the mark may be reliably compared with teeth is noted. The limitations of bite mark analysis and comparison are indicated.

Keywords: Bite mark analysis and comparison; Methodology; Distortion; Bias.

Introduction

Bite marks occur in a minority of forensic medico-legal investigations, usually because of humans biting one another. In the interests of science and justice, the controversy around bite mark analysis and comparison needs to be resolved. Due to the nature of skin and the action of biting, human bite marks in skin are distorted, partial representations of the biter's anterior dentition. The interpretation of ambiguous dental features in a bite mark involves subjective judgements¹ that are susceptible to cognitive bias. The unquantified degree of distortion in bite marks in skin and the unqualifiable influence of bias in the analysing odontologist create significant challenges to the reliable analysis of bite marks and comparison with teeth².

The manuscript examines and discusses the relevant factors in bite mark analysis and comparison, namely, dental uniqueness, distortion, forensic significance and cognitive bias. Research shows that the asserted uniqueness of the human anterior dentition is not applicable to the forensic analysis of bite marks in skin. The scientific evidence in distortion and cognitive bias is significantly limited compared to the extensive evidence supporting the forensic sciences that utilise the visual comparison of crime scene evidence with reference material. The application of techniques used in comparative forensic science limits the effects of distortion and bias, thereby, providing an evidence-based rationale for a methodology, termed, feature based analysis and comparison for the forensic investigation of human bite marks in skin. The current absence of scientific data prevents the determination of a bite mark's forensic significance that would support reliable comparison with teeth.

The stages of feature based analysis and comparison methodology are described for the forensic analysis of human bite marks in skin and comparison with teeth and the terms, predictive stage and comparative stage are introduced. The limitations of the forensic techniques of analysis and comparison are indicated.

The objective of the manuscript is to propose a feature based analysis and comparison methodology that provides reliability and validity in bite mark analysis and comparison.

Uniqueness of Human Dentition

Historically, the comparison of human bite marks in skin with teeth assumed the characteristics of the anterior dentition were unique and this asserted uniqueness was recorded in the bite mark³. Initial statistical research did not confirm the uniqueness of the human anterior dentition⁴. The study found that certain characteristics of the incisors and canines were inter-related and consequently, the products of their incidences could not be used to indicate an overall frequency. The finding, that certain features were not independent, meant the product rule could not be applied to the statistical assessment of dental uniqueness.

Statistical probability research concluded that a match of five anterior teeth in a bite mark would positively identify the biter exclusively⁵. However, the authors incorrectly assumed each tooth position was independent of the other anterior teeth and consequently, the calculation of overall probability relied on the erroneous application of the product rule to multiply the individual probabilities. Significantly, the tooth marks were recorded statically in wax to position tolerances of ± 1 mm and ± 5 degrees for each tooth. However, forensic bite marks are recorded dynamically in the incomparable medium of skin, rendering Rawson's tooth position tolerances inappropriate for bite marks in skin, thereby, invalidating the exclusive identification of the biter⁶.

A study using geometric morphometric techniques based on landmark data from the incisor and canine occlusal surfaces of 50 post-orthodontic casts, selected to have lower levels of individuality than the general population, found no two individuals with identical tooth morphology⁷. The limited study supported the notion of the individuality of the human anterior dentition and suggested that the product rule could be applied to the data.

Importantly, the study suggested that the unique features of the anterior incisal surfaces would not necessarily be transferred to a bitten substrate.

Research into the correlations and non-uniform distributions of the six anterior mandibular tooth positions in two sets of scanned dental models, found seven and 16 matches in the respective data sets, $n = 172$ and $n = 344$ ⁸. The results indicated that statements of dental uniqueness related to bite marks in an open population were unsupported and confirmed that the use of the product rule was inappropriate.

A systematic review of 13 eligible articles on the uniqueness of the human dentition found that uniqueness remained unproven⁹. A three-dimensional study of the incisal edges of 445 dental casts concluded that scientific evidence in support of the uniqueness of the human dentition was not observed¹⁰. The study noted that bite mark analysis should be considered carefully when the suspects present similar dental alignment and morphology.

The uniqueness of the human anterior dentition has not been proven to date. However, it is important to consider dental uniqueness in the context of forensic human bite marks in skin. The nature of skin and the action of biting determine that the medium and mechanism respectively do not support recording the mathematical tolerances of dental uniqueness. Consequently, the asserted uniqueness of human anterior teeth cannot be considered as a relevant factor in the forensic analysis of bite marks in skin and comparison with teeth.

Distortion of Bite Marks in Skin

Primary distortion occurs during the episode of contact between the teeth and skin; it consists of tissue and dynamic distortion¹¹. Tissue distortion is due to the visco-elastic nature of skin, distorting under pressure and reconstituting its contour when pressure is relieved^{12,13}. Dynamic distortion may be produced by the action of biting¹⁴. Every variation in force and movement during biting constitutes a potentially unique episode of contact between the teeth and skin. In cases of multiple contacts by a

single dentition, the resultant bite marks may exhibit significant variations in the type of tissue injury and incidence of identifiable features due to different episodes of contact¹⁵.

Secondary distortion arises after a bite mark is made in skin and may consist of time-related, posture and photographic distortion¹¹. Time-related distortion refers to changes in the appearance of a bite mark with time, in living and deceased victims. Posture distortion occurs when a bite mark is photographed in a body position that differs from the time of biting. Posture distortion may be minimised by recreating a victim's body position at the time of biting¹⁶. When this is not possible, it is suggested that bite marks are photographed in a range of positional possibilities¹⁷. Importantly, when the body position during biting is unknown, photographic superimposition comparison is meaningless¹⁶. Certain anatomical sites are susceptible to significant posture distortion, for example, female breast¹⁸ and limbs¹⁹. Photographic distortion is due to the angle of the film to the bite mark and body curvature²⁰. Ideally, a 90 degree angle produces parallelism between the camera and bite mark, with the planes of the rigid metric scale and bite mark being parallel and coincident²¹. The action of biting and the potentially unique episode of contact between the teeth and skin occur in three dimensions. Bite marks in skin are routinely recorded in two-dimensional images that demonstrate additional photographic distortion. The term photogrammetry is defined as the practice of obtaining reliable information about physical objects through the processes of recording, measuring and interpreting photographic images²². In practice, the photogrammetry of human bite marks in skin refers to processes that are routinely conducted empirically.

An unknown degree of distortion is intrinsic in bite marks in skin and may be produced by various factors^{12,16,21,23}. Distortion and its interpretation are the main factors in contentious cases²¹. The degree of distortion present in bite marks in skin is variable and unquantifiable¹¹. The absence of systematic statistical studies into distortion of bite marks in skin

prompted the application of established geometric morphometric methods^{24,25}; the studies found arch width as the principal variable in a bite mark.

The evidence that scaled photographs of human bite marks in skin are not scientific recordings of the biter's anterior dentition constitutes an enduring principle in the forensic techniques of analysis and comparison.

Forensic Significance of Bite Marks in Skin

Experimental research of bite marks in human skin is, by its nature, difficult to conduct and consequently, studies have mainly used artificial media or animal skin. The dentition that produced test bites in wax was recognised with a high degree of reliability by examiners; however, bite marks in non-vital pig skin demonstrated a much lower degree of reliability²⁶. Similarly, bite marks produced without movement in vital dog skin demonstrated a low degree of reliability by examiners²⁷. The ability of experienced odontologists to use computer-generated overlays on artificial bite marks in pig skin produced reasonable results, although the intra- and inter-examiner reliability scores were not strong²⁸.

Human bite marks in skin may demonstrate marked variation in appearance, from a mild bruise without identifiable features to a relatively detailed representation of the anterior dentition's biting edges. The recognition and interpretation of dental features determine whether the degree of correlation between a bite mark and teeth can be determined reliably²⁷. Clearly, the presence and identification of distinctive features in a bite mark is important^{29,30}. However, statistical research noted that classified bite mark characteristics on large sections of the population were unavailable³¹ and this statement remains true today. A scoring system designed to reflect the forensic significance of a bite mark numerically³², demonstrated a high degree of reliability between odontologists and the ability to differentiate between degrees of comparability²⁷. Furthermore, if a bite mark was analysed independently with a high level of agreement, this

supported the confidence level in the conclusions; this view echoed previous researchers^{29,33}.

Cases involving 49 bite marks that had been the subject of an appellate proceeding in the United States of America were examined; the bite mark evidence was part of the appeal hearing in each case³⁴. The study sample consisted of bite marks with low forensic significance scores; this was related to the contentious nature of the cases which introduced a degree of bias in the sample. This metric assessment demonstrated a clear relationship between the forensic significance of a bite mark and the experts' opinion. Marks of low forensic significance were more likely to result in disagreement between experts; conversely, marks of higher forensic significance were more likely to result in agreement. The study provided statistical evidence to support the hypothesis that below a certain level of forensic significance, a bite mark cannot be compared reliably. Furthermore, the selection of bite marks that were amenable to comparison due to high forensic significance and minimal distortion was proposed⁶. The authors considered the criteria essential for reliable bite mark comparison and reiterated the view that a level of forensic significance be determined, below which, bite marks should not be compared. This introduced the concept of qualifying criteria that, on completion of feature based analysis, would justify proceeding with comparison.

A bite mark severity and significance scale aimed to demonstrate and simplify the relationship between bite mark severity and the forensic significance of a bite mark³⁵. The value of the scale in determining forensic significance and in selecting a mark that was amenable to comparison with teeth was noted³⁶. Research to evaluate the forensic significance of bite marks using a standard reference scale such as the one developed by Pretty was suggested³⁷.

Cognitive Bias in Bite Mark Analysis and Comparison

Cognitive bias is a natural subconscious element of the human psyche²²; consequently, it is not

possible to consciously control bias when making a judgement, irrespective of professional training, qualification and experience. Cognitive bias is defined as a pattern of deviation in judgement whereby inferences about other people and situations may be drawn in an illogical fashion²².

Research on expert performance and decision making has been conducted in many branches of forensic science. Studies demonstrated that contextual information undermined the reliability of fingerprint experts making identifications^{38,39}. A meta-analysis of the two studies implied that the fingerprint experts' judgements involved a considerable degree of subjectivity⁴⁰. These findings are likely to apply to a forensic science that utilises the visual comparison of the crime scene evidence with the reference material, for example, bite marks⁴¹. Even the interpretation of certain complex DNA mixtures requires judgement that is subject to bias. The absence of biasing contextual information in a complex DNA mixture interpretation showed that confirmation biases may influence expert DNA analysts⁴². Cognitive bias has been demonstrated in many forensic science disciplines reflecting the challenges of forensic analysis⁴³.

Research has also demonstrated the significance of the sequence of information distribution in forensic science⁴⁴. Controlling the flow of task-irrelevant information to DNA analysts was referred to as sequential unmasking; the evidentiary samples were interpreted and completely documented before the reference samples were examined⁴⁵. Similarly, a procedure termed, Linear Sequential Unmasking (LSU), was suggested that required examiners to first examine the crime scene evidence and document their confidence levels before examining the reference material⁴⁶. Linear Sequential Unmasking specified a linear reasoning process, from evidence to suspect, that minimised bias by regulating the order of information transfer to the examiner, thereby ensuring decisions were based on crime scene evidence and task-relevant information. The rationale of LSU is due to the relatively low quality and quantity of information in

crime scene evidence being more ambiguous and susceptible to bias, compared to the reference material. Linear Sequential Unmasking ensures that crime scene evidence drives the comparative decision by limiting the potential for biased circular reasoning by working backwards from reference material. The limitation of cognitive bias in comparative decisions between crime scene evidence and reference material is clearly applicable to the analysis of human bite marks in skin and comparison with teeth.

Linear Sequential Unmasking is only applicable to the forensic comparison of crime scene evidence with specific reference material. Linear Sequential Unmasking-Expanded (LSU-E) was introduced to apply to all forensic decisions, not only comparative decisions⁴⁴. Linear Sequential Unmasking-Expanded specified that examiners should first form an initial opinion based solely on the raw data/evidence, devoid of any reference material or context, even if relevant. Only then can they consider what other information they should receive and in what order, based on its biasing power, objectivity and relevance.

The forensic techniques of bite mark analysis and comparison involve three components, crime scene evidence, reference material and odontologist. Cognitive bias may arise from a variety of sources in expert decision making⁴³. Certain types of crime scene evidence may contain potentially biasing information, for example, the type of tissue injury and anatomical location of human bite marks in skin can evoke emotions that affect decision making. Reference materials may bias the interpretation of crime scene evidence, for example, the dental casts labelled "suspect" are released first to the odontologist, enabling the reference material to drive decision making as opposed to the crime scene evidence; this disorder produces biased circular reasoning. Contextual information may bias the odontologist, for example, the nature and circumstances of the biting incident can evoke emotions that affect decision making. Base rate bias derives from the

odontologist's expectations generated from previous similar cases⁴⁷. Organisational factors may bias the odontologist in favour of the instructing authority⁴⁸. The odontologist's education and training can itself be a biasing factor. Many personal factors impact biases and decision making, especially when the crime scene evidence is ambiguous.

The examination and interpretation of the features in a human bite mark in skin and the comparison with teeth are cognitive processes, involving objective and subjective judgements^{37,49}. Of the various categories of cognitive bias that relate to specific aspects of a forensic investigation, contextual bias and confirmation bias are relevant to bite mark analysis and comparison with teeth. Contextual bias is the tendency for a consideration to be influenced by background information; contextual information may be either task-relevant or task-irrelevant⁵⁰. Confirmation bias is the tendency to test hypotheses by looking for confirming evidence rather than potentially conflicting evidence. Biasibility and reliability are significant factors in decision making⁵⁰. Biasibility refers to the effects of task-irrelevant contextual information and other biases on observations, interpretations and conclusions. Reliability refers to the consistency, reproducibility, repeatability of previous observations, interpretations and conclusions. Validity refers to the results being correct⁵¹. Inevitably, reliability is a prerequisite for considering validity.

The evidence supporting a biased judgement must be sufficient to form the judgement since a desired outcome cannot be rationalised with irrefutable, contrary evidence; this is precisely why ambiguous stimuli are particularly susceptible to confirmation bias and why many forensic judgements are subject to bias⁵². The term forensic confirmation bias was introduced to summarise the class of effects through which an examiner's beliefs, expectations, motives and contextual information influence the collection, perception and interpretation of evidence. The risks of cognitive bias in forensic science are lower when results are clear and unambiguous and greater when results

are complex, of poor quality and there is an increased reliance on subjective opinion²². Human bite marks in skin invariably demonstrate ambiguous features that render the forensic techniques of bite mark analysis and comparison with teeth susceptible to cognitive bias. This is referenced in the human tendency of seeing what one wants to see, inducing odontologists to over-interpret bite marks³⁶.

The absence of studies on the effect of cognitive bias in bite mark analysis, limits an assessment of the odontologist's evidence⁵³. Subsequently, a study demonstrated that bite mark comparisons were susceptible to contextual influences, although the mechanisms by which this occurred were unclear⁵⁴. Due to the lack of specific studies, the significance of cognitive bias in bite mark analysis and comparison has not been appropriately considered by odontologists previously. However, studies implied that fingerprint experts' judgements involved a considerable degree of subjectivity⁴⁰ and these findings were likely to apply to any forensic comparison of crime scene evidence with reference material, for example, bite marks⁴¹. The extensive research in the significance of cognitive neuroscience in forensic science is clearly applicable to forensic odontology.

The forensic investigation of human bite marks in skin and comparison with teeth requires a methodology that recognises, manages and limits the effects of bias. It is essential that the analysing odontologist recognises cognitive bias by accepting the subconscious nature of bias. In addition, it is recommended that the odontologist knows and understands the six fallacies of bias and eight sources of bias⁴³. The research in cognitive neuroscience established general principles to manage and limit the sources of bias in forensic science, including forensic odontology. The application of the principles to the forensic techniques of bite mark analysis and comparison results in an evidence-based methodology. Specifically, the proposed methodology manages and limits the effects of cognitive bias by firstly

examining the crime scene evidence, the bite mark, without the biasing power of knowledge of the reference material and contextual information.

Rationale for Bite Mark Analysis and Comparison

The nature of skin and the action of biting create a potentially unique, three-dimensional episode of contact that prevents the accurate and complete recording of the features of the anterior dentition in skin. Consequently, the asserted uniqueness of human anterior teeth cannot be considered as a relevant factor in bite mark analysis and comparison. Specifically, research indicated that statements of dental uniqueness related to bite marks were unsupportable in an open population⁸. Research also found that it was not possible to reliably differentiate between marks in human cadaver skin caused by similar dentitions⁵⁵.

Although the incidence of distortion in bite marks in skin is well recognised, it is not possible to quantify distortion in scaled, life-size photographs of human bite marks in skin¹¹. Research applying established geometric morphometric methods to marks impressed by teeth in human cadaver skin, found arch width as the principal variable in a bite mark thereby limiting the significance of conclusions based on arch width measurements^{24,25}. The studies were among the few in bite mark analysis that applied the types of systematic statistical methods common in medicine and the biological sciences. The studies were conducted under controlled conditions that contrasted with the additional factors in an actual biting episode suggesting that distortion in experimental bite marks was less significant than in forensic bite marks in skin.

The incidence of an unquantified variation in arch width results in distorted, scaled photographs of the bite mark. Clearly, the distorted, life-size bite mark photographs are scientifically incomparable with the non-distorted, life-size transparencies of the biting edges of the suspect's anterior dentition. Correspondence and non-correspondence in arch size and shape, between the superimposed

transparencies and photographs are meaningless and conclusions, either identifying or excluding the biter, are unreliable¹⁶. Additionally, the cognitive processes involved in superimposing transparencies of the anterior biting edges on the bite mark photographs exemplify confirmation bias due to the biasing power of viewing either correspondence or non-correspondence between the images. Human bite marks in skin are not scientific recordings of the biter's anterior teeth, consequently, the technique of superimposition based comparison is not scientifically valid and is biased, rendering the technique unreliable.

Research demonstrated the significance of distortion in human bite marks in skin and of cognitive bias in the odontologist conducting bite mark analysis and comparison. Clearly, it is not possible to either quantify distortion in a bite mark or to qualify cognitive bias in an odontologist. However, it is possible to limit the effects of secondary distortion and bias by applying a methodology based on the current scientific evidence². The rationale of the methodology, termed feature based analysis and comparison, derives from the evidence that distortion significantly alters the dimensions and shape of bite marks in skin while the individual features are relatively unaffected and from the evidence that bite mark analysis and comparison with teeth are techniques that are susceptible to cognitive bias.

The effects of secondary distortion and bias are limited by appointing two odontologists, evidence recording and analysing. The evidence recording odontologist is responsible for the preparation of the odontology productions, thereby, ensuring optimal standards are achieved and preventing contextual information reaching the analysing odontologist. The effects of bias are further limited by determining the order, timing of the transfer of contextual information and knowledge of the biter's teeth to the analysing odontologist. The next stage in the methodology is the examination, interpretation of the crime scene evidence i.e. the bite mark, and the preparation of a predictor of the

causal dentition's features, termed the predictive stage. The subsequent stages comprise the examination of the suspect biter's dental casts, followed by the comparison of the predictor with the dental casts' features, termed the comparative stage. Significantly, the linear sequence of stages is completed with no return to previous stages, ensuring that the unbiased interpretation of the crime scene evidence drives the feature based analysis by preventing biased circular reasoning. It is important to recognise that, even under optimal conditions, feature based analysis and comparison may only support limited conclusions in cases involving low forensic significance bite marks in skin due to the nature of the causal factors.

Feature Based Analysis and Comparison Methodology

EVIDENCE RECORDING AND INFORMATION TRANSFER

The effects of posture distortion and photographic distortion during the photography of bite marks in skin are limited by the evidence recording odontologist recreating the body position at the time of biting before positioning and holding the rigid, right-angled scale while supervising the photographer. This technique aims to produce optimal scaled bite mark photographs for analysis and comparison with a suspect biter's teeth. If the attendance of an odontologist is not possible, the photographer should be advised of the recommendations to achieve optimal scaled photographs. Important distinctions exist in cases where the body position at the time of biting was unknown and/or where the photography was conducted without odontologist supervision or advice. The resultant photographs will record an unknown degree of posture distortion and may also record photographic distortion.

Optimal photographs support the validity of the analysis and comparison techniques as opposed to suboptimal photographs that limit the validity of the techniques. The distinctions between optimal and suboptimal photographs are significant factors

in the analysis and comparison techniques, consequently, the status of the bite mark photographs is noted in the expert report.

Contextual bias and confirmation bias in the analysing odontologist are limited by the evidence recording odontologist being responsible for all case management with the instructing authority, supervising/advising bite mark photography, examining the suspect biter's dentition and obtaining impressions. This protocol enables the analysing odontologist to complete the examination and interpretation of the scaled, life-size photographs of the bite mark without the biasing effects of contextual information and knowledge of the suspect biter's teeth. The suspect's dental casts are only released to the analysing odontologist after completing a predictor of the causal dentition's features. This sequence allows the analysing odontologist to attest to the preparation of an unbiased predictor of the causal dentition.

The management of the sources of cognitive bias limits contextual and confirmation bias in the analysing odontologist. Important distinctions exist between limiting/not limiting all sources of contextual bias and confirmation bias and between determining/not determining the order, timing of the transfer of contextual information and knowledge of the suspect biter's teeth to the analysing odontologist. The distinctions are significant factors in the preparation of a predictor of the causal dentition and in the analysis and comparison techniques, consequently, the entire management of contextual bias and confirmation bias is noted in the expert report.

The attested production of an unbiased predictor of the causal dentition, limiting all sources of bias, determining the order, timing of the transfer of contextual information and knowledge of the biter's teeth support the validity of the analysis and comparison techniques. By contrast, the production of a biased predictor, not limiting all sources of bias, not determining the transfer of contextual information and knowledge of the biter's teeth limit the validity of the techniques.

INTERPRETATION OF BITE MARK, PREPARATION OF PREDICTOR OF CAUSAL DENTITION – PREDICTIVE STAGE

The human dentition demonstrates anatomical features that are classified as class characteristics and individual characteristics that may be evident in a bite mark. The representations of the class and individual characteristics of the anterior dentition form the basis of identifying the mark as a human bite mark and potentially identifying the causal dentition respectively.

The class characteristics of the maxillary and mandibular permanent anterior dentitions are related to the sizes and shapes of the teeth and arches. The incisors usually produce four linear/rectangular marks in the centre of each arc of marks. The mesiodistal crown dimensions of the maxillary permanent central and lateral incisors range between 8.1mm - 9.5mm and 6.1mm - 7.5mm respectively. The mesiodistal crown dimensions of the mandibular permanent central and lateral incisors range between 5.1mm - 5.9mm and 5.6mm - 6.4mm respectively⁵⁶. The canines produce either circular, triangular or diamond-shaped marks towards the end of each arc of marks. The adult male maxillary and mandibular inter-canine distances range between 30.7mm - 34mm and 23.5mm - 26.1mm respectively. The adult female maxillary and mandibular inter-canine distances range between 28.7mm - 33.6mm and 21.1mm - 25.1mm respectively⁵⁶. The shape of the anterior dental arch is normally described as a catenary curve. The actions of sucking and suckling produce marks in skin that also constitute class characteristics of human bite marks.

The class characteristics of the maxillary and mandibular deciduous anterior dentitions are related to the sizes and shapes of the teeth and arches. In cases involving bitten children, it may be necessary to consider the age of the biter by referring to the mesiodistal crown dimensions of the maxillary and mandibular deciduous central and lateral incisors and inter-canine distances⁵⁶. The biter's age may also be considered by referring to the first and

second transitional periods' data for the eruption of the maxillary and mandibular permanent central incisors, lateral incisors and canines.

The recognition and interpretation of the class characteristics represented in the bite mark photographs may support the statement that the mark is of a size and shape that is consistent with a human bite mark. The orientation of the bite mark, arch centre point, arch size and shape are determined by posing the following respective questions. Can the maxillary and mandibular arches be oriented in the bite mark? Can the arch centre point be determined? Can the arch size and inter-canine distance be determined? Can the arch shape be determined? The orientation of the arches is possible because the maxillary arch is usually represented by a larger arc composed of larger individual tooth elements. The orientation of a single arch representation is determined by the arch size and by the size and shape of the individual tooth elements. The arch centre point and arch size may be difficult to assess if the arch representation consists of an incomplete arc. The maxillary and mandibular arch representation is usually oval or almost circular.

The individual characteristics of the maxillary and mandibular anterior dentitions are related to the distinctive features of the incisors and canines. The teeth may be displaced and/or rotated. The incisal/cuspal edges may be distinctive due to function, fracture, restorative treatment, caries and developmental abnormality. The interproximal embrasures are important distinguishing features between adjacent teeth which may be spaced, for example an upper mid-line diastema.

The recognition and interpretation of the individual characteristics represented in the bite mark photographs concern the presence or absence, position, rotation and incisal/cuspal detail of each individual tooth element. The location of the mesial and distal incisal angles of incisors determines their width and centre point. The location of the cusps of canines enables the inter-canine distances to be measured. The cusps of first premolars are rarely

recorded. The petechial haemorrhages that are associated with the interproximal embrasures are a representation of the spacing between adjacent teeth. The absence of an individual element may be false; a non-injured space may indicate either an absent tooth or a deficiency in the incisal/cuspal level. The recording of an individual element may range from an indistinct mark to a detailed representation of the incisal/cuspal anatomy of a tooth. The number of individual elements recorded may vary from a few to almost a complete anterior dentition. The presence of clothing reduces tooth pressure on the skin thereby masking the detail of individual characteristics.

The representations of the class and individual characteristics of the anterior dentition form the basis for assessing the forensic significance of a bite mark. The distinctive individual characteristics of the incisal/cuspal anatomy are important factors in the assessment that relies on the analysing odontologist seeing, observing and interpreting the characteristics. The terms seeing, observing and interpreting are distinguishable; seeing is a photochemical excitation that produces a neurological experience; observing involves implicit reasoning of knowledge; interpreting involves explicit reasoning of knowledge⁵⁷. It is important to note that currently, there are no scientific data on the weighting of the factors that determine the forensic significance of a human bite mark in skin.

Due to the variable nature of multiple contacts by a single dentition and skin, the bite marks may exhibit significant variations in the type of tissue injury and incidence of identifiable features¹⁵. The soft tissue injury may consist of one or more types, for example bruise, abrasion, laceration and avulsion of the bitten tissue. The injury type may be indicative of the degree of causal force when the time of biting and the presence of clothing are known. The appearance of the injury may suggest an approximate timeline for biting to have occurred.

Analysis of the biting mechanism depends on the recognition and interpretation of the injury type and dental features. The presence of parallel linear

marks that are perpendicular to individual tooth elements is indicative of the movement of the biting edges as they scrape across the skin surface. Tooth scrape marks may demonstrate heaping of the epidermis at the point where the tooth movement stops. The appearance of tongue pressure marks and marks due to other mouth parts may be an indication of the nature of biting. The action of sucking may produce mild diffuse bruising in the centre of a bite mark due to reduced intra-oral pressure that can traumatise the capillaries in the embouched tissue. The presence of the palatal and lingual surface details of a biter's dentition is indicative of tongue pressure on the embouched tissue during suckling. The appearance of a butterfly-shaped mark is suggestive of soft tissue having been folded between the upper and lower anterior teeth. Multiple bite marks may be superimposed on one another because of successive episodes of contact at the same anatomical site.

The recognition and interpretation of the class and individual characteristics observed in the bite mark photographs enable the preparation of a predictor of the causal dentition's features. The preparation involves cognitive processes that are conducted iteratively, with intervening wash-out periods that allow the analysing odontologist to reflect on previous iterations, after a period of non-engagement. Iterations continue until the odontologist's reflections do not produce any additional interpretation of the bite mark's features. An iterative approach hypothetically supports the cognitive processes prepare a reliable predictor of the biter's anterior teeth. The predictor is completed prior to the analysing odontologist having any knowledge or sight of the suspect biter's teeth. The first viewing of the suspect's dental casts automatically precludes revision of the predictor due to the biasing power of viewing the dental casts. The subsequent comparative stages are driven by the crime scene evidence, followed by the reference material, thereby preventing biased circular reasoning. The attested adherence to the linear sequence of stages in the methodology, limits contextual bias and

confirmation bias in the analysing odontologist thereby ensuring an unbiased predictor of the causal dentition's features.

EXAMINATION OF SUSPECT BITER'S DENTAL CASTS

The examination of the dental casts commences after the attested completion of the unbiased predictor of the causal dentition. On receipt of the dental casts the analysing odontologist confirms that the casts conform to the accredited standards of dental stone and surface integrity.

The sizes and shapes of the maxillary and mandibular anterior teeth, arches and inter-canine distances are noted. The presence or absence, position, rotation and incisal/cuspal detail of the incisors, canines and first premolars are recorded; the teeth may be displaced and/or rotated. The individual characteristics and distinctive characteristics of the incisal/cuspal edges of the incisors, canines and first premolars are noted. The incisal/cuspal edges may be distinctive due to function, fracture, restorative treatment, caries and developmental abnormality. The levels of the incisal/cuspal edges of the anterior teeth are quantified relative to adjacent teeth. The width of the incisors' incisal edges and the interproximal embrasures are measured. The casts are manually articulated to observe the type of occlusion and record the overjet and overbite.

The examination of the dental casts is completed before the evidence recording odontologist's clinical notes and photographs are released to the analysing odontologist. This sequence ensures corroboration of the analysing odontologist's findings by the clinical examination notes and photographs.

COMPARISON OF PREDICTOR WITH DENTAL CASTS – COMPARATIVE STAGE

Adherence to the linear sequence of successive stages and the management of the sources of cognitive bias ensures that the comparison of the unbiased predictor with the dental casts is conducted blindly by the analysing odontologist. In effect, the linear sequence determines that the comparison of the crime scene evidence with the reference material occurs without the biasing

power of knowledge of the reference material in the first instance.

The predictor's class and individual characteristics are compared with the dental casts' anatomical features. The associative comparison includes the sizes and shapes of the maxillary and mandibular anterior teeth, arches and inter-canine distances: the presence or absence, position, rotation and incisal/cuspal detail of the incisors, canines and first premolars: the individual characteristics and distinctive characteristics of the incisal/cuspal edges of the incisors, canines and first premolars: the levels of the incisal/cuspal edges of the adjacent anterior teeth: the width of the incisors' incisal edges and the interproximal embrasures. The type of occlusion and degree of overjet and overbite are considered.

Ideally, the forensic significance of a bite mark is reflected in the predictor of the causal dentition. In empirical terms, marks classified as high forensic significance potentially enable relatively detailed predictors to be prepared; as the forensic significance diminishes, the ability to predict the causal dentition becomes more limited. The predictor's class and individual characteristics provide the basis for the associative comparison with the dental casts' anatomical features. The degree of comparability and/or incomparability between the features of the predictor and the dental casts provide the rationale for the analysing odontologist's opinions and conclusions stated in the expert report.

The applicability of bite mark comparison with teeth depends on the forensic significance of the bite mark. This introduces the concept of qualifying criteria to determine the level of forensic significance of bite marks in skin, above and below which, marks may and may not be reliably compared, respectively⁶. Clearly, research is required to determine the threshold level of forensic significance that would support reliable bite mark comparison.

Conclusions

Research shows that the asserted uniqueness of the human anterior dentition is not applicable to the forensic analysis of bite marks in skin and it is

not possible to reliably differentiate between marks caused by similar dentitions. The findings limit the scientific identification of the dentition that causes a bite mark in skin.

The scientific evidence demonstrates that distortion in human bite marks in skin and cognitive bias in the analysing odontologist are significant factors in the forensic techniques of bite mark analysis and comparison with teeth. A feature based analysis and comparison methodology is proposed that relies on an evidence-based rationale to limit the effects of secondary distortion and cognitive bias; the terms, predictive stage and comparative stage are introduced. A linear sequence of stages determines that the interpretation of the crime scene evidence occurs without the biasing power of knowledge of the reference material and contextual information. The limitations of the forensic techniques of analysis and comparison are indicated. Research is required to provide data on error rates and reliability of the proposed feature based analysis and comparison

methodology. Currently, there are no scientific data on the weighting of the factors that determine the forensic significance of a human bite mark in skin. Research is also required to determine the level of forensic significance or qualifying criteria that would justify the comparison of a bite mark with teeth.

The principle that scaled photographs of human bite marks in skin are not scientific recordings of the biter's anterior dentition renders superimposition based comparison scientifically invalid, biased and unreliable.

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