ODONTOLOGY

Contents

Overview

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Examination of the Mouth to Corroborate Identity

Starting from the premise that all forensic odontologists have a degree in dentistry, an examination of the oral cavity of deceased persons might be looked upon as a straightforward procedure. This is far from the case in many instances. Bodies requiring identification by odontological means are by their very nature often unrecognizable in a conventional way. This may be due to the effects of trauma, incineration, or putrefaction singly or in combination.

In extreme circumstances where a body or bodies have been badly burned, the first problem may be even to locate the head and the oral structures that remain. Large-format radiography, preferably real-time fluoroscopy, often has to be used to locate structures of interest (**Figure 1**). This problem obviously does not confront the dentist treating living patients.

Generally, oral structures that are useful in the corroboration of identity are preferentially preserved

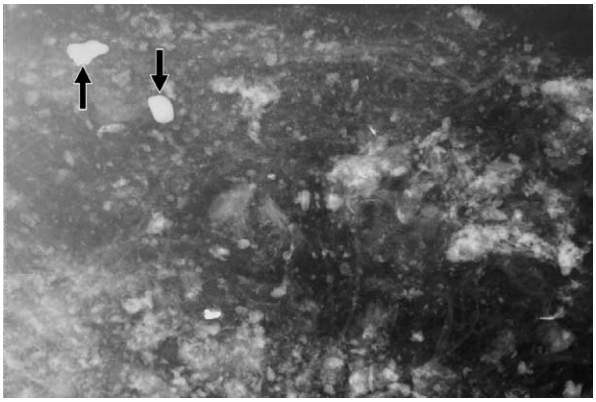

Figure 1 Large-format X-ray photograph (radiograph) of debris from a house fire in which some human remains were discovered. The two silhouettes (arrowed) are human teeth displaced from the corpse. Without this simple radiographic screening technique it may be impossible to find such small remains. Fortunately their very high density gives good X-ray contrast.

Figure 3 Teeth incinerated at high temperature for several hours. There has been some fragmentation of the teeth with enamel tooth caps lost from some of them. The bulk of the tooth is composed of dentine which has a similar composition to bone but is more highly mineralized.

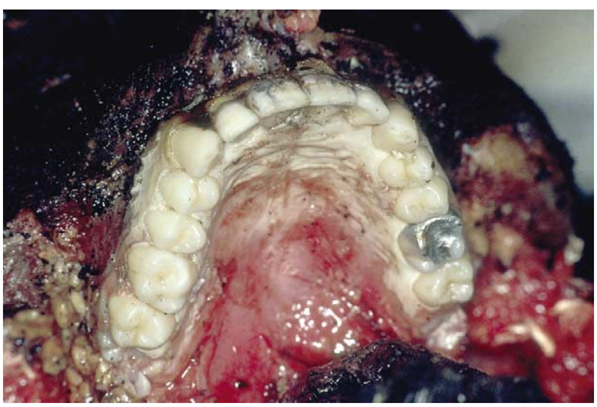

Figure 2 Badly burned body. All superficial soft tissues have been destroyed. Simple dissection reveals preserved teeth, dental restorations (a metal crown), and ridges in the soft tissue of the palate (rugae) which may indicate a racial affiliation or population of origin.

Figure 4 Badly burned jaws with the bone, that once covered the roots of the teeth, now destroyed.

during the destruction of a body by fire, hence the value of forensic odontology. The teeth are initially protected by the overlying soft tissues until they succumb to combustion. The heating of soft tissues often causes the tongue to protrude from the oral cavity (perhaps due to shrinkage of strap muscles in the neck) and for a time this too confers additional protection to the anterior teeth as the tissues of the tongue become fixed by heat covering the tooth crowns. The soft-tissue structures of the palate may also be useful features for identification (Figure 2). As the incineration progresses further, the soft tissues of the face and the protruding tongue are lost and then the facial surfaces of the teeth bear the brunt of the fire. Individual dental hard tissues are extremely resistant to heat, but the tooth crowns, comprising two different tissues, each of which responds to heating differently, quickly become friable as enamel cleaves from underlying dentine (Figure 3). Ideally, these fragments need to be located and collected at the scene of the fire so that the dentition may later be reconstructed as far as possible.

Eventually, as the bones of the jaws become exposed, they too begin to burn. As the outer plate of bone from the maxilla and mandible are lost the roots of the teeth are exposed and they too begin to be destroyed (Figure 4).

It is therefore important that body recovery teams have ready access to an odontologist who can identify orodental structures and stabilize them by wrapping so that fragile evidence is not lost at the scene or later dislodged, only to become lost or further reduced in size amongst the other contents of the body bag. If this precaution is not taken then a potentially positive identification can easily be thwarted. Crumbling tooth crowns can be stabilized with low-viscosity, quick-setting resins such as LocTite® or the more expensive dental fissure sealant. Burned heads should be bubble-wrapped and sealed with packing tape and bagged prior to any moving of the body. This will greatly enhance the value and efficiency of the dental examination, which will take place later in the mortuary. A further option to be considered is the *in situ* examination of the remains by the odontologist, but this does require adequate lighting and access to adequate dental instruments if the examination is to be conducted to the standard normally achieved in the mortuary setting.

At the mortuary, for a meticulous dental examination to be possible, it is very important to have access to high-quality illumination similar to that used in a dental surgery. Many materials used to restore tooth crowns are specifically designed to match the existing color and translucency of natural teeth and so can be very difficult to detect even under optimal conditions. Dental instruments used in a mortuary for autopsy work need to be more robust than those commonly used in clinical dentistry. In living subjects a great deal of interaction takes place between the dentist and the patient to optimize compliance and minimize discomfort for mutual benefit. In the postmortem setting not only is there no compliance, but also the tissues are often rigidly fixed due to the temporary effects of rigor mortis or the permanent effects of heat fixation of tissues. (Similarly, overenthusiastic cooling of the corpse to below freezing by mortuary staff also makes access to oral structures a practical impossibility for many hours, sometimes days.)

After discussion with the pathologist (who will probably wish to examine the body first) and the coroner, and with the feelings of the next of kin firmly in mind, a decision about the removal of facial tissues to gain access to the mouth needs to be taken. This decision should never be taken lightly. The final decision is often determined by the degree of disfigurement of the remains prior to autopsy. Obviously, incisions that would mutilate the face of undamaged bodies cannot be condoned. However, if a detailed, direct examination of the orofacial skeleton is mandated in such a case there are methods whereby the soft tissues of the face can be removed and replaced in a virtually undetectable manner. Such procedures require skill and take time – and time is a commodity that is often in short supply in the forensic context. The decision to dissect the face rather than remove damaged tissues to gain access needs to be carefully balanced between additional costs in time, any potential loss of trust by the community in the forensic practitioners involved, and the value of any benefits gained in additional forensic information.

If a body is very badly disfigured it has often been advocated that the jaws be removed to facilitate their more careful examination in a cleaner and more tranquil setting away from the distracting influences of bad odors and noise in the mortuary. Excision of jaws is simple and rapid, but cannot be achieved without destroying the maxillary sinuses. If the saw cut is too close to the crowns of the teeth the roots will be damaged and, if far enough away to avoid this problem in the maxilla, the paranasal structures have to be disrupted (Figure 5). So, whilst the narrow requirements of the dental examination may be made easier, features such as radiographic outlines of paranasal sinuses, which can be just as important for an identification, can be rendered completely useless. For this reason, provided that mortuary facilities in terms of lighting, ventilation, and adequacy of hand instruments can be relied upon, resection of the jaws should be avoided wherever possible. An additional argument against initial resection of the jaws is that at the time of the dental autopsy not all the antemortem records which may be available will have always been identified and located. This means that the best approach in the beginning should always be the most conservative and the least destructive.

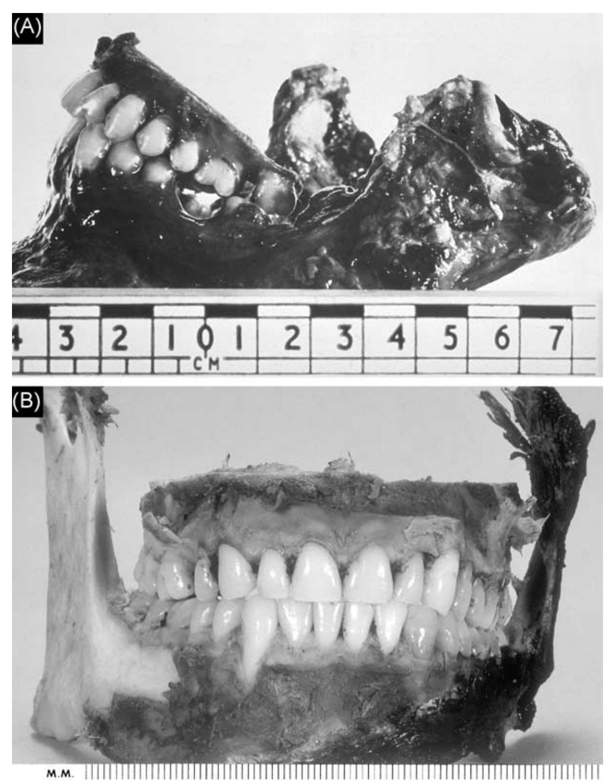

Figure 5 Resected jaws. The example shown in (A) was sawn too close to the teeth and the roots will have been damaged. Example (B) may have spared the tooth roots but has now destroyed paranasal sinus outlines which could have been useful for identification.

Should any organs be removed for examination elsewhere, an auditable continuity of evidence trail needs to be in place so that all organs removed for coronial purposes can be replaced in the body prior to its release for burial or cremation. Failure to observe this important point is highly likely to lead to the inadvertent retention of body parts, which then cannot be returned to the next of kin without causing additional distress and giving rise to more complications relating to the final disposal of tissues and organs.

As dental identification is essentially a comparative process, the form of the dental autopsy closely follows the conventions of a typical dental examination in a living person. This is because treatments or clinical findings recorded antemortem by the treating dentist are being verified or contradicted during the postmortem dental examination by the odontologist. In adults the dental autopsy records any teeth present together with any dental restorations or evidence, such as prepared cavities, that such restorations existed. It is common to find bodies in which restorative materials have either burned or melted from where they had been placed in the teeth. Nevertheless, the fine machining marks of the dental drill and the shape of prepared cavities can enable a reasonably comprehensive dental record still to be reconstructed, often sufficient for the remains to be identified.

With a temporal gap in the antemortem dental records prior to death it is quite possible that some additional restorations may have been placed in teeth, other existing ones enlarged, and some teeth extracted. If retrieval of all antemortem records is unsuccessful then these later modifications to the dentition will not be available for comparison. None of the unrecorded changes mentioned present an incompatible inconsistency when antemortem and postmortem records are compared. Furthermore, certain specific anatomical features or particular treatments like a single root canal filling or a fixed dental bridge may remain which, on their own, can provide ample evidence for individualization and matching (Figure 6). At the same time, teeth previously recorded as extracted cannot reappear during the postmortem examination. However, care has to be taken and clinical judgment exercised because not all dental charting is perfect and some teeth are often misidentified by the dentist when other teeth in that particular series of teeth are missing, thereby precluding comparison. This is a good example of where differences can arise between a specialist dental practitioner's opinion and that of an anthropologist who may have little knowledge of dentistry when looking at the same evidence. For a comprehensive interpretation the examiner must possess both the anatomical and anthropological knowledge of human tooth morphology and have an expert knowledge of dentistry and dental materials commonly employed in the treatment and repair of teeth.

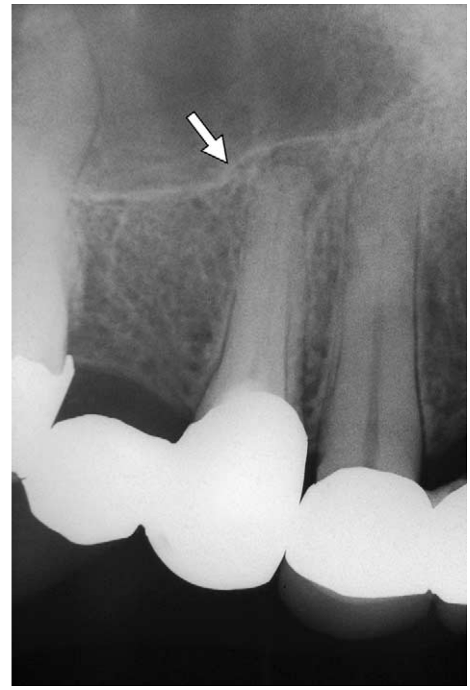

Figure 6 Radiograph of a fixed metal bridge (white). The shape of the roots present within the bone is seen. One has some pathology associated with the root apex. The floor of the maxillary sinus is seen as a thin white line (arrow) running just above the apices of the tooth roots.

Radiology

Dentists frequently take X-ray images of their patients' jaws and teeth and usually keep such radiographs as part of the clinical records. Additional larger radiographs requiring larger and more specialized X-ray equipment may have been taken elsewhere for the assessment of cranial anatomy in the context of an orthodontic assessment, or to assess the position of unerupted teeth such as third molars in young adults. These radiographs may be retained by the orthodontist or oral surgeon but may also have been given to the patient or his/her parents for safekeeping. As radiographs are so valuable to the identification process, it is important that agencies such as the police, who are frequently required to collect dental records on behalf of the coroner or other investigating authority, appreciate the need for early expert interpretation of any records obtained from any practitioner. Hidden in the clinical shorthand of the busy practitioner there is often a reference to other sources of

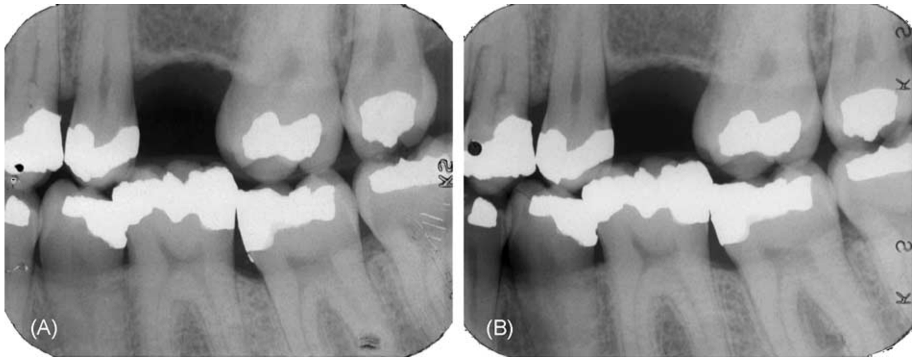

Figure 7 Intraoral radiographs (A) antemortem; (B) postmortem. There is an excellent match between the two images no matter which characteristics are compared. This is very good evidence to corroborate identity. Courtesy of Dr Richard Bassed, Victorian Institute of Forensic Pathology.

records but again, it may take a person with dental experience to appreciate this fully.

The most common dental radiographs are intraoral (Figure 7). These images are recorded on small packaged films which protect the contents from the oral fluids because the films are placed in the oral cavity inside the dental arches and the X-rays then directed at them from outside the mouth. These films, and their more modern digital equivalents, conveniently record the condition of tooth crowns and the periodontal tissues. Images, recorded at the quite high resolution needed to detect leakage of dental restorations and small carious lesions, contain a myriad of features which may be used for comparison (Figure 7). Unfortunately, the antemortem records may not match the quality of the radiographs recorded postmortem but the forensic scientist, like the archeologist or the paleontologist, has to work with whatever evidence is available. Some defects of poor or degraded antemortem images can be partially corrected by the careful application of image processing. Any improvements must be accompanied by the necessary audit trail so that others may reproduce the same transformations.

Extraoral films are larger and while being positioned prior to exposure are protected from the fogging effects of light by cassettes, many of which contain intensifying screens to optimize the performance of the film for the minimum radiation dose needed to record the image. It is these extraoral films that are commonly taken in specialist radiological centers. Lateral cephalometric films taken for orthodontic assessment and orthopantomograms taken more as a summary of the condition of the jaws and the position of the teeth within them (Figure 8) can be invaluable for comparative purposes. The lateral cephalometric radiograph often records the midline soft-tissue profile of the face. These features may be

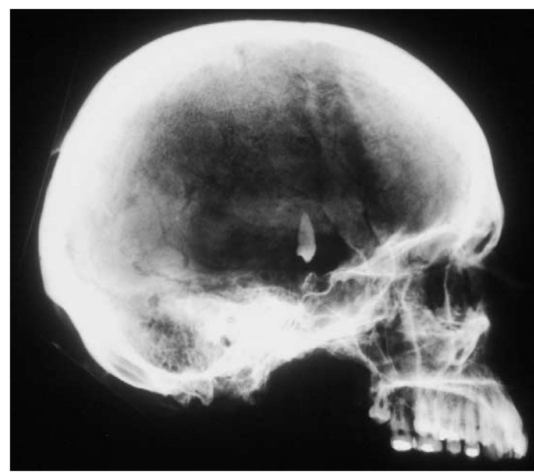

Figure 8 Lateral cephalometric radiograph. This postmortem specimen is unusual because it appears to shows a tooth inside the cranial cavity. This is due to postmortem displacement of teeth (the tooth is under the skull in the body bag) but images like this are sometimes seen when teeth have been displaced due to gunshot injury. Such radiographs reveal much about the anatomy and dimensions of the skull and these features can be compared with any similar preexisting antemortem images of a known person.

used as an aid to reconstructive anatomy and facial approximation methods used in forensic art which attempts to reproduce a likeness of someone in life from remnant skull evidence (Figure 9).

The use of dental implants to replace natural tooth roots to carry either a fixed or removable prosthetic superstructure like a bridge or denture is becoming a more popular, if still expensive, treatment option for some people in more prosperous societies. Implants are usually metallic and are therefore completely radiopaque, giving excellent silhouettes on radiographs. Postmortem images of implants within the jaws can be excellent for comparison with corresponding images taken at the time of surgery

Figure 9 Lateral cephalometric radiograph superimposed over a lateral view of a child's face. The relationship between the face and the underlying facial skeleton is revealed. An appreciation of these relationships is essential for reconstructive sculpting of faces upon remnant skull evidence.

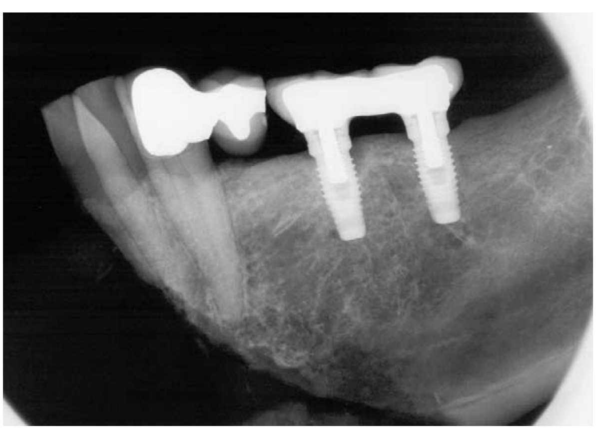

Figure 10 Endosseous implants. This radiograph shows natural teeth at the front of the mouth and metallic implants used to replace missing posterior teeth. There are many different designs of implant, each with its own silhouette. Images like this are unique.

or during healing to verify that osseointegration has occurred (Figure 10). The individualization and identification of remains where a putative identity has to be corroborated is aided by the wide range of implant systems which have found use to date. The durability of implants and their resistance to fire further add to their value as an aid to forensic identifications.

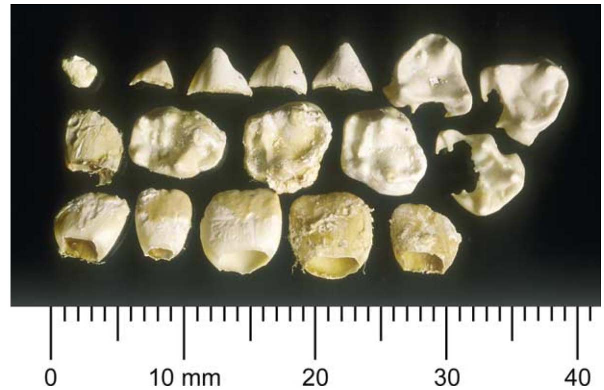

Figure 11 Deciduous tooth caps recovered from fetal remains. Gestational age can be estimated from the stage of tooth development.

Aging using Morphological Criteria

The determination of age from the dentition relies upon a balanced consideration of a number of factors, some related to the chronology of development, and some to physiological age changes which are much more susceptible to modification by customs, habits, and diet and which must therefore be given much less weight when all the available evidence is being considered together.

Prenatal Period

Aging of human remains in the prenatal period often cannot be separated from the corroboration of a human origin for skeletal remains. If the remains have been wrapped or enclosed in some way it is possible to recover most or all of the developing tooth caps which are easy to identify but which tend to become dislodged from the jaws after burial and later disinterment (Figure 11). As teeth develop in a known pattern and sequence, the chronology of tooth development can accurately age human remains in the prenatal period. Of course, osteological indicators of maturity should be cross-checked against the dental evidence but where there is a discrepancy, dental development, so vital to survival in times past, should be given more weight. The possibility of commingled remains or twins should always be borne in mind and the checks of number and symmetry always carried out.

The First Few Months of Postnatal Life

This period of human dental development still remains the one which least is recorded in the literature. For this reason it is illustrated here (Figure 12). The independent human is growing at its fastest

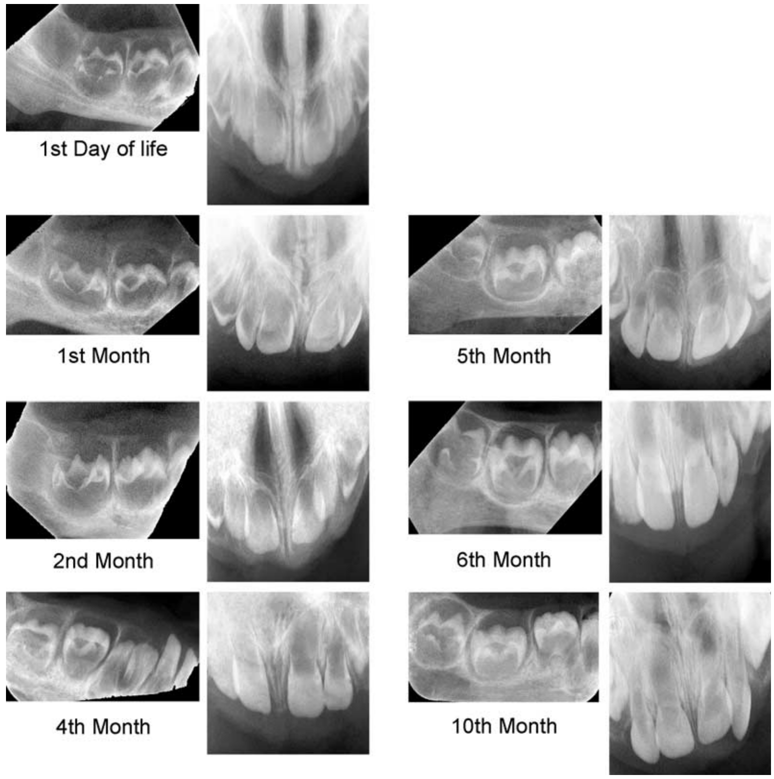

Figure 12 Radiographs of the stages of tooth development in the first 10 months of postnatal life. This period of tooth development has not previously been extensively studied and recorded. Each stage is illustrated by a radiograph of anterior teeth in the upper jaw and a corresponding radiograph of the posterior teeth for one quadrant of the mouth.

during this period. The jaws, so essential for nutrition and communication, develop rapidly but still amount to little more than a thin veil of bone enclosing the growing tooth germs of developing teeth. This period comes to an end about 6 months after birth when the first deciduous teeth emerge into the oral cavity. These are usually the mandibular central incisors.

Later Development of the Deciduous Dentition

The period of emergence of deciduous teeth into the mouth spans a period of about 2 years usually (but not invariably) beginning with the front teeth in the lower jaw. Since the third month *in utero*, some of the deciduous teeth have been forming within the jaws in bony crypts, yet tooth emergence does not begin until 6 months after birth. Similarly, root formation will continue in the last teeth to erupt for a period of another year or 18 months. This means that reliable criteria for age determination using the deciduous dentition alone may be available for examination for a period roughly twice as long as it takes for all the crowns of the teeth to emerge. The deciduous dentition should be considered as a transitional structure. The young child needs teeth during early childhood but those teeth would be inadequate for the demands placed upon them by the adult musculature.

The deciduous teeth emerge sequentially and in a pattern which approximates to the order in which their formation commenced, front teeth first with lower (mandibular) teeth often emerging just prior to their upper (maxillary) counterparts. Symmetry in tooth development within the jaws means that contralateral pairs of teeth emerge at similar times. Even the discovery of a few forming tooth caps allows the developmental status of the entire dentition to be reconstructed and hence an age at death inferred. Once all the deciduous teeth have formed completely it is much less reliable to estimate age using these features alone.

It is highly likely that the whole deciduous dentition never exists in its entirety at any one time. Just as the tips of the last deciduous molars are forming at the back of the mouth, the roots of the incisors, which formed much earlier, are beginning to resorb. Resorption of the deciduous dentition is an internal cell-mediated process whereby the hard tissues of the tooth roots and even some of the enamel of the crown of the tooth are degraded and solubilized. The process is phasic with periods of resorption being interposed with periods of hard-tissue repair. This occurs by the reformation of cementum, a bone-like tissue that normally covers the outer surface of tooth roots providing anchorage for the fibers of the periodontal ligament, the structure by which teeth are attached to the tooth socket. In living children who are shedding their deciduous teeth it is common to see teeth loosen as resorption shortens the tooth roots and then retighten as one period of resorption ceases and is followed briefly by cementum repair and temporary reattachment of the periodontal ligament. Each period of resorption erodes progressively more and more of the tooth roots until the tooth crown is eventually lost. This provides space in the jaw for the permanent successor. If the successional tooth is absent or displaced, deciduous teeth may be retained long into adulthood, but this is quite uncommon and would provide a characteristic which in itself would be individualizing.

When deciduous teeth are found with incomplete roots it is important to be able to distinguish between those teeth which are incomplete because their initial formation was interrupted and those teeth whose later resorption had begun because the two events occur at quite different periods in the life history of the tooth. It is also worth noting that teeth are often found which may simply have been fractured either antemortem or postmortem (even during recovery of the remains) and this can provide yet another example of teeth with incomplete roots. Generally good lighting and some modest magnification, either using dental surgical loupes or a dissecting microscope, are enough to be able to distinguish clearly between forming, resorbing, and fractured teeth (Figure 13).

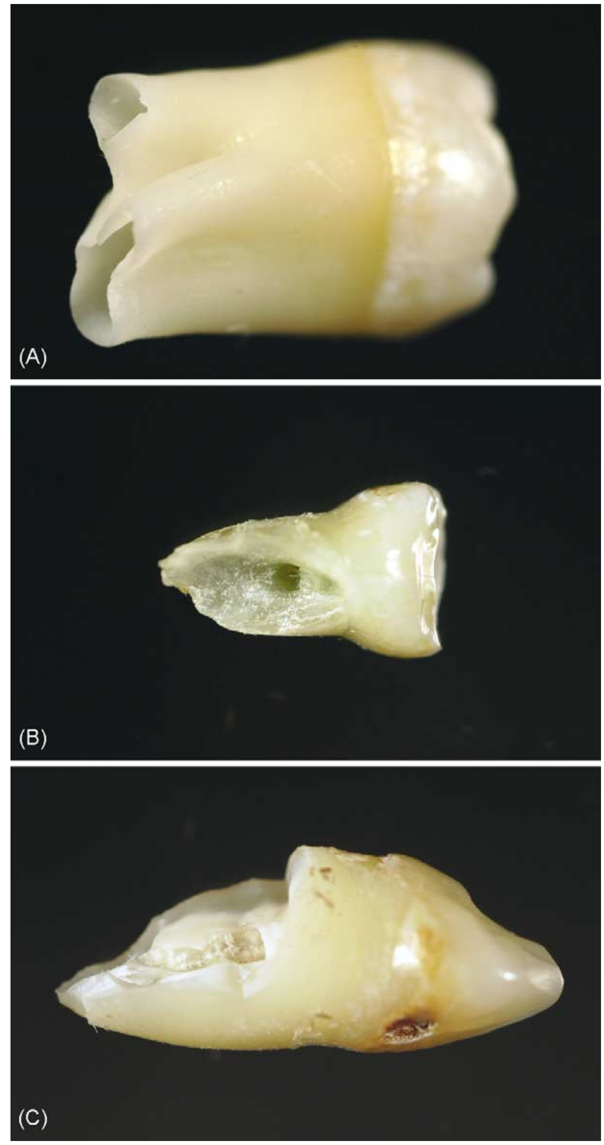

Figure 13 Teeth in three stages (A) forming permanent tooth root indicating that tooth formation was not complete at the time of death; (B) a resorbing deciduous tooth root prior to exfoliation or shedding; (C) a fractured tooth root. Such fractures can occur in life, perimortem, or postmortem during recovery of remains. Photos courtesy of Dennis Rowler School of Dental Science, University of Melbourne.

Mixed Dentition

At the age of 6 years all the crowns of the 20 teeth of the deciduous dentition remain in the oral cavity despite resorption of roots occurring within the jaws. Growth of the facial skeleton makes space for the first permanent molar to erupt at the back of the dental arch in each quadrant of the mouth, thereby enlarging the dentition. For the ensuing 5 or 6 years there is then a progressive complete replacement of deciduous teeth by their permanent successors (Figure 14). This process ends around 12 years of age when the permanent maxillary canines emerge. However, there is some slight variation in the pattern of replacement, often influenced by local factors such as tooth crowding, and so it may be the replacement of some deciduous molars which occurs last. Once the last deciduous tooth has been replaced the period of the mixed dentition comes to an end. Many studies of dental maturity have studied this period of human life, often using data obtained from radiographs. In some studies tooth development is divided into an arbitrary number of identifiable stages, whilst in others indirect measurement of tooth size from the radiograph is used as the growth parameter plotted against known age to obtain the necessary regression equations then used for the aging of unknown remains thought to come from the same population at the same period in history. Many of these studies are based upon concerns that data from one population may not apply to others but, in fact, interpopulation variation is quite small, perhaps another

Figure 14 A panoramic radiograph of the jaws (orthopantomograph or OPG) taken during the period of the mixed dentition. Some of the erupted teeth are deciduous and some are permanent. Within the jaws, under their remaining deciduous predecessors, several developing permanent teeth can be seen. These will still have incomplete roots for about 18 months after they have emerged into the oral cavity.

reflection of the imperative in past times for all humans to develop a functional dentition rapidly in order to survive.

Permanent Dentition

At the age of 12 or 13 years all the teeth present in the mouth are now permanent. It is around this age that the second permanent molars are added to the dental arches, bringing the number of teeth present to 28. Only the third molars or wisdom teeth remain to erupt between 17 and 25 years of age. These teeth are frequently congenitally absent or restrained from entering the dental arches due to lack of available space when they become jammed (impacted) against other teeth.

By the third decade of life most of the minor adjustments of the position of teeth within the dental arches to optimize alignment and fit of the teeth with one another are complete. After this period it becomes much harder to estimate age because the features which have to be used for this purpose are much more susceptible to modification due to environmental factors, some of which cannot be known or inferred when postmortem remains are being examined.

The consolidation of known progressive changes such as tooth wear, recession of soft-tissue attachment (i.e., “getting long in the tooth”), infilling of the pulp chambers with more hard-tissue deposition, continued accretion of cementum (an attachment tissue) around the apices of tooth roots, and increasing translucency of dentine (due to infilling of dentinal tubules with mineral) has been used to construct regression formulae from which age at death can be estimated. Such efforts were partially successful in Scandinavia in the mid twentieth century, probably due to the fact that Sweden still had a very ethnically homogeneous population at that time. Almost everyone enjoyed a similar high standard of living and education and probably ate a similar diet including constituents all prepared in a similar way. In essence the ethnic, cultural, and environmental influences that may affect the rate of change of structure in the teeth and jaws were largely controlled. Unfortunately, with greater mobility of peoples around the world in the late twentieth and early twenty-first centuries, such methods are of little use today.

Several later workers have striven to refine these early methods, but as might be anticipated, have had only partial success. However, of all the known changes with age, the increasing translucency of dentine is probably the least influenced by environmental effects and is likely to be the most physiologically regulated. Changes in the color of tooth roots with age have been studied and this color change may be related to the same changes in the optical properties of the dental tissues, which also give rise to translucency. Age estimation techniques based on color change alone have never found widespread application. The problem remains as to how to quantify the amount of translucent dentine deposited. Traditionally, teeth have been sawn lengthways to produce a longitudinal section which is then lapped down to a standard thickness (100 μm) when the proportion of the root length occupied by translucent dentine can be measured under a light microscope and plotted against known age. This method, whilst quite accurate, is subject to sampling errors. Once a section has been cut in one plane the tooth cannot be sectioned in another. Yet once the section has been cut the length of translucent dentine on one side of the root is frequently observed to be quite different from that on the other. Similarly, the acquisition of translucency may occur irregularly in zones which do not extend through the full thickness of the dentine and so are difficult to measure or estimate in terms of length. Hopefully modern technology will soon be able to provide a solution to this dilemma. High-resolution microcomputed tomography scanning is now becoming more available and is capable of quantifying mineral density in three dimensions throughout the entire domain of the dentine of the tooth. This will remove the sampling problems implicit in any two-dimensional method and should improve correlations between a progressive structural change in teeth and known age at death by permitting volumetric measurements of changes to dentine mineralization to be compared with the residual volume of still unaltered tissue.

Concluding Remarks

Despite advances in DNA technology, forensic odontology remains a very cost-effective and rapid means of confirming identity of deceased persons when teeth remain and antemortem records exist. This position is not likely to alter in the foreseeable future. These advantages come to have special importance in cases of mass disaster or in the investigation of mass graves after massacres following periods of civil unrest or warfare.

Similarly, dental examinations of living persons can be used to corroborate identity in cases where identity is disputed, such as in cases involving immigration authorities and questioned documents.

See Also

Anthropology: Bone Pathology and Antemortem Trauma; Morphological Age Estimation; **Crime-scene Investigation and Examination:** Recovery of Human Remains; **Fire Investigation, Evidence Recovery**; **Mass Disasters:** Principles of Identification; **Odontology:** Bite Mark Analysis; **War Crimes:** Site Investigation; Pathological Investigation

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Bite Mark Analysis

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Introduction

Bite mark analysis is currently an extremely contentious topic. For a subject with such potentially serious outcomes for both suspect and victim, little research in analyzing methods and evaluating outcomes is reaching peer-reviewed journals. Although admissibility of bite mark evidence has been explicitly established and routinely accepted in the USA and other legal systems for a long time, some odontologists argue that bite mark methodology has never really undergone critical examination and legitimately passed the “Frye” test for admissibility. Other legal observers are rightly concerned that forensic odontologists are giving insufficient critical attention to the quality of bite mark evidence presented to the courts.

In Australia, there are many uncertainties surrounding bite mark evidence. The natural tendency to see what one wants to see, thereby tempting examiners to overinterpret bite marks, has led to serious difficulties when bringing such evidence before the courts. Two pivotal Australian cases have seen bite mark evidence rejected as “unsafe” and convictions overturned on appeal. Perhaps for such reasons this area of forensic science is currently undergoing review and reevaluation. Generally, courts now look for quantitative rather than simply descriptive analysis before accepting scientific evidence and it can be anticipated that future developments in bite mark analysis will have to comply if convictions are going to be made with confidence.

Current Techniques

Collection of evidence from suspects may include obtaining impressions of their dentition, and their bite is analyzed from the resulting stone cast. This is a process where features of the suspect’s dentition are compared with impressions or marks left by the teeth on a variety of substrates, usually parts of the human body. A wide variety of techniques for bite mark analysis have been described in the literature, including computer axial tomography (CAT), scanning electron microscopy (SEM), video imaging, radiography, and the use of fingerprint powder to dust the impression. However, the predominant technique for comparison of exemplars is transparent overlays – analysis of the bite made using a 1:1 transparent overlay of the biting surface of the suspect’s dentition placed over a 1:1 photo of the bite (Figure 1). The five following commonly used overlay techniques are relatively cheap and the equipment and materials are easily obtainable:

1. computer-based (Figure 2)
2. radiopaque wax
3. hand-traced from wax
4. hand-traced from study casts; used in the Carroll and Lewis cases (see below)
5. xerographic.

With an abundance of methods and no standard agreed tests of their effectiveness, the analysis of bite marks and the consequences of presenting questionable bite mark testimony to the courts will continue to promote skepticism. The following two Australian

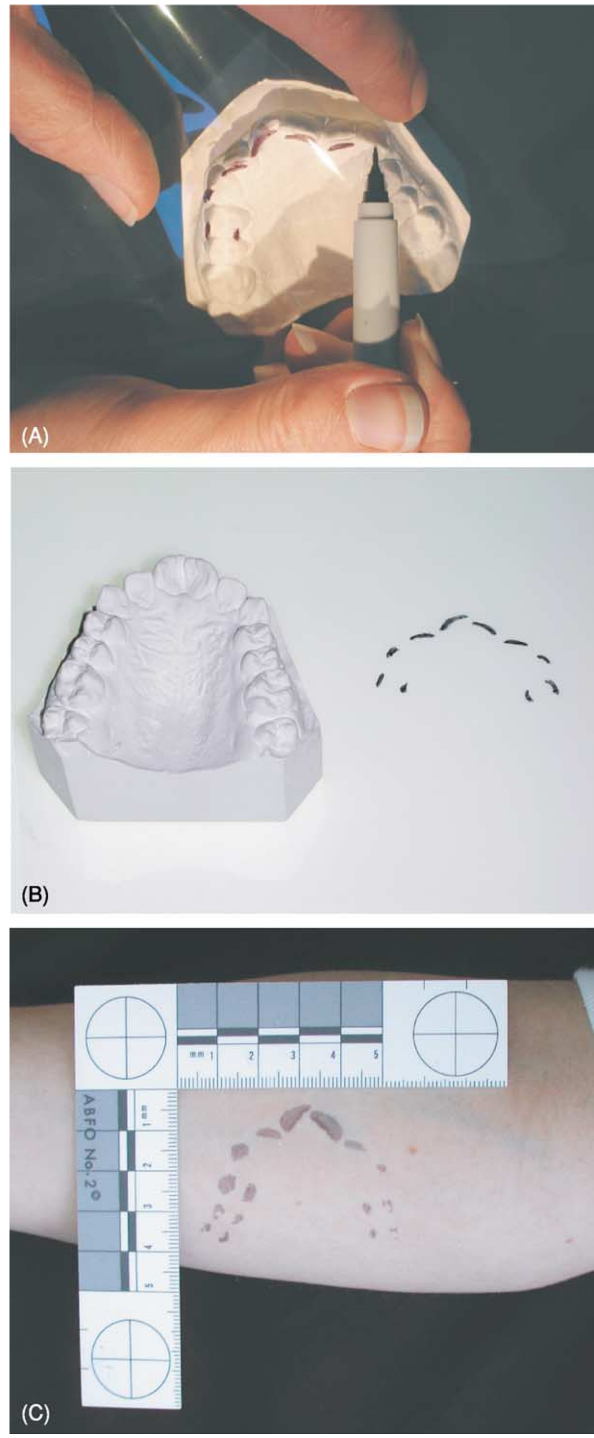

Figure 1 Historical method of bite mark analysis, hand-traced from study casts on to acetate sheet to provide overlay to be used for comparison with either photographs of injury at life size or directly with the wound: (A) highlighting of incisal edges and cusps with pen on to acetate; (B) tracing and model of suspect compared; (C) photograph of bite mark simulated using inked model shown in (A) and (B).

Figure 2 New method of bite mark analysis, computer-based overlays. In such cases the characteristics of the biting edges of the teeth have been highlighted from models scanned on a flat bed scanner using simple image processing techniques (i.e., lasso tool in Adobe® Photoshop®. Refer to Digital Analysis of Bite Mark Evidence using Adobe Photoshop by RJ Johansen and CM Bowers.).

cases remain controversial, and illustrate the issues at hand.

Two Australian Cases – Grounds for Concern

Raymond John Carroll v. *The Queen*

In 1973 a 17-month-old girl, Deidre Kennedy, was abducted, raped, and strangled and her body, dressed in women's undergarments, was discovered on top of a toilet block in Ipswich, Queensland. A bruise was found on her inner thigh just above the knee. This mark was identified by a forensic odontologist as being inflicted by human teeth. The odontologist went on to say that it would be "impossible to establish the identity of the biter."

Just under 9 years later another offense was committed in Ipswich at the women's quarters of the Royal Australian Air Force (RAAF) base. Items of ladies' underwear had been stolen and found vandalized along with pictures of scantily dressed women. Suspicion fell on Raymond Carroll, who was stationed at the RAAF base at the time. As both cases involved deviant behavior with women's clothing, Carroll became a suspect in the earlier murder of Deidre Kennedy.

In October 1983, 10 years after the Kennedy murder, casts of Carroll's dentition were made. The casts were then altered by an odontologist, based on dental records, in an attempt to recreate features obscured or altered by dental treatment in the 10 years since the child's murder. Comparisons were then made between a hand-traced overlay of Carroll's altered dentition and a photograph of the bruise on the child's leg. The bite mark evidence was examined by three odontologists who testified at the 1985 trial "that the bite-mark was made by the accused Carroll and no other." Subsequently the jury found Carroll guilty, largely on the unanimous conclusions of the three odontologists.

Carroll appealed, and in November 1985 the appeal was upheld and Carroll acquitted. The determination was based on the grounds that the judges of the Court of Criminal Appeal considered the evidence given by the three odontologists, although coming to the same conclusion, contained too many inconsistencies in methodology. Two odontologists associated the upper bruise pattern with all four upper central teeth, while the third associated the bruise with three of the four central teeth. Further, two odontologists associated the upper bruise pattern with the incisal edges while another with the palatal edges. One odontologist associated the lower bruise pattern with all four lower central teeth while the other associated it with only three of the lower central teeth. The judges concluded that a verdict based on this evidence would be unsafe, and because the original bite mark evidence had been pivotal to the case there was, therefore, no need for a retrial.

Twenty-seven years after the murder of Deidre Kennedy, police revisited the case in 2000 and reexamined the bite mark evidence. In highly unusual circumstances, Carroll was charged with perjury in relation to his 1983 murder trial. This reexamination of the bite mark evidence employed a new technique that involved three-dimensional imaging of a cast of Carroll's dentition. A computer model of Carroll's dentition was created by superimposing sequentially photographed layers of the cast as it had been gradually immersed in opaque ink. During biting, the teeth impinge on the skin at nonperpendicular angles, so the investigators estimated this angle. The immersion was then performed with the cast on this angle, generating a contour map that would reproduce the different contributions of individual teeth to the bite pattern. Numerous odontologists were consulted who testified to the reproducibility of this new scientific method and its acceptance by their discipline. The Supreme Court in Queensland deemed the evidence admissible and Carroll was convicted of perjury. However, at a later appeal the court concluded that to have brought a perjury charge before a criminal court in this case had been in conflict with the double-jeopardy principle of the common law and was an abuse of the process of the court. This decision, made almost 20 years after Carroll first became a suspect in the child's murder, gave him freedom and guaranteed his liberty.

Lewis v. *The Queen*

In 1986, whilst a young woman was walking home from a disco in Darwin, Northern Territory, a man approached her and offered to walk her home. She claimed that after she had refused his advances many times, he raped her. After the attack, the woman and the assailant were intercepted by the woman's boyfriend, who confronted the assailant. It was also alleged that the boyfriend was then bitten on the chest by the same assailant during a scuffle. Lewis, the suspect for these attacks, had been a regular patron at the disco and was arrested in connection with these offenses. This occurred despite alibis placing him elsewhere at the time of the alleged offense. He willingly supplied body samples and underwent a dental examination that included taking an impression of his teeth. It is important to note that Lewis had undergone dental treatment as a result of an injury to his teeth that occurred between the time of the alleged attack and the taking of the impression. Police investigations at the scene yielded no evidence to link Lewis to the location, and clothing seized from the accused was not contaminated with any blood, hair, or other evidence to link him to the rape or later attack on the boyfriend. Notwithstanding the fact that both the woman and her boyfriend were highly intoxicated on the night of the rape, which may have affected their recall of the attacker's identity, and that a taxi driver present during the later attack on the boyfriend had clearly stated that it was not the accused who had sat in the front seat of his taxi, Lewis was identified as the biter by two odontologists and convicted. This conclusion was reached by reference to a single black-and-white photograph of the bruise left on the victim's chest. This photo was compared with an acetate overlay that had been constructed by hand-tracing around the biting edges of the cast made of Lewis' dentition. The odontologists claimed with confidence, one with "100% certainty," that it was the incisal edges of five teeth from Lewis' lower jaw that had made the mark on the victim's chest. On appeal the following year, like Carroll, Lewis was acquitted, the basis being that the judges did not believe that the evidence of the odontologists was sufficiently sound for Lewis' conviction to stand, using the Carroll case as a precedent.

Problems with Bite Mark Analysis in the Carroll and Lewis Cases

Identification of Lewis was made using a black-and-white photograph of a bruise pattern of five teeth on a man's chest. Carroll was identified by a bruise pattern that was said to identify three or four of his upper anterior teeth. Bowers, a forensic odontologist in the USA unconnected to either case, wrote that the ability to attain a positive match has more to do with the number of tooth marks seen in the bite and not the uniqueness of each individual characteristic of either the defendant's dentition or the bite mark injury. Applying this criterion, there were probably not enough tooth marks present in either of the Carroll or Lewis cases for a detailed comparison to be made and definite conclusions to be reached about the origin of source of the injuries.

Each stage in the analysis of bite marks provides the opportunity for the incorporation of additional errors. The hand-tracing on to acetate of features from the study casts in both the Lewis and Carroll examinations is a method that has been shown to be one of the least accurate in terms of production of two-dimensional overlays. The validity of alterations made to the study cast of Carroll's dentition must also be questioned; the accuracy of the resulting replicas is difficult to quantify or validate.

Marks made by teeth on the human body are often left on curved surfaces such as the breast, arms, and buttocks. These bite marks may appear in the form of a bruise, or as indentations in the skin. When there are indentations, a replica of the bitten surface may be made and morphometric analysis carried out. However, when only a bruise is left, the exact origin of source of the mark is less easily determined. The bite mark evidence may only be good enough to exclude certain suspects whose dentition bears no resemblance to the pattern of injuries. Bruises heal, migrate, and smudge. The blood of the bruise may drain away from the site of initial injury and these factors can further hinder an accurate comparative analysis.

Forensic odontologists confidently testified in both the Carroll and Lewis cases that the poorly defined bruises seen on the surface of skin were made by the accused men and no other person. This was surprising because one odontologist who gave evidence at both trials agreed that "there was a body of opinion, held by experts whom he would not rate as being inferior in skill to himself," who believed that identification of teeth by comparing them to bruises was not reliable.

Consequences of the Carroll and Lewis Cases

Outcomes of the Carroll and Lewis cases have reduced the credibility of bite mark analysis, and future cases involving bite mark testimony will be forced to face the precedent set by these cases. Following these trials a Victorian report by Coldrey into the taking of body samples and examinations of suspects in custody concluded that the taking of bite mark evidence was of little value in criminal cases. This view was reached because bite mark evidence had been ruled inadmissible on a number of occasions and because the committee believed that bite mark evidence was subjective and rarely secure enough to support a conviction. However, the Coldrey report overlooked the potentially important exculpatory significance of even poor bite marks to an investigation.

Bite Mark Evidence Later Contradicted by DNA

The criminal justice system is not perfect and can be subject to error. The possibility of obtaining a false-positive conviction always exists. This is when an innocent person is imprisoned in error whilst the perpetrator is free and has the opportunity to reoffend. Although the number of false positives may be quite small compared to the number of true-positive convictions, wrongly "doing time" in prison or being executed cannot be reversed by monetary compensation for the accused or his/her family.

In February 2003, the annual meeting of the American Judicature Society focused on the conviction of innocent persons. Six causes of injustice were identified, including confirmatory bias in police investigations and false scientific evidence. The chance of obtaining false positives via erroneous scientific evidence (e.g., inaccurate bite mark analysis) is one issue that is currently under investigation in the American criminal justice system.

DNA Exoneration – Correcting the False Positives

In the USA, there has been a major shift in the criminal justice system over the past decade due predominantly to the impact of exonerations based on later DNA analysis. Currently, 30 states have enacted statutes addressing postconviction DNA testing.

In 1992, a nonprofit legal clinic was established at the Benjamin N. Cardozo School of Law in New York to assist convicted people who claim innocence. Over a period of 14 years, a total of 131 convictions have been overturned. In the following case, a man was wrongly convicted on the basis of bite mark evidence.

An American Case – *State* v. *Krone*

On December 29, 1991, the stabbed body of a 36-year-old woman was found in the men's toilets of the bar where she worked. Little physical evidence was found; however there were bite marks on the breast and neck of the victim's body. She had apparently told a friend that a regular customer named Ray Krone was to help her close the bar on the night she was killed. Krone was arrested and charged with murder and kidnapping. An odontologist took Styrofoam impressions of Krone's teeth for comparison with the bite marks on the woman's body. At the trial, dental experts for the prosecution testified that these bite marks matched the impression that Krone had made in the Styrofoam, and he was convicted and sentenced to death for the murder and received a consecutive 21-year term of imprisonment for the kidnapping. Krone appealed in 1996, but was again convicted, mainly on testimony relating to the bite mark evidence. This time he received a reduced sentence, life imprisonment. In 2002, DNA testing was conducted on the saliva and blood found on the victim. The samples matched a man named Kenneth Phillips, who had worked nearby but had never been questioned. After the unfortunate Krone had served more than 10 years in prison, all charges against him were dismissed, and he was exonerated and released.

Bite mark evidence in this case was incorrectly interpreted and this emphasizes the need to question current standards of bite mark analysis to prevent similar situations arising in the future.

Admissibility of Bite Mark Evidence

Currently, two tests exist for the admissibility of new scientific techniques in courts of law, implemented to protect the accused from being persecuted by methods that have not been proven or established. The "Frye" test, established in 1923 as an outcome of *Frye* v. *United States*, specifies minimum requirements that a new scientific procedure must undergo before being deemed admissible in a court of law: it must be "demonstrable," sufficiently "established," and have gained the "general acceptance of experts" working in the field/s to which the evidence belongs.

In 1993 the US Supreme Court abandoned Frye and adopted a more flexible validation standard resulting from the case *Daubert* v. *Merrell Dow Pharmaceuticals*. Daubert states that the reasoning or methodology underlying testimony must be "scientifically valid," determined by examining testability, error rate, peer review and publication, and general acceptance.

The problem with Daubert is that the responsibility is placed on judges to screen evidence for reliability and relevance, but many judges would agree that they are not sufficiently founded in science to be able to determine if expert testimony is reliable and risk admitting inappropriate testimony. Widespread concern is expressed that judges will become amateur scientists. Judges themselves express disquiet, one stating that "federal judges ruling on admissibility of expert scientific testimony face a far more complex and daunting task in the post-Daubert world" and that "we judges are largely untrained in science and certainly no match for any of the witnesses whose testimony we are reviewing." In 1994, Jonakait wrote that "if Daubert was taken seriously, then much of forensic science is in serious trouble." This statement is particularly relevant for the analysis of bite marks. However, because the Court decided Daubert on statutory rather than constitutional grounds, it remains the decision of individual states in the USA to determine the method by which scientific evidence is admitted. In 1995, 22 states apparently remained committed to Frye. Perhaps understandably, there has also been some reluctance to introduce Daubert into the Australian legal system.

In Carroll's original murder trial, the techniques used in the examination of the bite marks were deemed admissible by the court in accord with the Frye test; however, the conviction was overturned on appeal due to inconsistencies in methodology. It seems that existing methods for bite mark analysis are not robust enough to withstand courtroom challenges and the reputation of all bite mark analysis has been marred as a result. The scientific basis for bite mark analysis is yet to be established, and until this happens, it will be a difficult task to restore the credibility of bite mark analysis as a science.

Factors Affecting Our Ability to Analyze Bite Marks and Identify the Biter

Uniqueness of the Dentition May Not Translate into a Unique Bite Mark

The evidential value of bite mark analysis is predicated on an assumption of uniqueness in both the dentition of the biter and the corresponding injury left after biting. Although uniqueness of the dentition is well established in the identification of a person's remains by his/her teeth and uniqueness of a bite mark, the transfer of features of the same dentition to another surface is much more problematic. Taroni suggested that a perfectly sharp broken tooth could be viewed as unique. However, the same feature transferred to another surface by pressure can look blurred and merge into other adjacent patterns in the substrate.

In 1982, Sognnaes loosely examined individuality of the human dentition in a small study of five sets of identical male twins. This paper is often quoted as proof for the uniqueness of a bite mark in skin. The authors pressed stone dental casts of the dentitions of 10 twins into various substances such as wet plaster of Paris, wax, polyether, and silicone to record the mark left. These indentations were then filled with radiopaque material, radiographed, digitized, and computerized. The resultant bite patterns of each pair of twins were then superimposed and analyzed with respect to each other. From these superimpositions, Sognnaes concluded that the "illustrations of these computerized comparisons show the uniqueness of the human dentition" and that "in terms of occlusal arch form and individual tooth positions, even so-called identical twins are in fact not dentally identical."

Whilst Sognnaes' conclusions may well have been correct for plaster of Paris, wax, silicone, and polyether materials, these conclusions probably could not have been made if human skin had been used as the recording material. In addition, despite a careful approach, the researchers had no control over the depth of penetration of the dentition into the recording medium. In 2001, Pretty and Sweet considered this point and showed that variations in a bite mark pattern can be produced using the same dentition by only changing the pressure when it is forced into dental wax.

Other Factors to be Considered

Skin and underlying tissue are highly deformable substrates and there are many variables that affect the representation of the transfer of the biting surface of the teeth to human skin. A mechanism is required that accounts for these variables:

- amplitude and direction of biting forces
- sucking action (which may cause additional bruising)
- depth of penetration of the skin (if any)
- three-dimensional (curved) morphology of the substrate
- movement of assailant and/or victim during bite
- capacity of wounds to change during healing.

To illustrate some of these problems, DeVore conducted a simple experiment using an inked rubber stamp of a concentric circle which he pressed on to the arm of an individual. The stamp was then photographed with the individual flexing, extending, and rotating the arm in different directions. Included in the photograph was a ruler used to make accurate comparisons from the prints. DeVore concluded that there was up to 60% linear distortion of the stamp on the skin depending on the position of the body. Therefore, photographic images of bite marks to be used in comparative analysis should perhaps only be used if the position of the body at the time of the infliction of the injury can be replicated. This is a difficult requirement when it is understood that most bites are made during an attack, some of which are fatal for the victim (Figure 3).

Overlays still being the most common form of bite mark analysis, in 1986 the American Board of Forensic Odontology (ABFO) recommended guidelines for the collection of bite mark data and their analysis sufficient to inculpate or exculpate suspects, but, despite these recommendations, problems still exist that require resolution.

Admirably, much effort has been devoted to developing a reproducible method of overlay production using the medium of Adobe® PhotoShop®, but although this method corrects for certain types of distortion, it cannot completely compensate for the three-dimensional nature of the dentition and the surface that has been bitten. In photography, extremities of curved surfaces are distorted with respect to features seen at the center of the field of view. It will therefore be necessary to produce a set of rules that can make provision not only for the

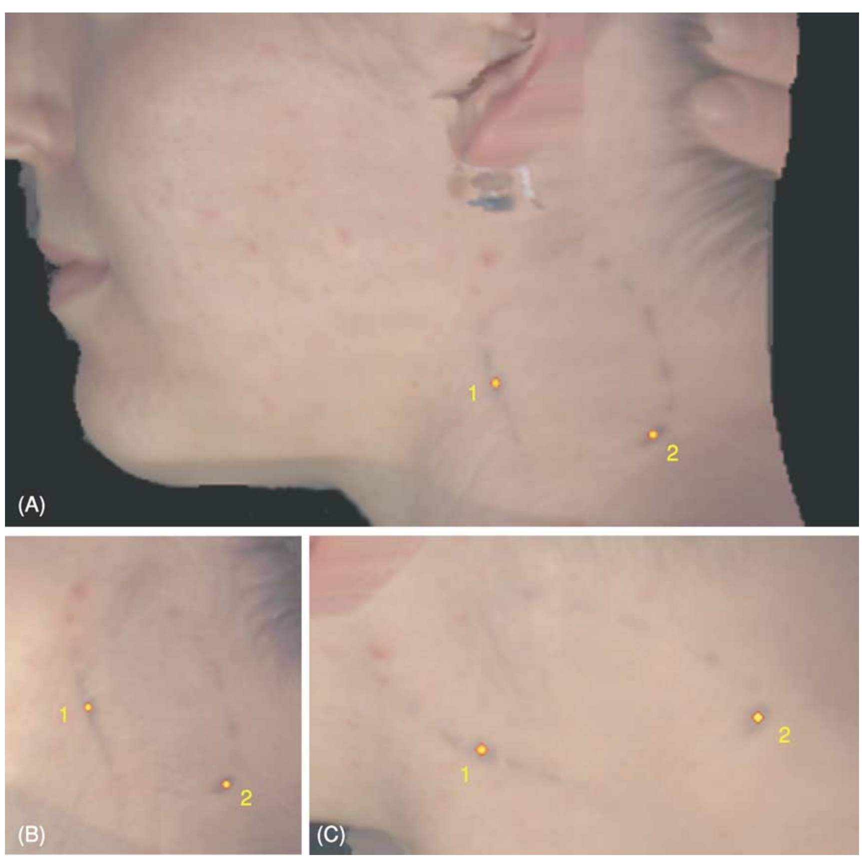

Figure 3 Two-dimensional images of a series of three-dimensional scans of a simulated bite on the neck of a person showing effects of simple postural distortion: (A) head erect 35.2 mm between points labeled 1 and 2; (B) head tilted away from bite 38.7 mm between points 1 and 2; (C) head rotated 49.7 mm between points 1 and 2. Distances measured in three-dimensional space, not simply in the plane of the two-dimensional image.

three-dimensional morphology of the skin but also the dynamics of biting and the distortion caused.

The issue of unconscious bias should not be ignored. The odontologist may work closely with police and prosecution lawyers. They are often requested to make a dental cast from a suspect's dentition and then asked to match the bite marks found on the victim with the dentition of the person in custody. This introduces confirmatory bias into the identification from the outset. Rothwell suggested using a line-up of dental casts that may or may not include the suspect's dentition, thus eliminating any bias the forensic odontologist might feel to "match" the mark with the suspect's dentition. In the Lewis case, an attempt was made by a third odontologist to demonstrate that the cast of another person's teeth (a person completely unrelated to the case) exhibited some similarities when compared with the photo of the bite on the boyfriend's chest, but this evidence was disallowed by the court. This makes it even more surprising that the opinion of the odontologists inculpating Lewis as the only possible biter could be held with such firm conviction.

The Future Direction of Morphometric Analysis in Bite Mark Identification

Bite mark, fingerprint, and DNA analyses, and more recently morphological facial identification, are similar in that a certain minimum number of points of concordance between two objects must be observed for a positive match to be concluded. Scientists have composed databases whereby fingerprint and DNA analyses can be expressed quantitatively as a numerical probability in the population. Although the individuality of the human dentition is commonly observed by dentists in practice, there is presently no database to express the uniqueness of the human dentition quantitatively.

It is not enough to believe that each dentition is unique. Where bite marks are being considered, what is important is the ability to discriminate between different individuals using morphometric criteria. The differences between some individuals may be so slight that, when they are masked by the degraded nature of the information contained in the wound, differences that could be measured between the dentitions of two or more potential suspects cannot be detected in the bite mark. Hence it becomes impossible to attribute the bite to any particular individual with certainty. The present lack of statistics relating the characteristics of the biter to the bite mark injury continues to spark controversy, prompting the need for further research efforts.

Three-Dimensional Imaging and Quantification of Bite Marks and Dentitions

Research on three-dimensional imaging and quantification of bite marks is progressing. It is only when the bite of the offender and the bite mark arising from the action of biting (both three-dimensional structures) can be compared in three dimensions that progress can be made toward scientifically valid quantification in bite mark analysis. Even when this has been achieved, the dynamic nature of the interaction between the teeth and the skin needs to be modeled. This will require an understanding of the behavior of tissues during the process of being bitten. This has yet to be achieved and, furthermore, it will require input from disciplines outside dentistry.

In research by the authors, dental stone models and simulated bite marks in an imperfect impression

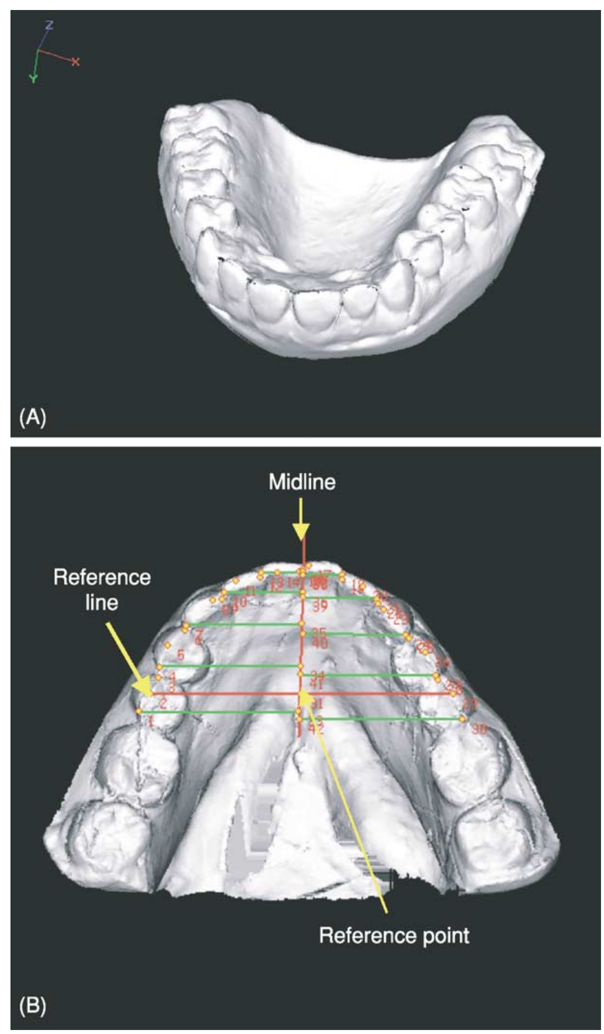

Figure 4 (A) and (B) Three-dimensional laser scans of stone dental models with some landmarks identified, which could be used for comparisons with potentially corresponding three-dimensional scans of wounds or bite mark injuries.

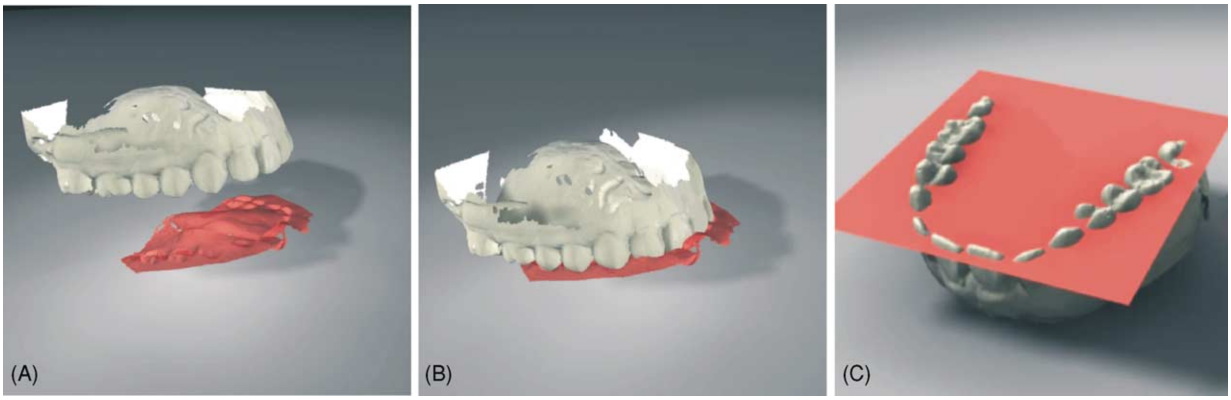

Figure 5 Stills taken from three-dimensional animations of comparisons between impressions in wax (red) and model of biter (white) (Website 5: www.dent.unimelb.edu.au/3dbitemarks): (A) Approaching contact; (B) In contact showing near perfect registration; (C) Use of a cutting plane to illustrate topography of biting surfaces of teeth. With three-dimensional scans of the body such simple cutting planes could be replaced by curved surfaces that are descriptive of the undeformed surface of the skin at sites of bite mark injuries. This could then be used to predict depth of bite in resulting injury patterns.

medium (dental wax) have been laser-scanned and a series of two- and three-dimensional measurement categories quantified (Figure 4). A numerical matrix has been developed to try to determine the proportion of dentitions that match a particular bite mark exactly within the tolerances introduced by the use of wax as a recording medium, the number that could possibly match, and the number that do not match at all. We strive to calculate the probability of predicting matches, possible matches, and definite nonmatches for a particular cohort. Animation of matching and nonmatching dentitions and bites has also been explored, and may prove to be of use in the future in assisting juries in a courtroom situation (Figure 5).

It is just such statistics that need to be presented to the courts in order to give the appropriate weighting to the opinion of the expert. At the end of the day, the process of coming to a conclusion may be less important than the performance of the expert in tests of competence, these coming in the form of correct answers in bite mark analysis simulations.

Summary

Pretty and Sweet's extensive critical review of bite mark literature confirmed that the scientific basis of bite mark analysis is currently very weak. Their research exhorts us to increase the rigor of our analyses. To address these deficiencies, we need to utilize experts in other fields, such as dermatology, mechanical engineering, and motor vehicle crash simulation, to gain a better understanding of the interactions of human skin with three-dimensional objects capable of inflicting injuries which leave a signature in the wound pattern.

See Also

Odontology: Overview

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