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Forensic Dentistry: 2. Bitemarks and Bite Injuries

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.

Clinical Relevance: Dentists should be aware of where bitemarks are most commonly found, and of their significance in cases of children, the elderly and spousal abuse.

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Introduction

Crime types

Bitemark injuries are found in some of the most serious crimes and may often be the only physical evidence available, especially in the late presenting living victim.[1,2] Crimes featuring bitemarks include abuse (child, spousal and elder), rape, assault, homicide, and exceptional cases such as bank robberies (where a suspect has held, for example, a cheque book between their teeth) can also be found in the literature. Owing to the serious nature of these crimes, investigators are keen to explore all the physical evidence and it is only correct that such injuries should be recorded, documented and described in terms of their size, location and severity. However, all bitemarks must be carefully examined and their forensic significance determined before any comparative analyses are undertaken.[3] The forensic significance of bitemarks is dependent on a number of variables and these are discussed in this article.

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Anatomical location

It is important that dentists, police officers, social workers, forensic pathologists and others involved in the criminal justice system be aware of where bitemarks are most commonly found. It is also important to remember that bitemarks can be both attack injuries (and therefore present on the victim) and defensive wounds (and therefore present on the suspect) and all individuals suspected of involvement in a crime against a person need to be examined for such marks.[4] A survey of 148 bitemarks was conducted in order to determine the anatomical areas most likely to be bitten; the results are shown in Figure 1.[1] Females were four times more likely to be bitten than males, and over 50% of the males in the study were the suspects in the case – reinforcing the need to examine carefully this group of individuals for bitemark evidence. Females were most likely to be bitten on the breast, arm and legs, and children on their genitals, legs and back. Most males were bitten on the hand, back or face.[1]

The anatomical location of a bitemark is also crucial in determining its potential to be analysed. If one considers that the breast is by far the most commonly bitten location, this presents a considerable problem. Breast tissue is highly mobile and easily deformed and therefore it can be difficult to determine the position of the breast during biting or the effect of the bite force on the deformity of the tissue and hence the injury.[5,6] Bitemarks on the arm and leg can be similarly affected, depending on their position at the time of biting.[5,6]

Presentation of bitemark injuries

Bitemarks will typically present as a semi-circular injury which comprises two separate arcs (one from the upper teeth, the other from the lower) with either a central area absent of injury, or with a diffuse bruise present.[7] It is not unusual to see only one arch of teeth on an injury and, if this is the case, it is most often the lower teeth that are present which relates to the mechanics of biting, ie the maxilla remains stable while the mandible moves until the teeth meet.[7] There are three main factors that influence the severity of a bitemark injury:

- The force by which the original injury was inflicted;
- The anatomical location bitten; and
- The time elapsed between infliction

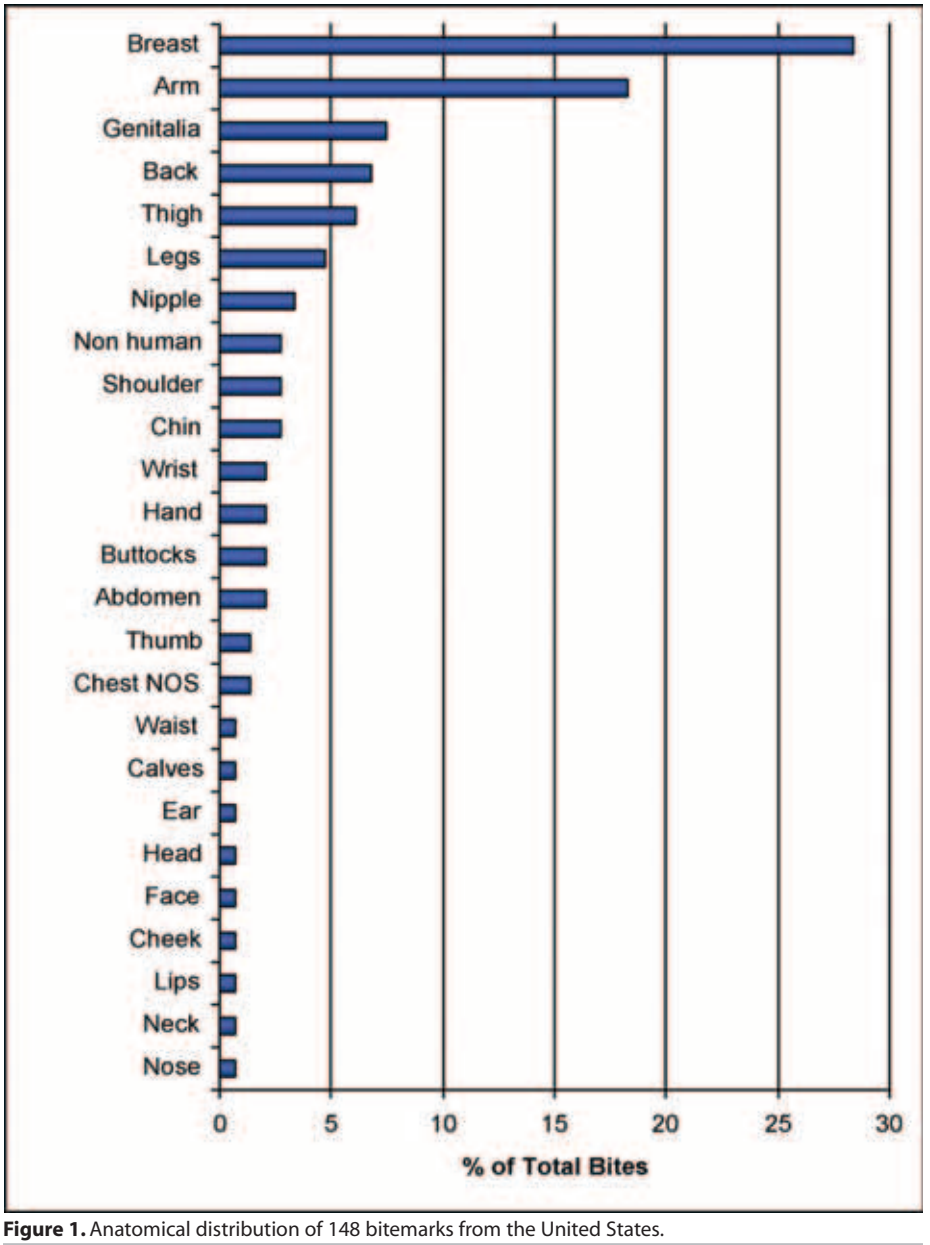


Figure 1. Anatomical distribution of 148 bitemarks from the United States.

of the injury and the presentation to the odontologist.

It is therefore possible to have a diffuse bitemark comprised only of faint bruising that may have been a severe bitemark but has presented some weeks after infliction.[8] The severity of a bitemark is an important factor within the assessment of the forensic significance of the injury and whether or not it can be compared with a suspect. Figure 2 illustrates the scale of severity and significance and Figure 3 presents illustrative examples of the index.

It can be seen from this scale that the most forensically significant bitemarks are those that fall in the middle of the severity scale, ie those that are too slight and those that are too severe rarely offer sufficient detail to be of forensic value. It is important to note, however, that a mild bitemark should not be considered a trivial injury. Any bitemark that is visible after more than a few minutes is likely to have caused considerable pain and therefore should be regarded as serious. In addition, any living individual who has received a bite that has broken the skin should receive medical attention as such wounds are highly susceptible to serious infections.

Collection of bitemark evidence

Two aspects of forensic significance have been discussed, the anatomical location and the severity. A third influence on the ability of the injury to be properly assessed is the quality of the evidence collection.[9] It is not unusual for forensic odontologists to be presented with evidence that has been collected in their absence, either because the case is being reviewed by them, for example in the case of a defence instruction, or as a result of the inability of the odontologist to attend the mortuary, hospital or custody centre.[10] It should be emphasized that it is always preferable that the odontologist attends if at all practical – the supervision of evidence collection ensures that this is of the highest standard.

Bitemark evidence is collected from both the bite victim and suspect, but it should be remembered that the bite victim could be the suspect in the case. In most instances the odontologist will collect the evidence from the bite suspect, as this involves techniques (such as impression taking) that can only be undertaken by a trained clinician. The American Board of Forensic Odontology (ABFO) has published guidelines that described the evidence that should be collected from both victim and suspect and they represent a sound basis for such collection. Deviations from these recommendations may be questioned and therefore it is the responsibility of the odontologist to inform, and possibly train, those individuals within their jurisdiction charged with the collection of such items of evidence.[11] The British Association of Forensic Odontology (BAFO, **www.bafo.org.uk**) have also developed broadly similar guidelines but these have yet to be published in the peer-reviewed literature.

Collection of bitemark evidence from the bite victim

The most important item of evidence from the bite victim is photography. Numerous photographs of the injury should be taken. Shots would include:

- With and without the ABFO No. 2 scale;

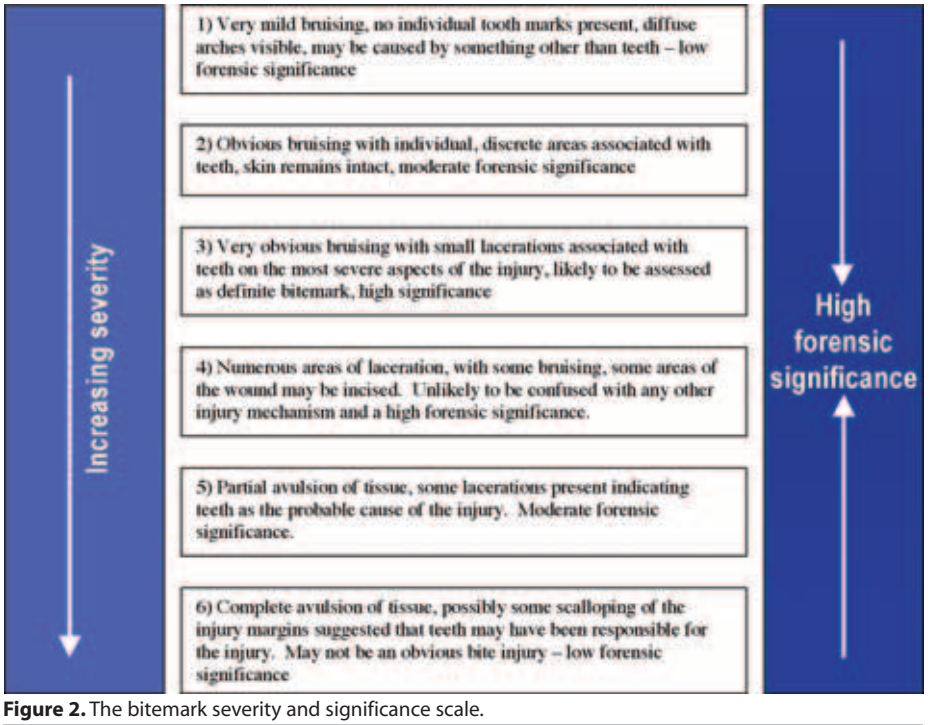


Figure 2. The bitemark severity and significance scale.

- In colour and black and white;
- On and off camera flash (oblique flashes can highlight the three-dimensional nature of some bites);
- An overall body shot showing the location of the injury;
- Close-ups that can easily be scaled 1:1;
- UV photography if the injury is fading;
- If the bite is on a moveable anatomical location, then several body positions should be adopted in order to assess the effect of movement.

All of the photographs should be taken with the camera at 90° (perpendicular) to the injury. It should be emphasized to forensic photographers that it is not possible to have too many photographs of an injury! It has been recommended that bitemarks are photographed at regular 24 hour intervals on both the deceased and living victim as their appearance can improve. Photographs of the bitemark will be employed in any subsequent analysis and therefore must be of the highest standard if the forensic significance of the injury is to be maximized. It is possible for a bitemark with high forensic value to be poorly photographed and thus lost as a valuable piece of physical evidence. Figure 4 demonstrates some common errors in bitemark photography and Figure 5 provides an example of a late presenting bitemark photographed under UV conditions. Figure 7 illustrates the impression materials that should be used for collecting impressions of the teeth and, if required, from the victim's skin. It should be noted that this is only undertaken when there is a great deal of three dimensional detail to the bite injury.

Following photography a number of other items should be collected:

- Dental impression of the victim – this is to exclude them as self-biting and for comparison to any bite injuries that may be discovered on a suspect.
- DNA swabbing of the injury site – this should be a double swab – the first moistened with distilled water and the second dry.
- Impression of the bite injury – this should only be performed if a significant degree of three-dimensional detail is present and, in the author's experience, rarely produces anything of analytical value.
- Skin removal – recommended by certain authorities as it permits trans-illumination of the bitemark but again has been shown to be flawed owing to skin contraction and therefore few odontologists practice this.

The role of this evidence in the ultimate analysis of the bite injury is described below. One interesting development in the collection of evidence from bite victims is the acquisition of 3D images of the bitemark. This is performed using specialist software, such as that produced by LuminIQ (LuminIQ, Seattle, Washington) and enables, by assessment of grey scale levels, a three-dimensional rendition of standardized images. An example of a bitemark processed in this way is shown in Figure 6. Further work is required to validate these techniques, but they may offer a means of demonstrating the depth of an injury without the problematic use of skin impressions.

Collection of evidence from the bite suspect

The collection of evidence from the bite suspect must commence only after proper consent has been acquired. Consent varies from jurisdiction to jurisdiction; in the UK, for example, the individual's consent is required before the collection of any intimate sample (dental impressions included), under the Police and Criminal Evidence Act (PACE), whereas in Canada a warrant can be obtained compelling the individual to provide such evidence. Once authority has been obtained, evidence collection begins, again, with copious photography. Shots that should be taken include:

- Overall facial shot;
- Close-up photograph of the teeth in normal occlusion and biting edge to edge;
- Photograph of the individual opening as wide as possible;
- Lateral view.

A thorough dental examination should be undertaken and a dental charting produced detailing the presence and condition of each of the teeth, as well as noting any recent dental treatments or dental modifications that have been undertaken.

The next stage is to take two high quality impressions of both the upper and lower arches. If the individual wears a dental prosthesis, impressions should be taken with this being worn and also without. The author recommends the use of poly-vinyl siloxane (PVS) impression material (Figure 7a), to be combined with plastic stock trays (Figure 7b). This enables the material to be poured and cast at a later time. The use of alginate materials is acceptable but they must usually be poured within 1–2 hours of the impression to prevent contraction. A further benefit of PVS materials is that they can often be poured multiple times should there be an error, for

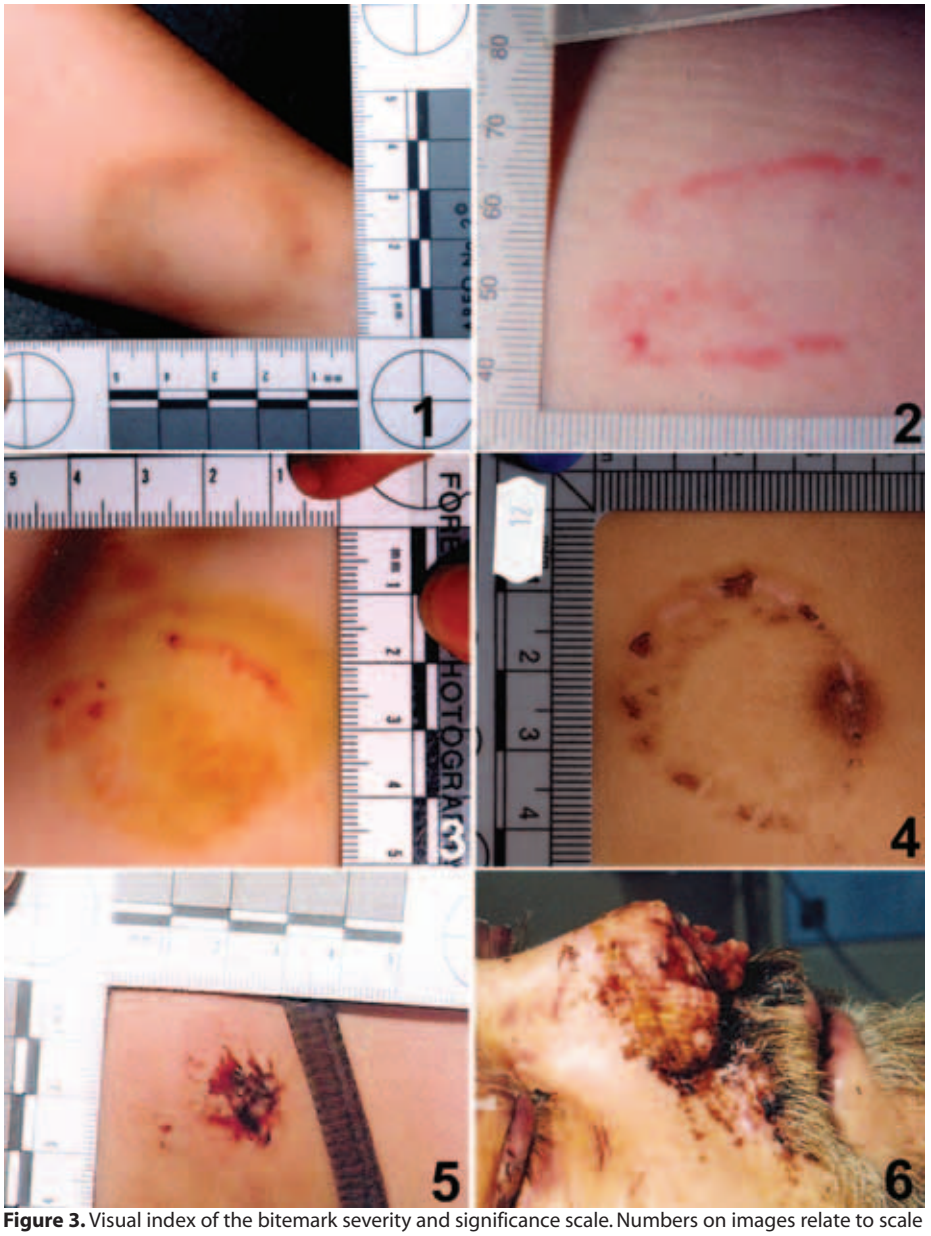


Figure 3. Visual index of the bitemark severity and significance scale. Numbers on images relate to scale shown in Figure 2.

example an air blow, in a cast.

An example of a set of dental casts is shown in Figure 8, which demonstrates the importance of multiple impressions if a suspect wears a removable prosthesis. A sheet of softened wax should be used to obtain an indication of how the individual bites together, providing an occlusal record (Figure 9). If indicated, a buccal swab should be taken of the suspect in order to obtain a DNA sample. In the UK, this will most likely be collected by the police during the normal booking procedure.

Analysis of bitemark injuries

The preceding sections have described the impact of a variety of factors upon the forensic significance of bitemarks. Only a bitemark that exhibits at least class characteristics of the biter should be analysed. This does not render the less significant bitemark worthless within an investigation. For example, if sufficient detail exists to identify the injury as a probable bitemark, this can be of assistance to investigators, especially in cases of child abuse where there may be several injuries that are ambiguous, ie may be accidental or non-accidental. The presence of a bitemark can often refute a parent or guardian's version of events; bitemarks are never considered accidental, although some injuries caused by teeth (for example a child accidentally strikes his/her parent in the mouth leaving tooth marks on the hand) may be.

The American Board of Forensic Odontology provide a range of conclusions to describe whether or not an injury is a bitemark. These are:

Exclusion – The injury is not a bitemark.

Possible bitemark – An injury showing a pattern that may or may not be caused by teeth, could be caused by other factors but biting cannot be ruled out.

Probable bitemark – The pattern strongly suggests or supports origin from teeth but could conceivably be caused by something else.

Definite bitemark – There is no reasonable doubt that teeth created the pattern.

The first stage of any analysis is to determine if the injury is a bitemark, and then to provide a statement on the forensic significance. If one or more suspect's dental casts are available, and the bitemark is suitable for analysis, then an overlay comparison can be conducted.

Pattern analysis in bitemark evidence

While metric analyses of bitemarks are a crucial stage within the analytical process, it is the assessment of the bite pattern that often serves to be the most revealing. Such analysis is usually conducted using a transparent overlay (Figure 10). Overlays are produced from the dental casts of suspects, and are a representation of the biting edges of the teeth reproduced on transparent sheets at life size.[12] The overlays are then placed over the scaled 1:1 photographs of the bite injuries and a comparison is undertaken. This process is highly subjective and has been the focus of much research, much of it determining that such analyses are neither reliable nor accurate, although this is very much dependent on the quality of the bitemark and the experience of the examiner.[13] If overlay analyses are restricted to those bitemarks displaying unique characteristics, the process, in the hands of an experienced odontologist, can be highly accurate. It is therefore crucial to the success of bitemark analysis that proper case selection is undertaken. Therefore, it would

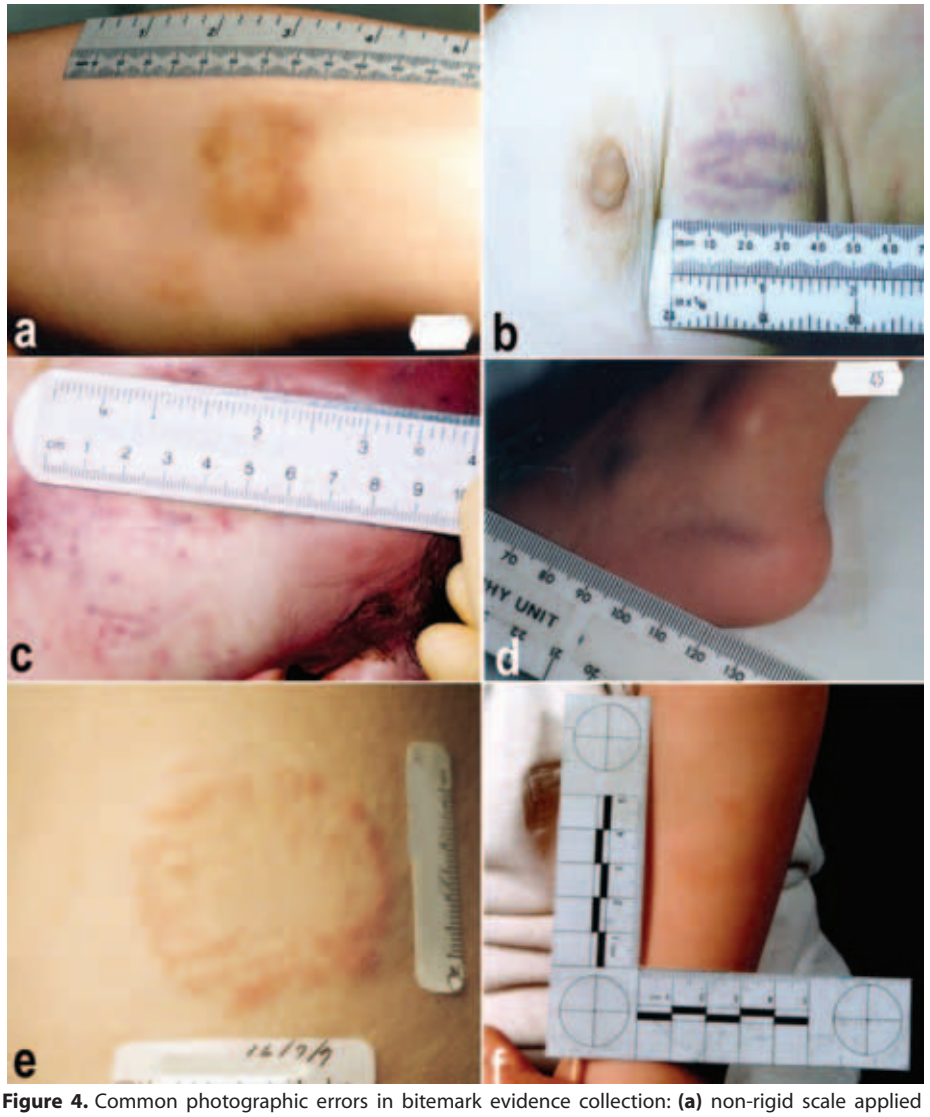


Figure 4. Common photographic errors in bitemark evidence collection: **(a)** non-rigid scale applied in inappropriate position on skin, no lateral element to the scale; **(b)** non-lateral scale that has been pushed into the breast tissue creating visual distortion; **(c)** non-lateral scale that is placed too close to the injury, possibly covering aspects of interest; **(d)** non-lateral scale held non-parallel to injury and poor illumination of wound; **(e)** focus is centred on an area in which there is no injury; as this is a curved surface numerous images would be required to correct for this. Inappropriate non-rigid scales; (**f**) a photocopy of the ABFO scale has been glued to cardboard – inaccurate.

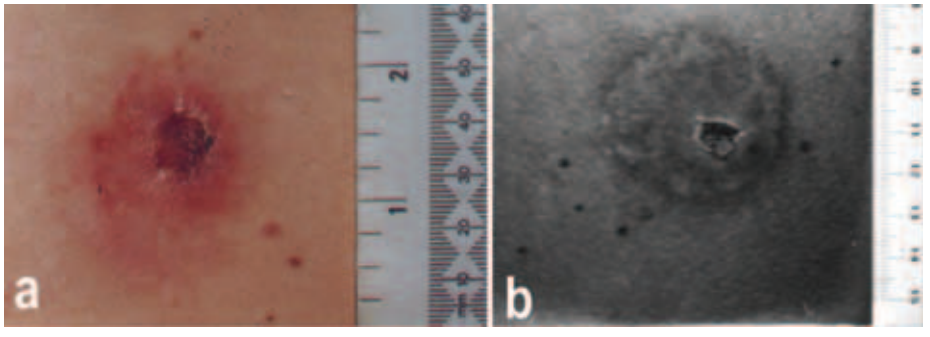


Figure 5. Example of UV photography on a bitemark some 8 weeks after assault: **(a)** injury photographed at presentation, living victim reports being bitten some two months earlier; **(b)** under UV conditions unique features of the dentition can be visualized.

be unwise to analyse an injury that was only determined to be 'possible', although there are always exceptions to these guidelines.[14] Many odontologists believe that bitemark analysis should only be used to exclude an individual, particularly if the evidence is not of the highest quality.

There are a number of methods for producing bitemark overlays and, again, these methods have been the subject of numerous research projects.[14] Two studies are described. The first assessed the five main methods of bitemark overlay production:

- Computer-based;
- Two types of radiographic;
- Xerographic; and
- Hand-traced.[15]

For many years, hand-traced overlays were the method of choice and these were slowly replaced by a photocopier technique. Sweet and Bowers determined that computer-generated overlays were by far the most accurate in terms of both tooth area and rotation. Given this, a number of different modifications of the computer-generated technique were developed and further research examined which of these was the most effective. Results demonstrated that both of the main techniques were reliable, and the choice of method was down to personal preference.[15]

However, while the overlay production method has been shown to be reliable, the application of these to the bitemark photographs, and the assessment of degree of match has not enjoyed as much scientific support. Again, a range of conclusions is available to odontologists to describe the results of a bitemark comparison: *Excluded* – There are discrepancies between

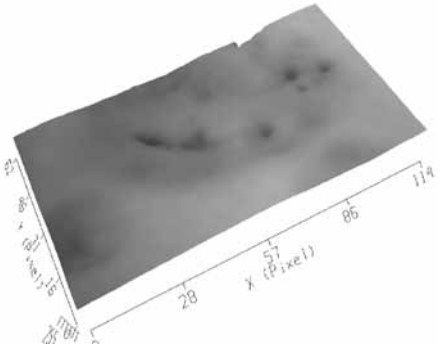


Figure 6. 3D rendering of a bitemark from a standard image.

Figure 7. Impression materials used in the collection of bitemark evidence: **(a)** impression materials including two grades (light and medium body) of poly–vinyl siloxanes and one of alginate; **(b)** stock impression trays such as these are appropriate for bitemark evidence collection.

the bitemark and suspect's dentition that exclude the individual from making the mark.
Inconclusive – There is insufficient forensic detail or evidence to draw any conclusion on the link between the suspect's dentition and the bitemark injury.
Possible biter – Teeth like the suspect's could be expected to create a mark like the one examined but so could other dentitions.
Probable biter – Suspect most likely made the bite; most people in the population would not leave such a bite.
Reasonable medical certainty – Suspect is identified for all practical and reasonable purposes by the bitemark – any expert with similar training and experience, evaluating the same evidence, should come to the same conclusion of certainty.

The second study examined the use of these conclusion levels with a series of 10 bitemark cases sent to experts in odontology. The results showed that the area under the ROC curve (a measure of sensitivity and specificity) was 0.8 (SD 0.18). However, at the level of 'reasonable medical certainty' the sensitivity was only 27.5%.[13]

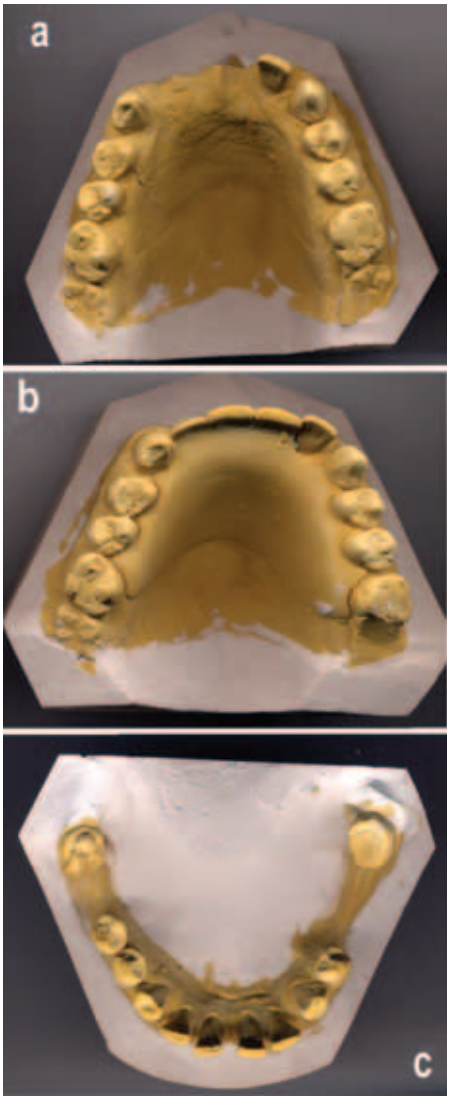


Figure 8. Example of stone casts produced from a bitemark suspect: **(a)** cast model of suspect's maxillary arch without dental prosthesis in place; **(b)** cast model of suspect's maxillary arch with partial denture in place; **(c)** cast model of suspect's mandibular arch.

The premise of these analyses is that human anterior teeth are unique and that this asserted uniqueness is replicated on the bitten substrate in sufficient detail to enable a match to a single individual to the exclusion of all others.[16] While in many cases this is possible, ie bitemarks of high forensic significance with good unique details, in the majority it is not and therefore caution should be taken when assessing any bite injury using pattern analysis. It should be remembered that skin is a poor bite registration material

Figure 9. Example of a wax bite obtained from a bitemark suspect.

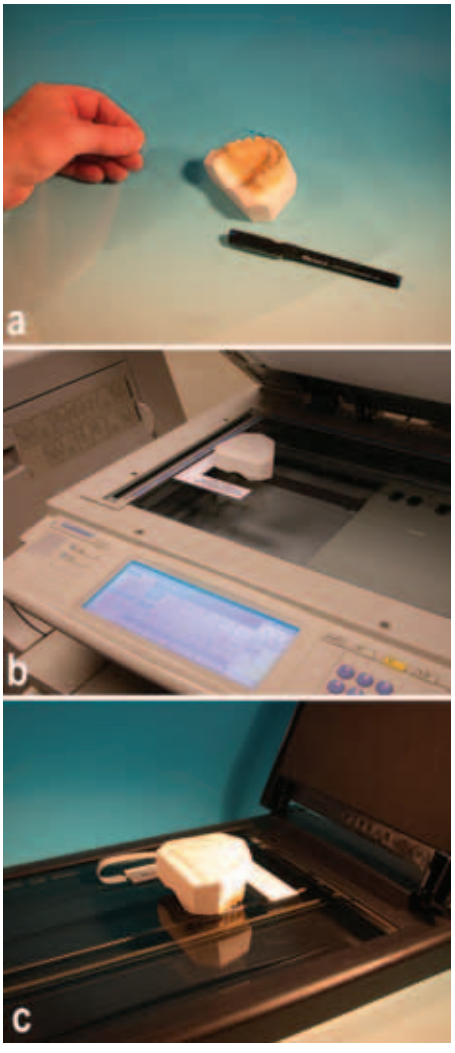
owing to its complex anatomy. A bitemark case example is shown in Figure 11.

Bitemarks and DNA

As with the introduction of molecular biology to dental identifications, the use of DNA in bitemarks was pioneered in an effort to eliminate the subjectivity associated with conventional analyses.[17] Much of this work was undertaken by Sweet, who investigated the deposition of saliva during the biting process and its collection over protracted periods of time from cadavers. In order to maximize the DNA collected, Sweet recommends that bitemarks should be 'double swabbed', the first swab being moistened with distilled water and the second being dry. It is thought that the wet swab rehydrates the salivary constituents, releasing more epithelial cells from the dried deposit.[18] Sweet has further used these techniques in numerous bitemark cases, with a good example being provided in the literature where a conventional bitemark comparison was undertaken followed by a DNA analysis.[19] The DNA was collected from a victim who had been in a fast running river for over 5 hours (Figure 12).

Other methods of analysing bitemarks

A number of additional, somewhat esoteric methods for bitemark analysis exist. A fundamental problem in the adoption of new technologies into bitemark analysis is the nature of the practitioners. Most forensic odontologists practice part-time, with the majority of their work taking place within private or hospital practice. Many do not have



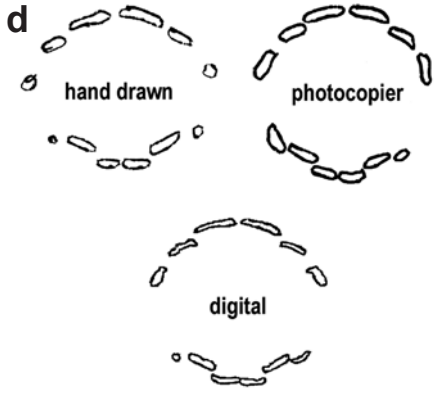


Figure 10. Overlay production methods and example of resultant overlay: **(a)** hand-drawn technique using acetate sheets and marker pen; **(b)** photocopier technique (note ABFO scale included to check scaling); **(c)** digitally scanning cast (note ABFO scale included to check scaling); **(d)** example of each type of overlay.

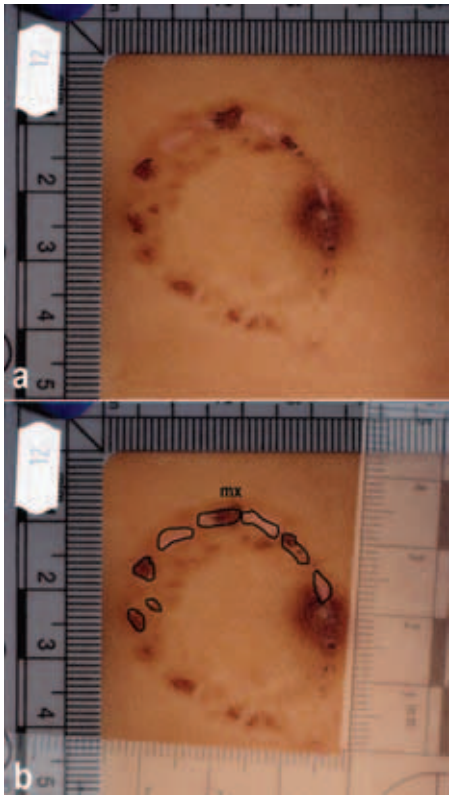


Figure 11. Bitemark case example: **(a)** photograph of bitemark demonstrating unique features of dentition therefore of high forensic significance – a positive bitemark; **(b)** the suspect's maxillary overlay (produced digitally) placed on the scaled photograph demonstrating a positive match for the unique features without any unexplained discrepancies. The suspect is identified as the definite biter.

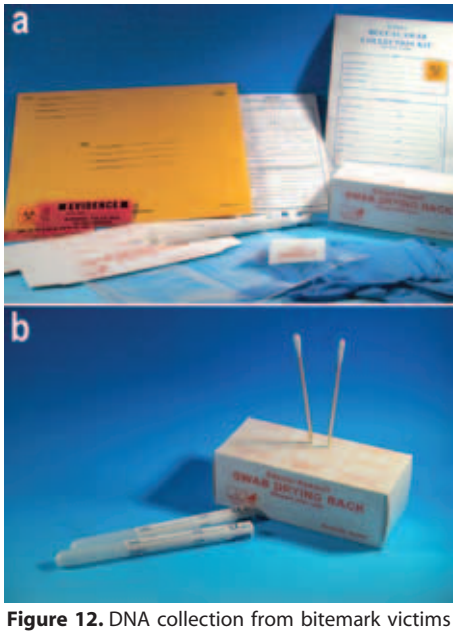


Figure 12. DNA collection from bitemark victims and suspects: **(a)** kit required for collection from either victim or suspect, including two swabs (for skin only, buccal suspect swabs require only one), gloves, card drying rack, evidence stickers, sealable plastic bag, documentation and evidence envelope; **(b)** example of a double swab being dried prior to placement in sealed evidence bag. Drying is a crucial stage and can take up to 30 minutes.

access to laboratories or extensive facilities that would enable them to implement methodologies such as DNA typing of bacteria or SEM analysis of bite wounds.[20]

While the recovery of salivary DNA has been reported as described above, the recovery of DNA is not always assured. It has been proposed that the presence of nucleic acid-degrading enzymes (nucleases) within saliva can rapidly degrade DNA, especially if it is on a living victim, as the skin's ambient temperature accelerates the process. This is perhaps why Sweet's double swab technique works; it collects DNA sequestered within the oral epithelial cells as a result of the re-hydration, rather than just relying upon pure 'salivary' DNA. However, accepting that limitations exist, researchers have investigated other markers that may be of discriminative value within saliva deposited during a bitemark. One such method is the recovery of bacterial DNA.[21]

The human mouth contains over 500 distinct species of bacteria, and every individual will have a slightly different combination, dependent on, for example, oral hygiene status, dental status and the presence or absence of a prosthesis. One research group has suggested that the genotypic identification of oral streptococci may be of use in bitemark analyses and, while accepting a number of limitations to the technique, have published findings which are encouraging. They assessed a single, experimental bitemark against 8 possible suspects. A total of 105 genotypes were isolated from these 8 individuals and none was shared, and the bitemark was correctly identified. Interestingly, the researchers resampled the volunteer suspects one year later and found that their genotypes had remained stable and the biter could still be correctly identified. Perhaps most importantly, the remainder of the suspects could be excluded.[21] The

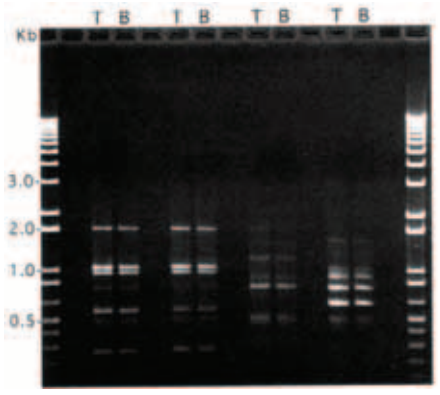


Figure 13. DNA profiled from oral bacteria. Comparison of AP-PCR products derived from four *Streptococcus* colonies isolated from a self-inflicted bitemark (B) with four from the lower incisors of the biter (T). Reproduced with permission from Dr J. Keiser.

Figure 14. Bitemark on non-human substrate, perishable items. Bites such as this should be carefully photographed, swabbed and then an impression should be taken to allow a 'docking' analysis to be conducted. Depending on the item, long-term storage in a freezer may be possible, for example in the case of cheese.

technique is therefore a valuable addition to the armamentarium of the forensic dentist, although its widespread use will be limited by access to the expertise and equipment to undertake it (Figure 13).

Bites on perishable items, non-human substrates

The previous sections of this article have concentrated on bitemarks on human skin, as this is by far the commonest bitten substrate that forensic dentists are asked to assess. However, bites can occur in many other substrates and case reports describe such things as apples (Figure 14),[22] cannabis resin,[23] sandwiches,[24] bank books, pencils,[23] pacifiers, Styrofoam cups, envelopes, and, of course, cheese.[23,25,26] The forensic value of bites in such materials is based upon the nature of the material itself, ie a bite in Styrofoam is likely to yield more information than one on bread, and cheese more so than on an apple and, in the case of perishable items, how long ago the bite took place and what steps were taken to preserve the object.[7]

A bitemark survey conducted by the American Academy of Forensic Sciences described Diplomates of the ABFO undertaking only 13 cases of bites on non-human substrates and only one of these was presented in Court.[27] Since that time a number of case reports have been presented where DNA was acquired from inanimate objects; impressively one from cheese and an item known to confound DNA analyses[28] owing to its bacterial content. So, while not a common undertaking, it is important for both investigative professionals and odontologists to be aware that bitemarks in inanimate objects can be of assistance in criminal investigations, although the same principle of bitemark assessment applies, ie that the bite must hold a high level of forensic significance before it can be considered for comparison to a suspect for the purposes of identification. The collection of a DNA swab from such items should always be considered and the double swab technique, with adequate drying and storage, should be the method of choice.[15]

The analysis of bitemarks on inanimate items varies. For example, in bitemarks on cheese, chocolate, or apples a 'docking' procedure may be undertaken. In these cases, the dental model of a suspect is applied to a cast of the bitten object to determine if they 'dock' or match. Such analyses are relatively simple, and are easily documented for presentation in court. Bites on flat surfaces, for example on paper, can be analysed using an overlay technique, as would be done for a bitemark on skin. The conclusions that are reached are the same as those for traditional bitemark analyses.

Conclusion

The field of bitemark science is expanding, and the need for individuals trained and experienced in the recognition, collection and analysis of this type of evidence is increasing. The often serious nature of the crimes in which bites are found dictates that the highest level of forensic standards should be applied and that analyses of such injuries should only be undertaken if unique or, in certain circumstance, class characteristics exist. Research into more objective methods of bitemark analysis has produced techniques such as salivary DNA recovery and bacterial genotyping, although further efforts to reduce subjectivity in standard physical techniques are required.

Acknowledgements

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