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PORCINE SKIN AS AN *IN-VIVO* MODEL FOR AGEING OF HUMAN BITE MARKS

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ABSTRACT

Porcine skin has been shown to have similar histological, physiological and immunological properties to human skin and has been suggested as a good analogue for medical and forensic research. This study was undertaken to examine the appearance of bite mark wounds inflicted at known time intervals before and after death. Under general anaesthesia, a series of bite marks were created on a pig's abdomen with a device designed to mechanically produce simulated human bite mark wounds. The pig skin model showed that bite mark characteristics are similar to those found on human skin. This study has provided information on the window of time showing clearly detailed bite marks occurring around the time of death. It also demonstrated that it is possible under certain conditions to determine that a bite mark was made before or after death in a porcine model. Under these experimental conditions, the results suggest that an *in-vivo* porcine skin model should be considered as a representative model for the study of human bite marks.

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Key words: bite mark, porcine skin, animal model, biting device

INTRODUCTION

A bite mark is a form of patterned injury, which is the physical result of a biting action applied to skin or other material such as food or other inanimate substrates. A human bite mark on skin is commonly described as consisting of contusions or abrasions, which correspond to dental arches, individual teeth, or both. The degree of detail recorded on the bitten surface varies from case to case and may or may not retain visible features for physical comparisons to be made. A representative bite injury for possible biter identification should include features such as a well-delineated dental arch and individual tooth injury depicting the metric or specific pattern characteristics of the biter. Bite marks of little evidentiary value may occur in the form of vague, diffuse contusion injuries, suggestive of being the result of a bite but lacking detail for comparison. Occasionally bite marks may be non-specific and may not be recognised as such.[1]

For ethical reasons, human skin is difficult to use for *in-vivo* bite mark research. Therefore researchers use a myriad of animal models and *in-vitro* systems for skin experimentation to circumvent the ethical and methodological difficulties. Effects of a wide variety of injuries or new agents in experimental animals are possible but would be unjustifiable in man.[2] Animal skin has been extensively investigated to find a suitable experimental model. The selection of an animal model depends on a number of factors including availability, cost, ease of handling, investigator familiarity and, most importantly, anatomical and functional similarity to humans. Small mammals are frequently used for studies; however, these animals differ from humans in important anatomical and physiological ways.[3] Pig skin offers the most appropriate model, from the perspective of dermatology and wound investigation, of all experimental animals.[4]

One of the earliest studies of pig skin was by Flatten in 1896.[5] Since then, a multitude of morphologic, anatomic, immunohistochemical, dermatologic and pharmacologic studies have demonstrated that pig skin has important similarities in morphology, cellular composition, and immunoreactivity to human skin.[6] Differences are seen, however, with respect to micro-morphology and function.

Epidermis and dermis

The thickness of the epidermis in various species varies inversely with hairiness. Thus pigs have the thickest epidermis of all domestic animals species. Humans also possess a thick epidermis, with a striking similarity in the number of cell layers in the viable as well as in the cornified layers.[7] Both possess intersecting lines which form characteristic geometric patterns and groove the skin surface. The underside of porcine epidermis is arranged into rete pegs with regular, alternating large and small ridges, while that of man is simpler in arrangement.[8,9] These rete pegs and dermal papillae show similar organisation and structure in both species.[6,7,10,11] The epidermis of the pig is reported as varying in thickness from 30 to 100 μm[11] and 70 to 140 μm, thus being within a range similar to that in man, i.e. 10 to 120 μm.[9] Like man, porcine epidermis varies in thickness in different anatomic locations, mainly because of differences in the thickness of the stratum corneum, which in the swine remains compact with an extensive keratogenous zone.[9] Marcarian and Calhoun[6] reported that porcine dorsal skin is thicker than ventral skin, which holds true for man.[12,13] The dermal-epidermal ratio of porcine skin varies from 10:1 to 13:1. These measurements are comparable to those of human skin.[4]

The dermis of pig is divided into 2 layers, which blend without distinct demarcation: the upper papillary layer and the lower reticular layer.[5,8] One striking resemblance between human and porcine skin is the large content of elastic tissue in the dermis[5-8,14] compared to those of other mammals. Unlike human skin, the elastic fibre content of porcine skin is relatively low, but nevertheless still higher than other mammalian species.[5,8] Collagen in the porcine dermis shows a remarkable similarity to human collagen α1 and α2 chains.[15] It is arranged in a three dimensional network of fibres and fibre bundles, which cross each other in two principal directions, passing obliquely between epidermis and subcutis. Smaller fibre bundles pass through the network in other directions resulting in a densely interwoven mesh.[16]

Vascular structures
The vascular organization of porcine skin is similar to that of man. Pigs possess a lower, a mid-dermal, and a sub-epidermal vascular plexus.[6,17] The dermis has a well-differentiated papillary body in both species, but human skin receives a greater vascular supply than porcine skin.[9]

The deep region of the hair follicles and other appendages in the pig are poorly supplied with vessels in contrast to the well vascularised hair follicles and glands of human skin. Since pigs do not possess eccrine sweat glands as do man, the regulation of peripheral blood flow through the dermal vascular plexi is thought to play an important role in thermoregulation.[9,18]

Sub cutis and adipose tissue
One of the prime factors that underpin the resemblance of porcine to human skin is that both species rely on fat and not fur or hair for insulation. The major difference between the human and porcine subcutaneous fat layer is that it is much more pronounced in the pig.[9,19] The adipocytes are deposited in pockets of elastic and collagenous tissue (fat chambers).[9] In this respect, porcine subcutis resembles the human subcutis.[4,9] The subcutaneous fat layer of both pig and human shows distinct sex and age differences relating to the latticed and lamellar structure of the collagen fibres and also to the formation of the fat chambers. The amount of subcutaneous fat also shows considerable variation in both porcine and human skin, depending on the anatomical site examined and also on the nutritional state of the animal.[4]

Hair and hair follicles
Unlike most other experimental animals that possess much hair or fur, the skin of the pig shows a follicular pattern that is rather sparse and arranged in single hairs or groups of two or three follicles, similar to man.[5,8,9,20,21] The great variation in hair follicle density seen in man is not obvious in porcine skin. In man, some areas are afollicular (e.g. palmar and plantar surfaces), whereas the greatest density is found on the scalp and face. Sex differences, genetic factors and the age of the individual are also important factors to be considered, such as genetic baldness in human males.[4]

Sebaceous glands
The holocrine sebaceous glands of porcine skin are associated with the hair follicles and are present in the superficial part of the reticular layer. They are small and discharge into the dermal pilary canal of the hair follicle.[9,19] In structure, the porcine sebaceous glands resemble those of other mammals; however, they are relatively small when compared with those of man from the same region of skin.[5,8]

Sweat glands
A significant difference between porcine and human skin is that the pig possesses apocrine glands instead of the eccrine sweat glands found in human skin. There are no eccrine glands in porcine skin.[8,9,18] The apocrine glands of pig, like those of most other mammals, open upon the surface, independent of pilary orifices,[19] whereas those of man open mostly inside the pilary canals. Special function of the porcine apocrine glands has not been elucidated, but it is unlikely that they function in thermoregulation.[8,9]

Biochemistry/Enzyme activity
The keratinous proteins of pigs and man are similar.[10] The enzyme pattern of porcine epidermis corresponds in its overall histochemical profile to that of man. In the pig, there is positive alkaline phosphatase activity in the basal parts of the rete pegs

and strongly positive acetylcholinesterase activity in the epidermis, a finding differing from human skin. [8,9]

Endogenous epidermal lipase activity is similar in both species, reflecting the similarity in composition of lipid films on the surface of the skin. Both pig and man possess skin surface lipids composed mainly of triglycerides and free fatty acids, in contrast to the lipid composition of the skin surface of densely-haired mammals.[9,22-25] Finally, the sebaceous glands of the pig contain more alkaline phosphatase when compared with man.[8] Table 1 shows a summary of the similarities and dissimilarities between human skin and porcine skin.

Animal skin differs morphologically from that of humans, making extrapolation from human histology misleading. Species-to-species variation is also marked in terms of epidermal and dermal thickness, types and arrangements of hair follicles, and adnexal structures. Similarly, there is substantial variation in the morphology between regions of the body in an individual animal.[7] While similarities between pig and human skin are numerous, there are also differences with respect to structure, immunohistochemistry and function.[6] Nevertheless, the domestic pig seems to be the most suitable animal; having an epidermis and dermis that can be used as a model as there are clear structural, functional and biochemical characteristics comparable to human skin.[3,9]

AIMS OF THE STUDY

The ageing of bite mark wounds in relation to time of death is an aspect of forensic odontology that has legal consequences. There is a lack of objective information available on whether bite mark wounds can be accurately aged in relation to time of death, and there is no sound data that distinguishes between those made before death and those made after death.[26]

The purposes of this study were: first, to utilise an instrument which would permit the infliction of simulated human bite marks on porcine skin using a controlled and quantifiable force; second, to study experimental bite mark wounds using an *in-vivo* porcine model as the bite mark substrate inflicted at known time intervals, before and after death, by means of clinical observation and comparison as well as metric analysis.

MATERIALS AND METHODS

Pig preparation

Ethics and Animal Care Committee approval was obtained from the Division of Comparative Medicine of the University of Toronto. A female juvenile Yorkshire pig weighing 35.4 kg was purchased one week prior to the study, allowing the pig to acclimatise to the new environment and reduce stress. The pig received a complete examination including blood tests to rule out any systemic diseases or hematological disorders. The day of the bite mark

Table 1: *Similarities/dissimilarities between human skin and porcine skin*

Similarities	Dissimilarities (porcine skin)
• Thick epidermis with similar organisation and structure of the rete pegs and corresponding dermal papillae • Relatively high content of elastic fibres in the dermis compare to other mammals • Vascular organisation • Similarities in the structure of the collagenous tissue framework and the adipose chambers of the subcutis • Sparsely-haired coat • Similarities in enzyme pattern • Similarities in epidermal tissue turnover time and the character of keratinous proteins • Significant parallels in the composition of the lipid film of the skin surface	• Poor vascularisation of the cutaneous glands and partly also in the region of the subepidermal capillary plexus • Extensive deposition of fat below the subcutis (mature animals) • Smaller holocrine sebaceous glands • Absence of eccrine sweat glands (apocrine glands instead but unlikely to play a role in thermoregulation)

procedure, pre-medication of the pig was done with an intramuscular injection to the thich of ketamine (33mg/kg) and atropine (0.5mg/kg). The pig was put under general anaesthesia comprised of oxygen and isoflurane (1.0-1.5 %). A blood pressure cuff was placed on the right front leg of the pig to monitor blood pressure during experimentation.

Biting device
An instrument was constructed to mechanically produce simulated human bite marks on skin. This device was made available by the Bureau of Legal Dentistry (BOLD), University of British Columbia, to produce experimental bite mark injuries. The device consists of acrylic upper and lower models fixed to a locking C-clamp #11 vice-grip.* The biting device (Fig.1) has been used as a method of simulating human bite marks and is currently used in teaching situations for the study of bite marks.[27] A pressure-sensitive load cell and a pre-configured indicator[†] were added to the device to display real-time loads for pressure consistency at a pre-selected incisor tooth (Figs.2A and 2B). Few studies have been made to determine the pressure exerted by human incisor teeth, with forces ranging from 6.0 to 23.5 kg with a mean of 8.9 to 11.4 kg depending on the study reported.[28-30] Pressure consistency was selected at 23 kg representing the maximum force applied by human incisor teeth according to the literature.

Experimental procedure
A series of simulated bites were created on the pig's abdomen. The pig skin is generally thicker on the dorsal than on the ventral aspects of the body and on the lateral than on the medial portions of the limbs.[19] The abdominal region of the pig therefore represents the widest surface and the thinnest epidermis and cornified layer.[5,31] Four bite mark wounds were made on each side of the pig's flank for a total of 8 bite marks. Each bite was impressed into the tissue using the biting device and the upper and lower arches of the device were held closed for 60 seconds.

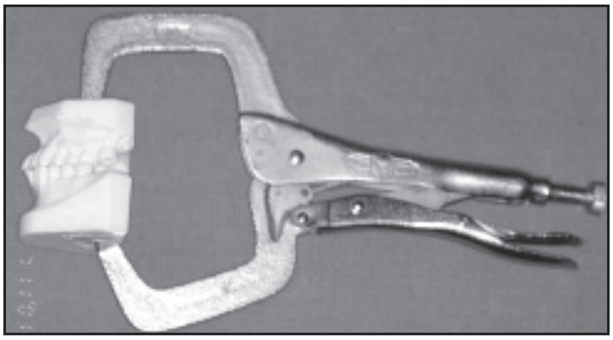

Fig.1: *Biting device consisting of upper and lower acrylic models mounted on a vice-grip*

The right and left side of the pig were bitten so that, after being euthanased, the influence of post-mortem lividity (livor mortis) could be evaluated. Paired bite marks were made on each side of the pig one hour before death, five minutes before death, five minutes after death and one hour after death. Intra-venous injection of T-61[§] was used for euthanasia. Tanax® is commonly used in veterinary medicine

* MasterCraft® Canadian Tire Corporation Toronto,Canada
† A-Tech Instruments Ltd., Scarborough, Canada
§ Tanax® Intervet Canada Ltd., Whitby, Canada

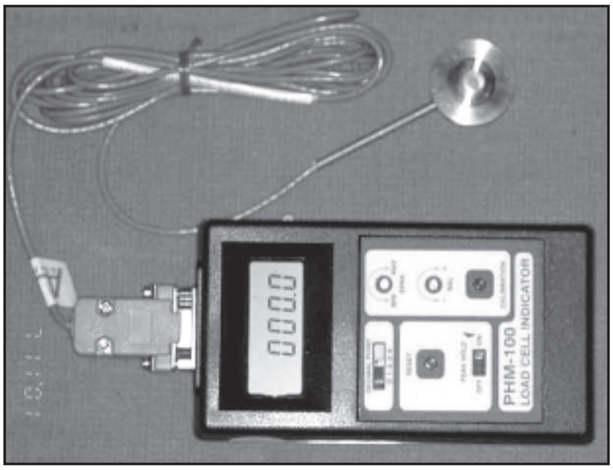

Fig.2A: *Monitoring device with load cell*

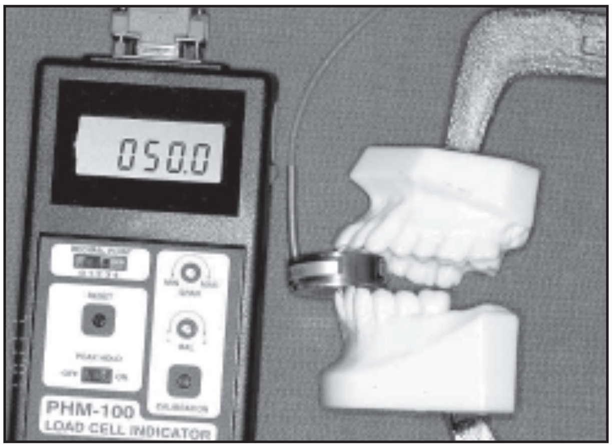

Fig.2B: *Biting device inducing a pressure of 50lbs (23kg) on the load cell* for its narcotic and curariform-like activity and consists of a mixture of embutramide 200 mg/ml^{-1}, mebozonium iodide 50 mg/ml^{-1} and tetracaine hydrochloride 5 mg/ml^{-1}. These compounds are dissolved in a mixture of dimethylformamide 0.6 ml/mg^{-1}.[32] Observations, measurements and conventional photography of the bite markings were made. The pig was positioned on one side to allow settling of blood by gravitational forces (the dependent side). Comparisons were undertaken throughout the study between the bite mark wounds from the dependent and the non-dependent sides.

After the procedure, the pig was transported to the Coroner's Office where it was stored under standard mortuary conditions (4°C). Preparations for the study of ante-mortem and post-mortem bite marks were made the following day. A supporting plastic matrix was fixed to each bite mark on the pig's skin using cyanoacrylate and silk sutures to preserve the original anatomical configuration of the skin during necropsy.[33] Each ring had a reference number and anatomical reference points for identification and orientation. After the rings were fixed to the animal (Fig.3), the specimens were excised and studied in their fresh state and following 35 days in 10% formalin fixative solution.

The sections removed for study went deep to the viscera, which made them dimensionally stable. Since the tissue blocks removed were very large, the specimens were not coated with a supercoat of stabilising impression material.

Scaled photographs[34,35] were exposed for visual observations and metric analysis examination made at the time of injury and before and after skin fixation to the plastic rings, as well as of fresh and formalin fixed tissues.

The measurements were made with the ABFO No. 2 reference scale.¶

The arch width measurements were taken from the maxillary permanent canines and the distance between the cutting edges of the upper and lower central incisors was measured from the most labial maxillary permanent central incisor and the most labial mandibular permanent central incisor (Fig.4).

Statistical analyses

Statistical analyses were undertaken to study the dimensional stability of the bite mark specimens. To determine if the known size of the bite mark changes significantly before and after formalin fixation non-parametric statistical analyses were performed with SAS v8.2. Significance levels of $p=0.05$ were used for all statistical tests.

Non-parametric methods were used due to the small sample sizes; these methods are more robust for small samples since they do not make assumptions regarding the distribution of observations. Wilcoxon signed-rank tests were used to compare the previously defined arch width (distance between maxillary canines) at the time of injury, the day after the injury, and following formalin fixation. Identical tests were also used to compare the distance between the cutting edges of the upper central incisors and lower central incisors (length). Furthermore, Wilcoxon rank-sum tests were used to determine if the difference in measurements was significantly different between the dependent side and the non-dependent side as well as bite mark measurements prior to and following fixation.

¶ Lightning Powder Co. Inc, Salem, U.S.A.

Fig.3: *Fixation of 8 plastic rings before removal of the skin en bloc (dependent side up)*

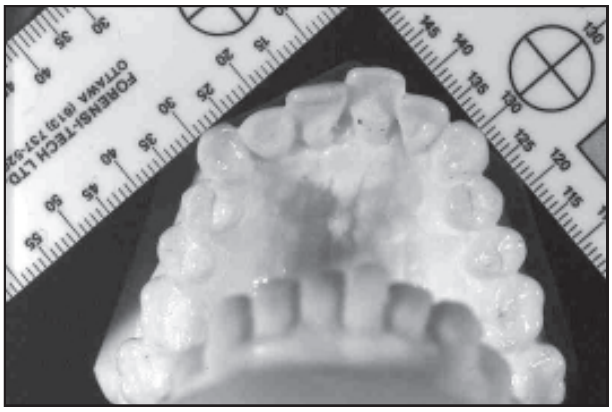

Fig. 4: *Arch width and cutting edges measurements*

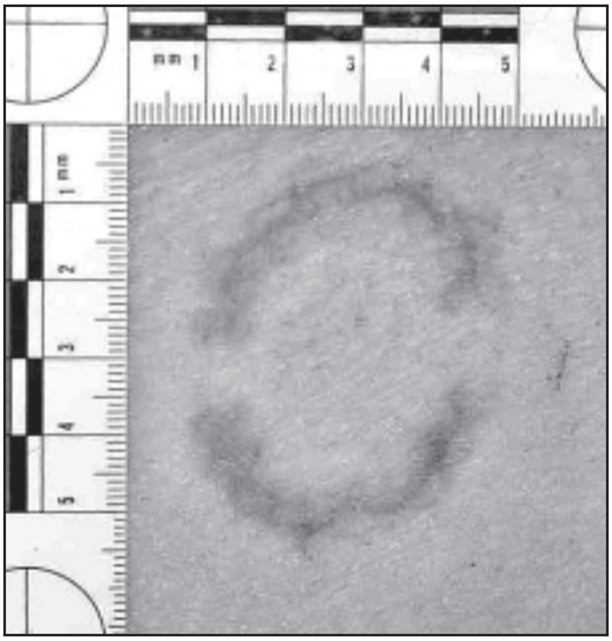

Fig.5A: *Five minute antemortem bite marks from the non-dependent side*

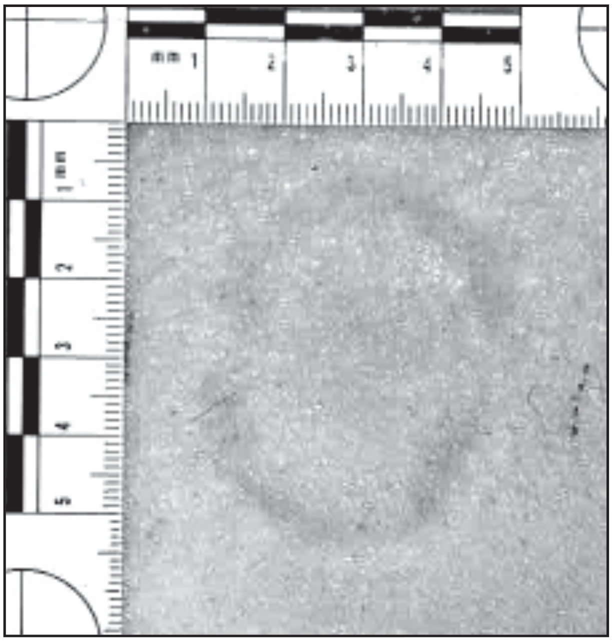

Fig.5B: *Five minute postmortem bite marks from the non-dependent side*

RESULTS

The bite markings were clearly evident and viewable as distinctive oval patterns on the day the injuries were inflicted. Maxillary and mandibular arch measurements were assessable in every specimen. The markings faded one day post-injury and as time progressed, making metric analysis progressively more difficult, and indeed impossible in some cases. The most stable and detailed bite mark injuries were those made five minutes prior to death followed by those five minutes after death.

Ante mortembite marks on the non-dependent side showed pale central indentations surrounded by red outlines (Fig.5A). The class and individual characteristics were easily recognised even when the tissue was excised. The postmortem bite marks from the non-dependent side were homogenous, paler and less defined without central pale indentations representing less obvious class and individual characteristics than the ante mortem ones (Fig.5B). Only the antemortem bite marks from the non-dependent side exhibited areas of intramuscular erythema (Fig.6).

The pattern injury of the bite marks was influenced by presence of livor mortis. The bite mark located on the dependent side in areas represented by settling of blood by gravitational forces within vessels showed clear white indentation on a purplish blue background (Fig.7). Whether the bite mark was inflicted ante mortem or postmortem did not change the pattern characteristics of the tissue.

Postmortem comparison of maxillary arch width at the canines was not possible since only two of eight specimens could be measured. The cutting edge measurements at the central incisors were all readable at the time of necropsy except for one of the specimen bitten 1 hour after death. After formalin fixation, five of seven (71.4%) specimens had larger inter-incisive measurements than at the time

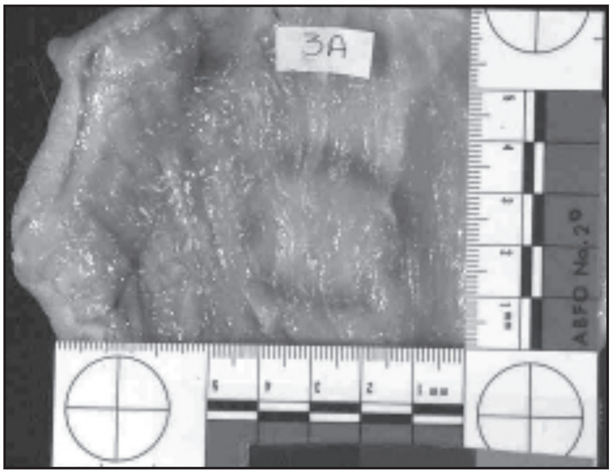

Fig.6: *Five minute antemortem bite mark showing intramuscular erythema*

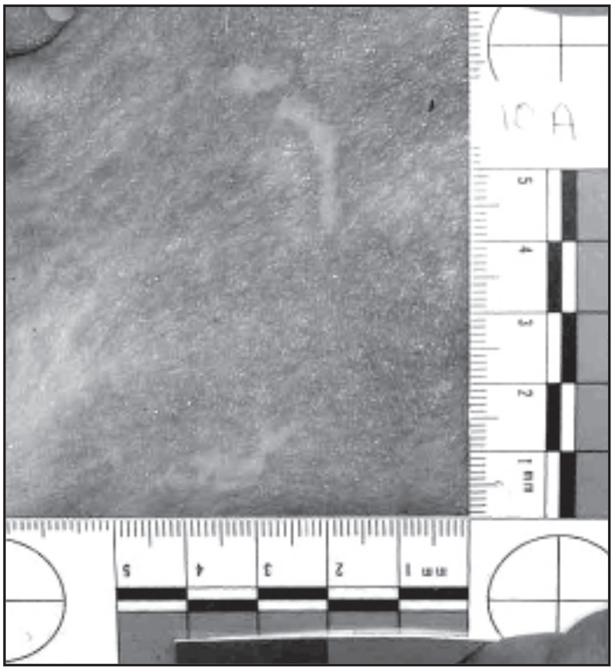

Fig.7: *One hour postmortem bite mark from the dependent side in an area of livor mortis*

of injury. Overall, the increased cutting edge measurements were not statistically significant (p=0.172). Analyses to determine if the measurements were comparable between specimens from the dependent side, and the non-dependent side also demonstrated that these measurements were not significantly different (p=0.858). Table 2 depicts metric analyses at different points in time, after each documented procedure.

DISCUSSION

The *in-vivo* porcine model offers several advantages over other laboratory animals. The animal is relatively small and docile, and being essentially hairless, enables clinical evaluation of surface alterations. Most importantly porcine skin has structural, functional and biochemical features that are remarkably similar to human skin.[6] However, they grow rapidly and considerable space is required to accommodate them.[36]

In any bite mark comparison, it must be kept in mind that numerous variables such as force applied, location of the bite, tongue pressure, suction, mental state of perpetrator, mental state of the victim, whether the victim was alive or dead and the time lapse between the bite and the examinations may all influence the imprint pattern inflicted upon the skin. The appearance of bite marks is also modified by the mechanical properties of the skin. These properties vary from one individual to another and even from site to site within the same individual.[37] Skin is a poor medium to capture marks left in it by various tools, weapons and teeth. From the time the mark is made until the case data is obtained, the skin continues to change. If the victim is alive, bruising may appear. If deceased, then postmortem changes occur.[26]

Antemortem and postmortem bite mark injuries located on the dependent side showed a different pattern compared to the bite mrks made on the non-dependent side. Antemortem or postmortem bite marks in a site obscured by livor mortis seemed to affect the bite pattern characteristics on the tissue.

Table 2: *Bite mark measurements*

Reference Number	Measurements in cm				
	At time of injury	The day after	Fixed to ring	After skin removal	Formalin fixed
1A	4.0 x 5.0	* x 5.5	* x 6.9	* x 6.4	* x 6.7
2A	3.5 x 9.0	* x 8.3	* x 8.4	* x 8.0	* x 8.8
3A	4.0 x 4.2	3.0 x 4.3	3.0 x 4.8	2.8 x 4.5	* x 4.8
4A	4.4 x 4.8	3.2 x 5.1	3.7 x 5.0	3.5 x 5.1	3.1 x 5.2
7A	3.8 x 4.8	* x 4.4	* x 4.7	* x 4.1	* x 4.2
8A	3.8 x 4.6	* x 4.9	* x 5.0	* x 4.9	* x 5.0
9A	3.2 x 4.6	*	*	*	*
10A	4.0 x 4.5	* x 5.7	* x 5.6	* x 5.7	* x 5.7

Bite mark measurements from maxillary canines X (and) upper and lower left central incisors
Original biting device arch width (from maxillary canines): 3.7 cm

1,2: 60 minutes ante-mortem
3,4: 5 minutes ante-mortem
7,8: 5 minutes post-mortem
9,10: 60 minutes post-mortem

Odd numbers: Dependent side
Even numbers: Non-Dependent side

** Measurement cannot be assessed*

Clinical observations regarding intramuscular erythema that was seen only on the antemortem bite marks on the non-dependent side need to be evaluated in the future. Settling of blood by gravitational forces within dilated, toneless vessels (Fig.8) could clinically be masking erythematous area caused by the trauma.

Porcine skin as well as human skin is an elastic medium capable of distortion due to its inherent properties, force and anatomical location of the bite. The non-linear nature of skin forms pre-existing tension lines similar to Langer's lines. These directional variations or tension lines alter with movements and changes of the body.[29] The orientation of the cleavage lines on the porcine abdomen is mostly parallel and transverse in arrangement,[38] which is similar in orientation to the tension lines of human skin. Distortions in bite marks, which are produced by such directional variations, will therefore be dependent on the position of the subject during biting as well as the anatomic location of the bite.[29,37] Due to elastic fibres in the dermis, skin tension varies greatly with the location of the bitten area. Factors such as whether the bite was made into loose or firm skin and on a flat or curved surface influence the resulting pattern.[39]

There was not a consistent unidirectional change seen in any measurements. The specimens also became visibly paler with time and the depth of indentations diminished which complicated measurements. These findings are in agreement with another recent study that was done with post mortem bite marks on dressed pig carcasses.[40] In the present study, the clearest, most detailed bite marks were ones produced five minutes before death followed by the ones made five minutes after death. After the force is released, fading of the impressions may follow quickly due to elastic recovery of the skin but if death occurs about the time of the biting episode, the skin may lose elasticity and the impression of the teeth may remain. Future studies are required to verify the change in skin elasticity over time and its influence on bite mark appearance.

CONCLUSION

The surface appearance of bite marks varies with time. How this pattern varies and how it is related to changes in the dermal tissue remains unknown. The mechanical properties affecting the quality of a bite mark on sub-adult *in-vivo* porcine skin are similar to those seen clinically in humans. Numerous variables influence the appearance of bite marks and no form of artificial biting can precisely replicate bite mark mechanics or tissue response.

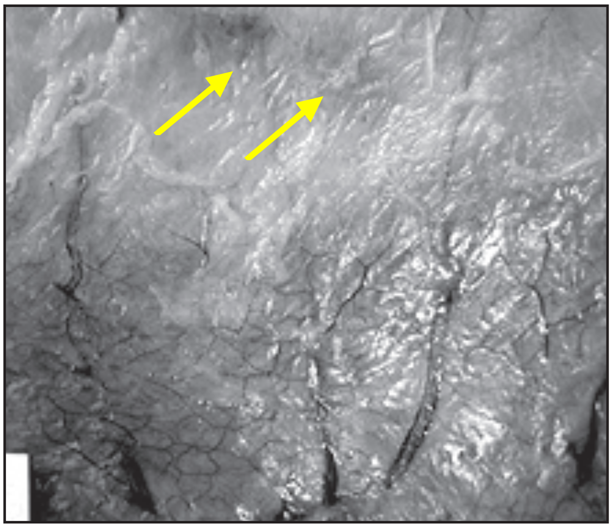

Fig.8: *The bottom half of this figure shows dilated, toneless vessels that could clinically be masking the erythematous area of one of the arches of the bite mark while the upper half is not affected by this livor mortis and shows focal erythematous zone (arrows) representing the other arch of an antemortem bite mark*

The passage of time will result in loss of tooth depressions in human or porcine skin. Oedema from injury, post mortem change and the ability of the dermis and sub dermal tissues to reconstitute the original contour of the body surface all contribute to the changes in the pattern and individual tooth characteristics. The status of the tissue at the time of biting; the time elapsed between the biting and when the analysis is made; condition of the skin injured; the clarity of the marks and the site of the wound; must all be considered in determining the evidentiary value of any bite mark.

This study provided a window of time showing that clearly demarcated bite marks occur at or around the time of death. It also allowed the examiners to determine, within a short window, whether a bite mark is made before or after death on a porcine model. Finally simulated bite marks permitted consistent quality in the physical alteration produced, allowing parity between each of the bites.[41]

This ability to ascribe antemortem and postmortem timing to a particular bite mark can not directly be applicable to all types of bite marks since only eight bite mark specimens were available in this single animal. The use of a window of five minutes prior to and after sacrifice of the animal does however provide a basis for further bite mark studies where numerous other variables affecting the appearance of bite marks can be individually assessed. Variables such as anatomical location, teeth used to create the bite, bite pressure and relative movement between the biting device and the subject animal could be controlled and standardised in this animal model. This study represents the first of a series of experiments that uses both an *in-vivo* model and antemortem and postmortem bite mark wounds.

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AN HISTORICAL SKULL COLLECTION AND ITS USE IN FORENSIC ODONTOLOGY AND ANTHROPOLOGY

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ABSTRACT

The Institute of Forensic Medicine, Copenhagen, houses a collection of historical skulls of unclear origin, marked with a general geographic or "racial descriptor". Would these historical skulls be of any value for the forensic odontologist and anthropologist concerned with teaching and casework? We tried to clarify this question by recording non-metric dental traits and by performing craniometric analyses.

A morphological and morphometric investigation of anatomical/dental traits in 80 adult skulls was performed. For each skull four non-metric dental traits using the ASU-System and three non-metric cranial traits were recorded. Nineteen cranial measures were also taken following the FORDISC programme manual. The non-metrical data were tabulated as frequencies, and the metric data were entered in the FORDISC programme. Observed non-metric trait frequencies were compared with published data. The FORDISC programme computed a discriminatory analysis for each skull and thereby assigned the skull to the most probable ethnic category.

The results for the non-metric traits showed that the traits generally followed the expected frequencies in 80% of the cases. The FORDISC programme correctly assigned ethnicity based on skull measurements in overall 70% of the cases.

It was found that this historical collection does show expected dental non-metric and craniometric traits and the collection may be of value in forensic casework in terms of comparison and for teaching purposes.

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Keywords: non-metric dental traits, FORDISC programme, ethnic group evaluation, historical skulls

INTRODUCTION

Forensic odontologists and anthropologists are regularly asked by the police to describe the physical traits of unknown dead bodies. The purpose of these descriptions is to assist the police in their search for a missing person with a matching description, leading to identification of an unknown body. The forensic team has various methods to obtain information about the deceased, such as evaluation of sex, age and ethnic origin.[1, 2]

The various methods employed for determination of ethnic origin include both metric and non-metric assessments. For example, computer programmes have been developed which match certain craniofacial measurements with a database containing craniofacial measurements from osteological material of known ethnicity.[3] However, the assessment of non-metric traits may be more subjective, as they cannot be discretely quantified, but rather reflect the training and experience of the investigators in identifying and recording these traits. Furthermore, when evaluating ethnicity it may be those self-same non-metric traits, least commonly seen by the investigator, which prove the most crucial. In Denmark, for example, shovel shaped incisors are rarely seen in the general Danish population, but forensic identification cases may involve the remains of purported Greenlanders (Inuit/"Mongoloid"), who often have these traits. Thus a Danish forensic odontologist, with Danish odontological training, may simply not have much experience in discerning these traits. This may be remedied by studying skeletal collections, which include material of varied ethnicity. While such collections do exist, especially in North America,[4] most European collections tend to be of an historical and archaeological nature.

The purpose of this investigation was to apply some of the methods used for evaluation of ethnicity to a large collection of historical and archaeological skulls, in order to evaluate the usefulness of an older anthropological skull collection concerning casework, in terms of training and teaching. Non-metric dental traits were recorded and craniometric analyses performed. Results were compared with the known ethnic provenance.

MATERIAL

The material belongs to different skull collections at the University of Copenhagen. Three groups of different ethnicity labelled as; "Black", "Chinese" and "Eskimo" were evaluated. These skulls were collected in the 17th and 18th century. Most only had a general geographic descriptor as "Africa", "China", or a general racial descriptor as "Black" or "Chinese". The Eskimo material was excavated in Greenland during 17th-18th century, and consists of both pre-colonial Inuit (i.e. prior to AD 1721) and post-colonial Inuit (postdating AD 1721) material. The post-colonial population might reflect the present Greenland population better as it is known that there has been significant commingling between Europeans and Inuit.[5] We therefore specifically chose the more recent 17th and 18th century material for this study, even though some skulls did not have a precise archaeological description. In all, 80 adult skulls were analysed; 26 Greenland Inuit/"Eskimo"; 29 Africans/ "Blacks"; and 25 Asians/"Chinese or Malay". All skulls with intact crania were selected. In some individuals the lower jaw was missing and in several cases part of the dentition was lost postmortem.

METHODS

Four non-metric dental traits were recorded for each skull:

1) shovel-shape on upper central incisors, breakpoint 3-6 (c-f);
2) Carabelli trait on upper first molars, breakpoint 5-7;
3) cusp number on lower second molars;
4) enamel extensions on upper first molars.

The standards of the Arizona State University Dental Anthropology System (ASU) were used for registration.[6,7]

Three non-metric cranial traits were recorded in the jaws;

1) palatal shape;
2) palatine torus;
3) mandibular torus.

Palatal shape was recorded to be either horseshoe-shape, v-shape or parallel-sided as described by Byers *et al.*[9] To keep the recording as simple as possible description of palatal shape was based only on morphological evaluation and not on measurements.[8] Mandibular and palatine tori were recorded by the ASU system.[7]

Along with the recording of the non-metric traits mentioned above, the investigators assigned whether the skull was African, Inuit or Asian. The non-metric data were tabulated as frequencies and compared with published data.[6-11]

Nineteen cranial measures were taken following the FORDISC programme manual,[3] and the metric data was entered in the FORDISC* programme. The FORDISC programme computed a canonical discriminatory analysis for each skull and thereby assigned the skull to the most probable ethnic category. The programme assigns both sex and ethnicity, but for this study only ethnicity was tabulated. The programme allows scoring in various ethnic categories and it was decided to include scoring for the category "White", as several of the individuals may represent mixed ancestry.

All observations and measurements were made in blind trials, although some of the skulls had ethnicity or provenance written on them in the parietal region (Fig.1). Cohen's Kappa was used for evaluating agreement of the predicted ethnicity. Ten skulls were re-evaluated a month later with no significant difference between the results of the two evaluations.

RESULTS

Table 1 shows the distribution of the dental non-metric traits. Three of the traits (Carabelli cusps, Cusp number and Enamel Extensions) could be scored in most cases (50/80, 46/80 and 50/80, respectively), while Shovel-shape could be scored in only 27/80 cases. This was due to postmortem loss of the incisors. This was especially evident for the Inuit skulls, as these represent skulls retrieved from inhumation

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Fig.1: *All observations and measurements were made in blind trials, although some of the skulls had their ethnicity or provenance written on the parietal surface*

Table 1: *Distribution of dental non-metric traits*

Dental Trait		"Black"	"Chinese"	"Eskimo"	Total
Shovel shape	present	0	4	2	6
	absent	14	7	0	21
	Total	**14**	**11**	**2**	**27**
Carabelli´s cusp	present	2	2	0	4
	absent	18	13	15	46
	Total	**20**	**15**	**15**	**50**
Cusp number	4 cusps	7	8	6	21
	5 cusps	8	7	10	25
	Total	**15**	**15**	**16**	**46**
Enamel Extensions	present	19	3	4	26
	absent	1	7	16	24
	Total	**20**	**10**	**20**	**50**

Table 2: *Distribution of jaw traits*

Jaw Trait		"Black"	"Chinese"	"Eskimo"	Total
Palatal Shape	horseshoe-shape	1	7	20	28
	v-shape	10	12	4	26
	parallel-sided	13	3	1	27
	Total	**24**	**22**	**25**	**71**
Palatal tori	present	1	1	6	8
	absent	24	21	19	64
	Total	**25**	**22**	**25**	**72**
Mandibular tori	present	1	0	8	9
	absent	21	19	15	55
	Total	**22**	**19**	**23**	**64**

Table 3: *Agreement between ethnicity as by dental traits (columns), versus labels (rows)*

Ethnic category	African	Asian	Inuit	Total
"Black"	**20**	3	1	24
"Chinese"	3	**16**	3	22
"Eskimo"	0	5	**21**	26
Total	23	24	25	72

Table 4*: Non-metric agreement rates and Cohen´s Kappa values for each ethnic category*

Ethnic category	Overall agreement	Cohen´s Kappa
"Black" - African	0.90	0.78
"Chinese" - Asian	0.81	0.55
"Eskimo" - Inuit	0.88	0.73
All	0.79	0.69

Table 5a: *Dental non-metric frequencies compared with published frequencies*

Dental Trait		Published data	Recorded data
Shovel shape	"Black"-African	0.11	0.00
	"Chinese"-Asian	0.37	0.39
	"Eskimo"-Inuit	0.73	1.00
Carabelli´s cusp	"Black"-African	0.14	0.09
	"Chinese"-Asian	0.17	0.11
	"Eskimo"-Inuit	0.20	0.00
Cusp number (4 cusps)	"Black"-African	0.43	0.47
	"Chinese"-Asian	0.50	0.55
	"Eskimo"-Inuit	0.26	0.38
Enamel extensions	"Black"-African	0.0-0.8	0.00
	"Chinese"-Asian	0.55	0.55
	"Eskimo"-Inuit	0.47	0.52

burials. Indeed, only in two cases was it possible to determine shovel shape among the 26 skulls of Inuit provenance. Conversely, the three non-metric traits of the jaws could generally be scored in most cases (Palatal Shape in 71/80; Palatine Tori in 72/80, and Mandibular Tori in 64/80) (Table 2).

The dental non-metric traits provided a good basis for deciding ethnicity or provenance (Table 3). It was possible to assign ethnic provenance to 72 of the skulls. The overall agreement was 0.79 and Cohen´s Kappa was 0.69. The agreement rates and Cohen´s Kappa values for each ethnic category is given in Table 4. It is seen that Africans/ "Blacks" had the best agreement, while the Asian/"Chinese" category had the worst.

The results for the dental non-metric traits showed that the traits in general followed the expected frequencies (Table 5a). For the non-metric jaw traits "Inuit" in general had horseshoe shaped palates, "Chinese" had v-shape, and "Blacks" had parallel sided palates. Mandibular and palatine tori were rare in the "Black" and "Chinese" groups while both kinds of tori were frequently seen in the Inuit group (Table 5b). Jaw traits were compared with published data. Overall the above mentioned characteristics of this material were also described in former publications. [8-11]

The FORDISC programme correctly assigned ethnicity based on skull measurements in 71 % of the cases (Table 6). Cohen´s Kappa was 0.59. Ten skulls were assigned to the "White" category. The agreement rates and Cohen´s Kappa values for each ethnic category is given in Table 7. These values are generally comparable to the values for the non-metric traits: in both instances Asians/"Chinese" have the lowest agreement, and low Kappa values.

DISCUSSION

The purpose of this investigation was to evaluate whether an old collection of skulls was of any value with regard to morphology studies. Due to the quality

Table 5b: *Frequencies of recorded non-metric jaw traits*

Jaw Trait		Recorded data	Published data
Palatal Shape	"Black"-African Parallel sided	0.54	0.46
	"Chinese"-Asian V-shaped	0.55	-
	"Eskimo"-Inuit Horseshoe shaped	0.80	0.50
Palatine Torus	"Black"-African	0.04	0.05
	"Chinese"-Asian	0.05	-
	"Eskimo"-Inuit	0.25	0.25
Mandibular tori	"Black"-African	0.05	0.08
	"Chinese"-Asian	0.00	-
	"Eskimo"-Inuit	0.35	0.47

Table 6: *Agreement between ethnicity as by morphometry, (columns) versus labels, (rows)*

	African	Asian	Inuit	European	Total
"Black"	21	3	1	3	28
"Chinese"	2	13	1	6	22
"Eskimo"	1	4	19	1	25
Total	24	20	21	10	75

Table 7: *Morphometric agreement rates and Cohen´s Kappa values for each ethnic category*

Ethnic category	Overall agreement	Cohen´s Kappa
"Black" - African	0.87	0.71
"Chinese" - Asian	0.79	0.47
"Eskimo" - Inuit	0.89	0.75
All	0.71	0.59

of the skull material, with a number of missing teeth and fragmented jaws, it was not possible to record all traits in all individuals. There were some difficulties especially concerning shovel-shape on Inuit incisors. These teeth have extremely short roots resulting in the fact that the majority of these were lost postmortem. We chose to record the non-metric traits, which in our experience are the most used in forensic odontological casework. Results were compared with published data and overall the frequencies of the dental non-metric traits recorded in this study were in accordance with data published by Scott and Turner.[6]

Palatal shape was based only on a morphological evaluation. No measurements were taken to evaluate this trait. The results were compared with data published by Gill[8] and Byers *et al.*[9] and seemed to follow the pattern described. However, direct comparison was not possible in all cases. Concerning frequencies of tori, the Inuit group tended to have these traits more often than the two other groups. This is in concordance with data published by Hrdlicka,[10] Petersen[11] and Hauser *et al.*[12]

As seen in Tables 4 and 7, there was a slightly better overall agreement when using non-metric traits than morphometrics, although for the case of Inuit/"Eskimo" category the opposite was the case. The lower agreement is to some extent due to the fact that the FORDISC programme was allowed to score a case as "White", even though none of the cases was labelled as such. When judging the non-metric traits, assignment was made to only the three categories of provenance. Even though our study was conducted in blind trials, the investigators knew that all cases were belonging to the categories "Black", "Chinese" or "Eskimo". It should be added that the FORDISC programme has data on Inuit skulls from our collections, but these data were collated from the pre-colonial part of the collections.

Even though the FORDISC programme has scored sex of the individuals, it is not published here since the aim of this study was to evaluate ethnicity.

As a test for non-metric traits *per se*, we could have included skulls of European (Danish) extraction but chose not to. This was because the aim of the study was to evaluate not the single traits, but rather how these traits were represented in the collection. However, Cohen´s Kappa statistic for evaluating the agreement was included, in order to see if the predicted categories did reflect real ethnic differences in trait frequencies and skull morphometrics. Except for the morphometric analyses of the Asian/"Chinese" skulls, with a Kappa statistic of 0.47, the Kappa statistics were in the range 0.55 - 0.78, indicating fair agreement.

Underlying the whole project, both in terms of the labelling of the cases, as well as the tabulation of traits and measures by ethnic group, is the question of race. When the collections were established, skulls were traded and swapped between anthropological institutions. It was thought that even just a few skulls could clearly "define" the special characteristics of the different races, although it was not clear what was meant by the term, nor how many races there were. Indeed, in the collections there is a skull labelled as "Gypsy", and another as "Swede". Clearly, such labels are meaningless as the variation of population, even inside smaller population groups, is much bigger than can be accounted for by a few skulls. The labelling of the skulls is clearly inadequate: what exactly is meant by the term “Black” or “Chinese, from Penang”? On the other hand, geographical differences in dental and cranial traits and sizes do exist, but it cannot be seen as definite, discriminate groups, but rather as “clinal” differences.[13,14] However, it was found that traits and cranial measures, as recorded for modern population groups, are reflected in the collections. This means that the skull collection can be used as training material, as it does allow the forensic odontologist or anthropologist to see these traits and perform morphometrical analyses.

The acquisition of this collection, sometimes by indiscriminate exhumation of graves, sometimes from local anatomical departments in far away countries (at the time run by European doctors and clerks), cannot be considered ethical by today’s standards. On the other hand, while some material has been repatriated, this requires a specific knowledge of provenance. In the case of the Greenland samples, for example, an agreement has been made with the Greenland National Museum so that it now owns the Greenland material, and research may only be performed following permission from the authorities. The material still resides at the University of Copenhagen, as it is considered a scientific and archaeological material. It may ultimately be fitting that these skulls may assist in better and faster identification of the dead, and not only be an example of racial prejudices of the past.

CONCLUSION

This historical collection does show expected dental non-metric and craniometric traits and, as such, may be of value in forensic casework in terms of comparison and for teaching purposes. Although not all skulls have definite archaeological descriptions, we would argue that this may indeed be an advantage, as it must be foreseen that previous strict geographical or ethnic categories will not be applicable in the future.

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FORENSIC FACIAL APPROXIMATION: AN OVERVIEW OF CURRENT METHODS USED AT THE VICTORIAN INSTITUTE OF FORENSIC MEDICINE/VICTORIA POLICE CRIMINAL IDENTIFICATION SQUAD

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ABSTRACT

Forensic facial approximation involves building a likeness of the head and face on the skull of an unidentified individual, with the aim that public broadcast of the likeness will trigger recognition in those who knew the person in life. This paper presents an overview of the collaborative practice between Ronn Taylor (Forensic Sculptor to the Victorian Institute of Forensic Medicine) and Detective Sergeant Adrian Paterson (Victoria Police Criminal Identification Squad). This collaboration involves clay modelling to determine an approximation of the person's head shape and feature location, with surface texture and more speculative elements being rendered digitally onto an image of the model. The advantages of this approach are that through clay modelling anatomical contouring is present, digital enhancement resolves some of the problems of visual perception of a representation, such as edge and shape determination, and the approximation can be easily modified as and when new information is received.
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Key words: Forensic facial approximation, face perception, facial recognition, forensic facial reconstruction, forensic art

INTRODUCTION

Forensic facial approximation involves approximating the appearance of an unknown individual in order to establish both the legal requirement and social right to identity. In Western countries 0.1% of deaths cannot be readily identified,[1] and therefore a facial approximation may be performed. Melbourne University and the Victorian Institute of Forensic Medicine prefers the term 'facial approximation' over the more popular 'facial reconstruction', given that the aim is to produce a likeness. That is, no aspect involved in the process can be regarded as absolute; recommendations for modelling the head and face are built upon reasonable assumptions drawn from statistical averages of human variation, and are therefore approximate.[2-4] In order to achieve identification, an image of the approximation is broadcast in the media to stimulate recognition in the minds of those who knew the person in life. Those whose memories are triggered by the approximation may be family, friends or colleagues, but some leads to identification have been provided by more casual acquaintances.[5]

Many forensic facial approximations are either manual (clay modelling) or virtual (computer graphic simulation), with the focus of much recent research being on the virtual. Virtual approximations typically involve scanning the skull, producing a wire-frame image, and then applying soft-tissue depths at appropriate points to produce a representation of a face. As clay modelling requires anatomical knowledge, sculptural ability, experience and time, it is hoped that a virtual approximation will both simplify the process and be faster.[6] However, to date virtual methods tend not to allow for the contouring of facial anatomy, being dependent on a limited set of craniofacial points, although this data set is expanding.[7,8]

Since 1990 the Forensic Sculptor to the Victorian Institute of Forensic Medicine (VIFM) has collaborated with the Victoria Police Criminal Identification Squad, which has resulted in a method which utilises the advantages of both clay modelling and computer graphics. That is, modelling is used to determine an approximation of the person's head shape, anatomical contouring and feature location, and computer graphics to enhance edge and shape definition and add more speculative elements, such as hair style. Although the generation of leads through public broadcast is dependent on the timing and extent of media coverage,[3,5] to date this collaboration has involved eight cases, contributing to two successful identifications.

Modelling

The clay modelling phase of the approximation occurs in a team environment, drawing on a range of forensic specialisations, including, but not limited to, forensic pathologists, odontologists, anthropologists and crime scene investigators.[1] The skull and post-cranial remains are examined to suggest the most likely population of origin, sex and age,[9] and if present, evidence from the scene can also suggest body weight, hair shape and colour. While some forensic sculptors prefer to work directly onto the original skull,[10] use of a plaster cast for the facial approximation reduces the risk of damage to the original skull and ensures that the original is available for reference during the approximation process. Due to the method used, the completed cast retains important information about muscle attachments and bony landmarks that assist in the reconstruction process.[11]

In order to build the anatomy of the face upon the skull, modelling incorporates soft-tissue depth data. That is, statistical averages of soft-tissue depths at specific craniometric points, taken from living individuals through the use of ultrasound.[5,12] Soft-tissue depths are applied to the skull by the use of pegs, which involves drilling holes in the plaster cast of the skull at 19 craniometric points, and inserting the pegs to the length indicated (Fig.1). As Brown *et al* point out, no standard set of craniometric points currently exist,[13] but the VIFM modelling method uses Helmer's ultrasound data set as this includes variation according to the approximated age, sex and body weight of the person.[14]

Once the pegs are in place, the soft-tissues of muscles, glands, fat and skin are built up as individual components in a stylised, yet systematic fashion, and the tissue depth pegs are used as general indicators (Fig.2). Overall head shape is largely determined by the morphology of the cranium and mandible, and the bulk of the temporalis and masseter, with muscle position and strength being indicated by attachment markings on the skull.[5,12,15] Research by Wilkinson, and Stephan, has resulted in guidelines for approximating nose projection and pronasale position,[12,16] mouth width,[12,17] eyeball placement and projection.[12,18] Fedosyutkin and Nainys

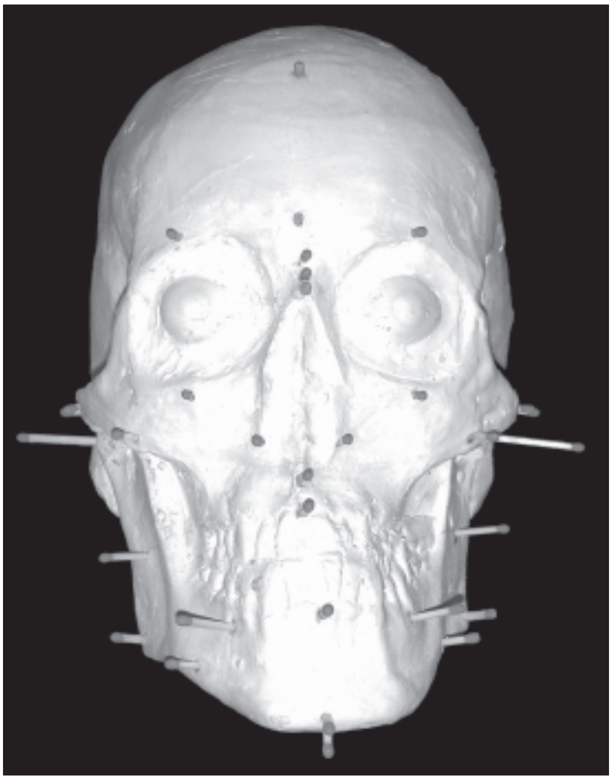

***Fig.1:** Plaster cast of skull with soft-tissue depth pegs*

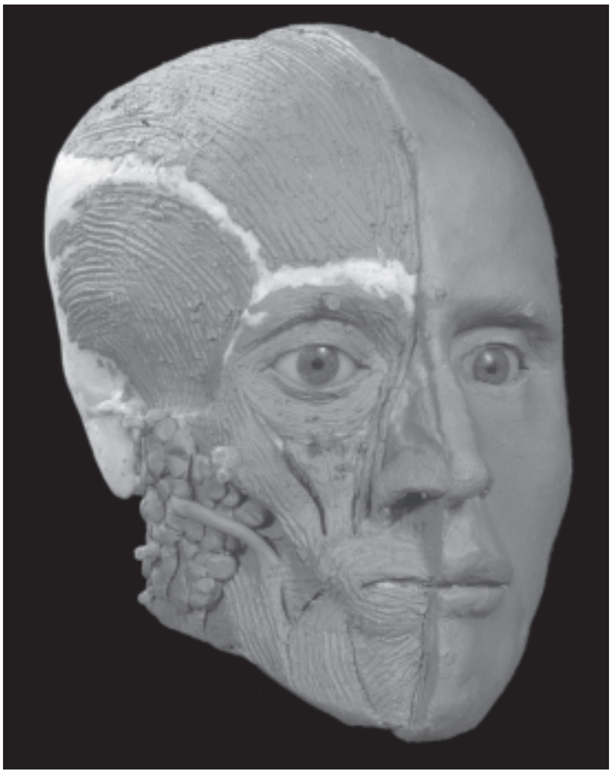

***Fig.2:** Anatomical modelling of soft-tissues*

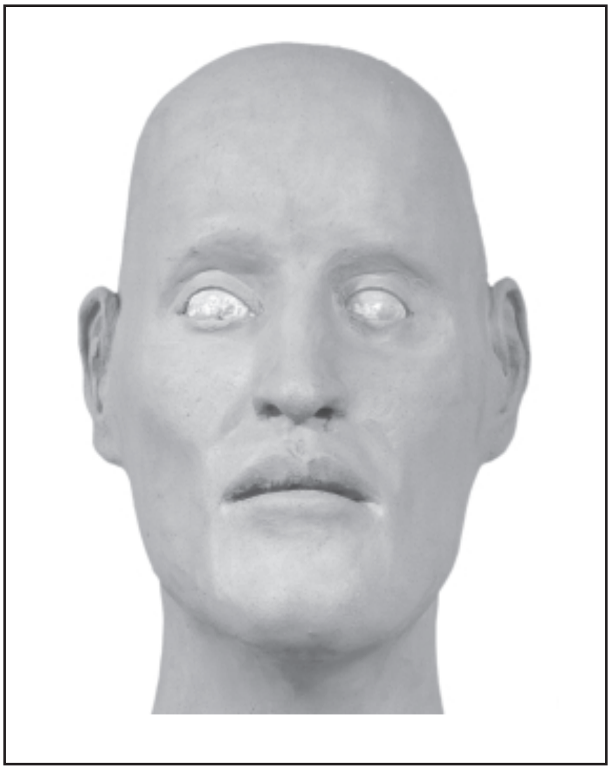

Fig.3: Base-line model

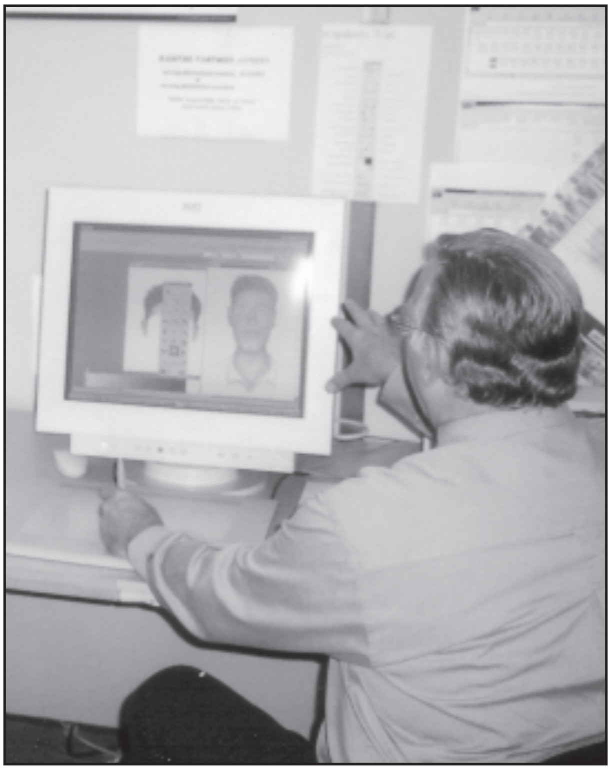

Fig.4: CIS image database

provide approximate morphological relationships for the location and length of the eye slit and brow shape,[15] while lip thickness can be inferred from dental occlusion patterns,[12,19] and ear location from the position of the external auditory meatus.[12]

What cannot be approximated from the morphology of the skull alone includes hair style and colour, eye colour, skin colouration and texture, nose and ear shape, and the lines and folds of the skin,[12,15] though Neave[20] has developed a series of typical age-related changes in an adult face.

In keeping with the need for the most accurate approximation based on the morphology of the skull, the method for modelling utilises an unembellished style. That is, the technique allows facial shape to predominate and feature location (eyes, mouth, nose) to be clearly seen (Fig.3). The desired outcome at this stage of the process is to produce a forensically defendable base-line model. This is not, however, the final appearance of the approximation. Research suggests that face perception and recognition requires the addition of surface appearance and some speculative detail,[12,21] particularly when viewing a representation, or likeness, of a face.

Graphics

Recognition research suggests that memory for faces is primarily triggered by the overall shape of the head and face and the spatial relations between the features.[22] The identification of strangers is more reliant upon the external aspects of face shape and hair style, while recognition of familiar faces tends to focus on internal features,[21] with the eyes taking precedence over the mouth, and the nose being less important.[12] With the exception of hair style, accurately approximated clay modelling complies with these requirements for recognition, providing overall head and face shape and featural location. However, face perception requires further information concerning texture and indications of depth and form,[12,21] elements which are often obscured by, or absent from, approximations of the face. Using the skills and technology of the Victoria Police Criminal Identification Squad (VPCIS) these elements are added digitally to the model.

Once the modelling stage of the approximation is complete, a digital image is taken under neutral lighting. The resulting file is loaded into the VPCIS graphics programme, and the Facial Automated Composition and Editing (FACE) database accessed

(Fig.4). FACE was initially developed in Victoria in 1986, and currently comprises an extensive database of facial components according to population of origin, sex and age.[23]

The first stage of the digital approximation process is to select an appropriate flesh tone according to the deceased's population of origin. Hair colour and texture is then selected, drawing from the database a close match to any hair that may have been found by the forensic team. If no hair is available, the tone used to render the hair is darker than that used to show skin, but not overly so. A mid-dark tone with highlights used to indicate external light enables multiple readings of 'colour', even light coloured hair.[10] The style of the hair depends on the age and sex of the deceased, and the year that death occurred, and is modified to 'fit' the shape of the cranium, which Fedosyutkin and Nainys suggest influences hair style.[15] However, as hair style and head shape constitute key requirements for recognition,[21] care is taken to ensure the hair style, which is speculative, does not detract from the overall head shape provided by the clay model.

Eyebrows are matched in colour and texture to the hair, and applied. While the supraorbital ridge and superciliary arches can suggest brow shape,[15] thickness is speculative, and therefore the rendering is unobtrusive.

Despite featural location, and to an extent, shape, being clearly indicated on the model, one effect of clay, even with a flesh tint overlay, is to produce a monotone. Monotone has the visual effect of diffusing edge boundaries, making shape discrimination difficult and reducing the ability to recognise a familiar face.[12,21] Using a graphics tablet, the next stage is to emphasise the edge and shape information available on the model. Lash lines are drawn in to more clearly indicate the eye slit, and the pupil and iris blocked in. Colour of the iris will be dictated by population of origin; for Caucasians a hazel iris is recommended as it is visually inclusive of a fairly wide range of possibilities.[10] Shading and highlights are used to show the vermilion line, lip tonal density, and to subtly emphasise the nasal wings and pronasale. As with most forensic art the light source used to add highlights, general facial contouring and plane shifts (such as temple to forehead) is multidirectional, to ensure all features are given equal visibility.[10] Dramatic lighting, where part of the face is given greater visual weight, can radically alter appearance and there is evidence that this disrupts facial recognition.[24]

Because face perception and facial recognition require both edge and shape information, the best angle to present the face is three-quarter profile, similar to that utilised by portrait artists.[21] Most forensic images of the face, as with standard identification images, are full face,[10] which perception research suggests is the hardest to see. What is most obscured by a full face view, however, is the shape of the nose.[21] However, determination of the nose from the morphology of the skull can only suggest the likelihood of nose projection and placement of the pronasale;[16] the finer details of shape are more speculative. Therefore, as edge and shape information is generally clarified through shading, and ambiguity concerning nose shape more accurately represents what can be approximated, a full face view is more advantageous. Further, recognition research indicates the three-quarter view only really benefits memory of a previously unfamiliar face, with familiar face recognition being not as view dependent.[21]

The overall graphic style utilised for adding textual elements is smoothly blended, which as well as being unobtrusive, has the added advantage of reducing pixelations formed during the digital process (Fig.5). Although it is possible to produce an image with a simulation of a photographic finish, such an effect implies specificity, not approximation,[10] and may mislead the viewer. In addition, according to

Fig.5: *Completed facial approximation for broadcast*

visual processing research, vision is an active process, both enhancing and interpreting what is received and drawing on past experiences and expectations in order to 'see'.[21] To enable this active process, which is necessary for face perception to take place, a represented face (as opposed to 'real') requires areas of less definition, of ambiguity; areas that can be filled in by the individual.[25]

Although the final image can be printed in colour, for forensic facial approximations the preference is for greyscale. This is because greyscale allows for multiple readings of skin, hair and eye colour;[10,21] information that cannot be determined from the skull alone. If the evidence gathered by the forensic team suggests a range of possibilities regarding body weight and hair style then the approximation may be reworked and alternatives produced, allowing for differences in the fullness of the face, length of hair, the presence of facial hair, and so forth. The purpose of the final approximation is to evoke recognition, not prove identity, and variations in the more speculative elements of the deceased's appearance are used, when required, to further stimulate public interest and input.

CONCLUSION

The VIFM/VPCIS method of forensic facial approximation works within both the known parameters of clay modelling upon the skull and the visual requirements for perception and recognition of a represented face. Following skull replication and insertion of appropriate soft-tissue data guidelines, clay modelling is used to establish an approximation which clearly displays head and face shape, anatomical contouring and feature location. The VPCIS image database and graphics program is then used to overlay more speculative elements, such as hair style and texture, and a graphics tablet is used to add perceptual information concerning shape and edge definition. Where there is confidence concerning the likely appearance of a particular facial feature, such as head shape and feature location, these elements are emphasized, with less detail going to the more indeterminate aspects. A benefit of this method is that the digital image can be easily modified should subsequent forensic examination alter the initial findings, or when new leads concerning the possible identity of the deceased are received.

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UNUSUAL FATAL DOG ATTACK IN DUNEDIN, NEW ZEALAND

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ABSTRACT

A case of a fatal dog attack on a middle aged woman is presented. The offending dog was her own Bull-mastiff, which had previously shown signs of aggression towards her. Most of the injuries were found on the victim's face, neck and skull. A noteworthy feature of this attack was that the victim was known to suffer from Huntington disease. It is postulated that the involuntary movements, progressive dementia and increased moodiness characteristic of the disease may have had a significant role in triggering the attack.

(J Forensic Odontostomatol 2005;23:51-4)

Key words: bite marks, animal attacks, dog bite

INTRODUCTION

Man's best friend sometimes doesn't live up to the billing. Despite dogs having been domesticated for an estimated 12,000 years[1], the capacity for any animal to become violent when sufficiently provoked remains inherent. Dog attacks on humans receive considerable attention in the media and are an ongoing area of interest for medicine, veterinary science and forensic science.[2-7] Veterinary behaviourists note that canine aggression is usually directed towards persons known to the dog, and is ascribed to the diagnostic criterion of 'dominance'.[8-10]

With a population of 4 million, it is estimated that there are over 600,000 dogs in NZ .[11] Two previous studies have examined the incidence of hospitalisation for dog bites in New Zealand. In the first study, Langley [12] gathered data from the period 1979 to 1988 and reported that there were 961 dog bites resulting in hospitalisation, with no fatalities reported over this period. The second study examined hospital records between 1989 and 2001 and found that there were 3,119 hospitalisations and one fatality.[13] Of these, 94 were estimated to have been from being 'struck' by a dog, rather than being bitten. Thus 3,025 hospitalisations were estimated to have resulted from dog bites. Additionally, the New Zealand Health Information Statistics recorded 309 overnight visits after dog bite incidents in 2000, 293 in 2001, and 324 in 2002. These figures appear to represent an escalating trend in admissions similar to that observed in other countries.[14]

Marsh[13] reported that in New Zealand, Europeans represent 52% of the total bite victims, Maori 28% and others 20%. Maori make up 15% of the total population, and hence are over-represented. He also found that, where location was specified, 30% of victims were bitten at home, 6% on the street and 1% on a farm. Of the total sample 60.5% of bites were to males.

In this report we detail a recent fatal dog attack in Dunedin, New Zealand, a case which is complicated by the suggestion that the victim's medical condition could have provoked her dog's behaviour.

CASE REPORT

On 18 August, 2004, a Dunedin woman was savaged to death by her pet Bull-mastiff dog. A confrontation had apparently occurred in the lounge of her family home after which the dog dragged her outside and continued the attack. The victim received major head, neck and upper-limb injuries in the attack. The Bull-mastiff is thought to have released its owner of its own accord and was wandering around the back yard in an agitated state when police arrived.

The 5-year-old male dog had been the subject of four reports to animal control teams in the previous 18 months – twice for barking, once for straying and once for its aggressive behaviour towards the victim. The victim had also previously contacted the local authority to complain of the dog's increasingly aggressive behaviour, but then withdrew consent for it to be impounded.

The victim was a slightly built (46kg) woman of 39 years of age. Examination showed extensive bites

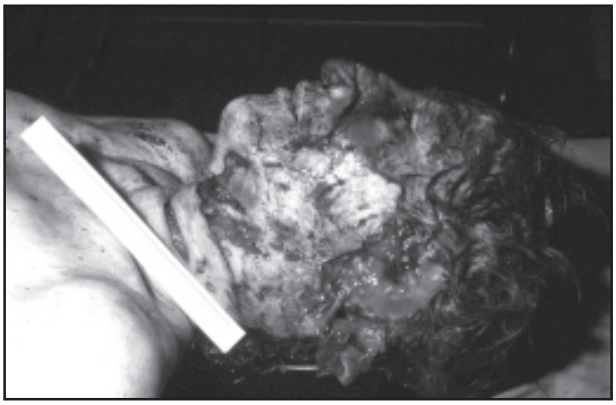

Fig.1: *Multiple injuries on the left half of the face and neck, and loss of the left ear of the victim*

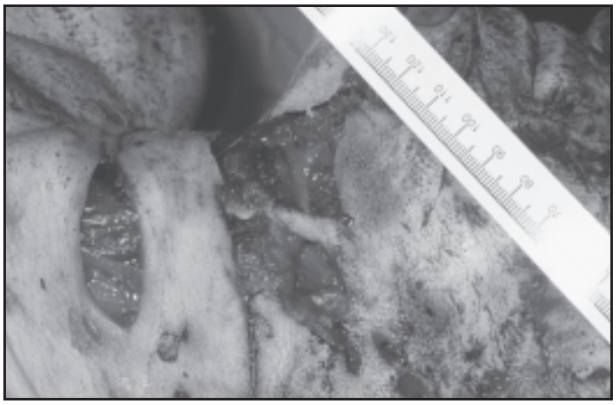

Fig.2: *Dog bite wounds on the neck of the victim*

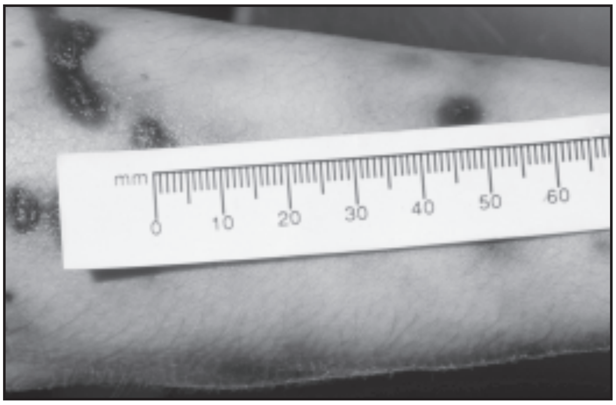

Fig.3: Canine puncture marks on left arm of the victim

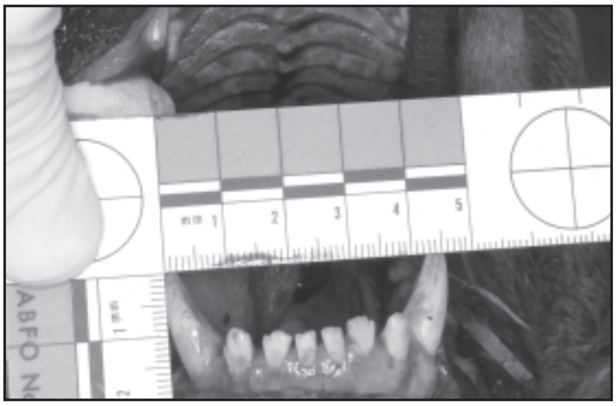

Fig.4: Lower anterior dentition and intercanine distance in the dog involved

to both right and left arms, originating just above the elbow. While there were what appeared to be healed bite marks and bruises on her lower legs, there were no fresh bite marks in these areas.

The majority of the serious wounds were found on the victim's face, neck and skull (Fig. 1). A laceration (70mm long, 8mm wide) extended from 1cm below the right inner canthus across the bridge of her nose and terminated above the left infra-orbital foramen. The left ear and soft tissue covering the back of the skull was missing. There were firstly, a 25mm laceration running medially over the right temporalis above the level of the eyebrow and secondly, a 35mm gaping laceration midway between the brow and the hairline extending from above the outer canthus of the eye to the midline. Her lower face was untouched. The largest wounds were to the back and left side of

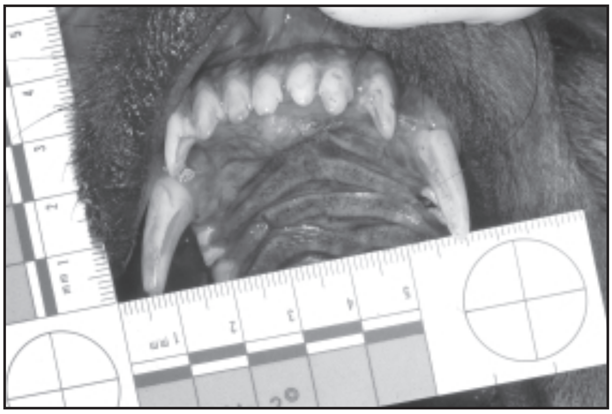

Fig.5: *Upper anterior dentition and intercanine distance in the dog involved*

the neck (Fig. 2). The back of the neck showed a large gaping wound, 70mm long, just below the hairline, whilst the left side had a 55mm long tear running horizontally at the level of the thyroid cartilage. Superior to this were two lacerations of 30mm each with a small isthmus of tissue separating them. Each of these terminated over the region of the hyoid. Numerous canine drag marks were visible over the skull, upper face and arms. There were also extensive bite wounds on both the left and right forearms and on the left arm there were two canine puncture marks 46mm apart (Fig. 3). This corresponded to the Bull-mastiff's intercanine distance measured at autopsy (Figs 4 & 5). A canine puncture wound was found in the trachea on her left side coincident with the most caudal of the three lacerations found in that region.

In the light of the autopsy findings, the coroner attributed the cause of death to exsanguination and asphyxia.

VICTIM'S MEDICAL HISTORY

What makes this a noteworthy case is the interesting effect that the victim's medical condition may have had on the attacking dog. She was known to have Huntington disease (HD), also known as Huntington chorea (HC), an inherited disease (autosomal dominant with complete penetrance) characterised by choreiform involuntary movements and slowly progressive dementia.

It is known that a significant number of persons affected by HD present with primary complaints of involuntary movements or rigidity. For the remainder of cases, the primary presentation is of mental changes that initially appear as increased irritability, moodiness or antisocial behaviour. Patients may become emotionally volatile, argumentative, erratic or physically aggressive. The classical presentation of choreiform movements begins as a piano-playing motion of the fingers or as facial grimaces. As the condition advances it involves the trunk, and a characteristic dancing gait results. Although patients appear to be off-balance, the ability to balance is actually well preserved. Patients may be impulsive or seem to act irrationally.[15]

Canine aggression has traditionally been attributed to dominance, or an attempt by the dog to achieve a superior rank among members of the household.[10] However, it is also recognised that dogs showing dominance aggression might actually be responding to anxiety rather than to a challenge to their perceived rank.[16,17] This may have been a precipitating factor in the present case.

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DENTO-MAXILLO-FACIAL RADIOLOGY AS AN AID TO HUMAN IDENTIFICATION

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ABSTRACT

Analysis of some anatomical structures of the face using radiographs is fundamental for human identification. The position of the postmortem skull relative to the radiographic machine and the film, as well as the exposure time, are the greatest problems found by the forensic dentist. In view of this fact, some recognised radiographic techniques that are used *in vivo* must be adapted. This paper shows that simple devices can make the process easier and that variation of kVp or exposure time in different situations may increase the quality of the radiographs.
(J Forensic Odontostomatol 2005:23:55-9)

Key words: human identification, radiology, radiographic techniques

INTRODUCTION

Identification by means of dental elements is a process known to have existed since 49 AD, when the first case was recorded. Agripina, Nero's mother, ordered her enemy Lollia Paulina to be sacrificed, demanded her head and was convinced only after Agripina had found traceable signs of her dentition. This identification process continued to be performed empirically for centuries, until Oscar Amoëdo published "L'Art Dentaire em Médicine Legale" in 1898, where he suggested that a uniform system should be used internationally to perform an odontogram, a procedure that eventually gave rise to Forensic Dentistry.[1]

In addition to a clinical examination and the annotations on a patient's clinical file, the forensic dentist can make use of dento-maxillo-facial radiography. When bodies are to be identified, radiographs are made of the deceased person and compared with any radiographs of the presumed individual when alive. The following anatomical details should be used as parameters: tooth and root shape, missing and existing teeth, residual roots, supernumerary teeth, attrition or abrasion, coronal fractures, degree of bone reabsorption due to periodontal disease, bone pathology, diastemas, shape of the cavity fillings and cavity liners, dental caries, endodontic treatment, intraradicular posts and intracoronary pins and dental prostheses.[2-6] Several papers also denote the importance of radiography for human identification by the comparative method using trabecular bone patterns,[2] frontal and maxillary sinuses,[3,7] cephalometric[8] and dental radiographs,[9] and growth of finger phalanges.[10]

In cases where there are no previous records to serve as a reference for comparison an alternative is to obtain the most amount of information from the deceased in order to build a profile to assist identification. Sassouni,[11] as well as several other authors,[12-17] reported the great diversity of methods to estimate age through: the chronology of third molar eruption,[12,13] formation of the dentition[14-17] and sutures. Estimating gender by dental anatomy[18,19] and by cephalometric radiography, as well as determining ethnic groups by dental anatomy, are also addressed by Sassouni.[11]

There are several possible radiographic techniques that may be used on corpses to aid human identification. However, if these are performed incorrectly, either antemortem or postmortem, the result may hinder effective identification. Many forensic odontologists have adapted techniques to address the problems of postmortem radiography. The methods presented here are a simple and cost-effective alternative. Radiographic factors that may influence accurate identification are also discussed.

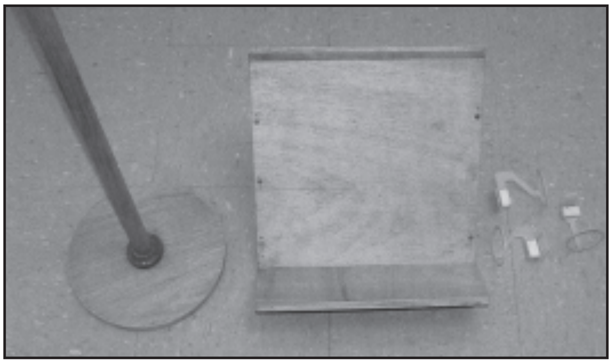

Fig.1: *Supports used for the skull: wooden pole, inclined plane and periapical film support*

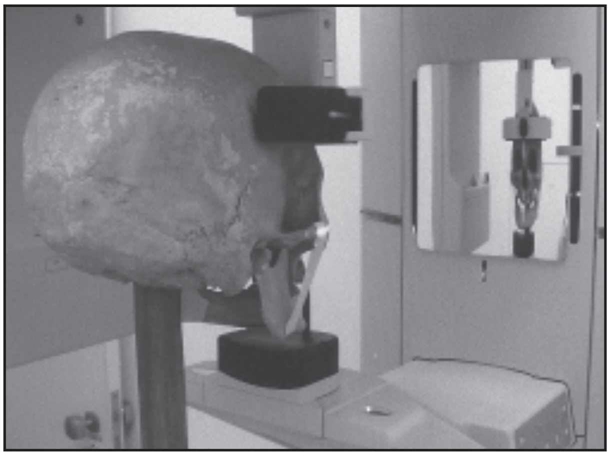

Fig.2: *Skull placed on a wooden pole and positioned in the panoramic x-ray machine*

MATERIAL AND METHODS

About 90% of the anthropological forensic cases that we examine are cleaned skulls, which had already been studied by other forensic professionals. The decomposed tissues are cleared away prior to examination using techniques by Snyder, Burdi and Gaul.[20] To simulate this, skulls retrieved from the archives of the Medical Legal Institute of São Paulo, Brazil have been used to demonstrate techniques that we have found useful in casework.

In general, radiographic film must be placed parallel to the area of interest and x-ray angled perpendicularly to the skull.[21] This presents problems in machines designed for living patients. Fixation supports must be used for the skull to be radiographed in such a way that correct positioning of the skull(s) may be achieved for each technique to be used.

We have used an intraoral unit (Siemens* 70 kVp; 7mA; 0,64s exposure), an extraoral x-ray machine (Instrumentarium-Orthopantomograph†; 81 kVp; 12mA; 0,4s of exposure and 15s for the panoramic technique) and also the following apparatus: a wooden pole with circular base, a wooden inclined plane and crepe paper (to articulate the mandible). The inclined plane is particularly important to individualise one region of interest in the mandible, preventing anatomical structures overlapping. It is fundamental that the positioners be made of wood, since the density of this material allows the x-rays to pass through without interfering with the final image (Fig. 1). Han Shin positioners§ are used for intraoral views.

Radiographic Techniques Adapted for Postmortem Skulls

1. **Postero-Anterior** (to assess maxillofacial and frontal sinuses)
   •Skull: meatal-orbital line 90 degrees from the film
   •X-ray beam: parallel to the meatal-orbital line
   •Central point: midway between the occipital protuberance and the chin, level with the mandibular angle
   •Support used: 1.5m wooden pole with a circular base 25cm in diameter cephalostat.

2. **Towne** (to assess the condyle)
   •Skull: occipital part turned toward the film, meatal-orbital line 90 degrees from the film
   •X-ray beam: 30 degrees from the meatal-orbital line
   •Central point: 5cm above the nasion
   •Support used: 1.5m wooden pole with a circular base 25cm in diameter/cephalostat.

3. **Lateral Technique** (to assess facial bones, sinuses and cranium)
   •Skull: on the cephalostat to standardise the skull positioning, as used in orthodontic assessment
   •X-ray beam: entering perpendicular to the film and parallel to the line formed by the infra-orbital foramina
   •Support used: 1.5m wooden pole with a circular base 25cm in diameter/cephalostat.

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* Siemens AG, Munich, Germany
† Instrumentarium Imaging, Tuusala, Finland
§ Han Shin Technical Lab, Japan

4. **Panoramic Technique** (to assess adjacent structures related to all teeth)
   •Skull: positioned according to the cephalostat (Fig. 2)
   •Support used: 1.5m wooden pole with a circular base 25cm in diameter

5. **Lateral Oblique Projection** (to assess mandible body and retromolar region)
   •Skull: median sagittal plane parallel to the chassis and inclined 60 degrees in relation to the horizontal plane to assess mandible angle and mandible ramus (Figs. 3 and 4) or median sagittal plane turned in 30 degrees towards the chassis and inclined 60 degrees in relation to the horizontal plane to assess mandible body.
   •X-ray beam: rests on the mandibular angle
   •Support used: a wooden inclined plane measuring 22.5cm x 22.5cm x 32 cm, with the following angles: 45°, 45°, 90°, and a base to position the skull, measuring 35cm in length by 12cm in width, perpendicular to the inclined plane.

6. **Intraoral Techniques** (to assess teeth and adjacent bone structures)
   •X-ray beam: vertical angle is varied according to the antemortem radiograph, in order to obtain the most plausible and approximated comparative image.
   •Support used: Han Shin positioner to hold the film

DISCUSSION

Humans have 32 teeth that, in addition to having variable anatomical characteristics, may also be implanted in the bone in several ways, or may contain restorations of differing positions and materials or prosthetic reconstructions of different shapes. All this ensures the individuality of each dentition.[11,22] Teeth are relatively indestructible, and, as such, represent important evidence in the identification process.[23,24]

Both the teeth and the maxillary and mandibular bones may be visualised in intraoral or extraoral radiographs. Hence, the use of radiographs becomes fundamental in identifying humans. Since the great majority of the population today has already had some type of radiograph taken at the dentist's or the doctor's office, the records of these professionals provide a vast source of information that should be kept responsibly in an organised file.

These radiographs may be compared with that of the supposed deceased individual in order to aid identification. However, in so doing, the expert must observe some fundamental points such as the position and fixation of the skull relative to both the x-ray machine and the film position.

It is important that the expert be aware of some of the limitations he/she will come across when

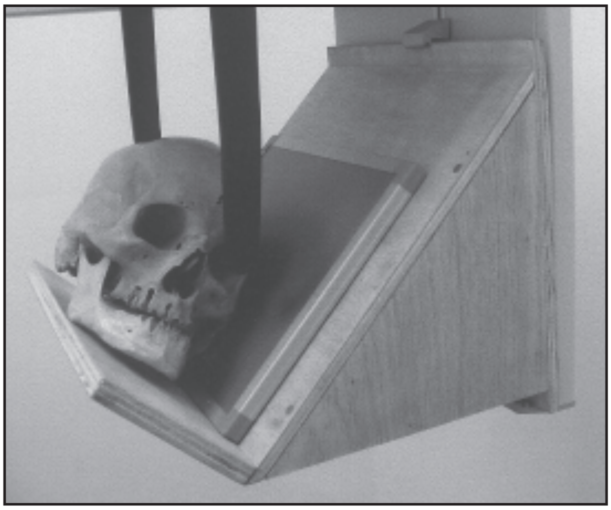

***Fig.3**: Skull placed on the inclined wooden plane adapted to the chassis holder of the teleradiography x-ray machine to make lateral oblique radiographs of the mandible for angle and body*

***Fig.4**: Lateral oblique radiograph of a mandible for angle and body obtained with the same positioning as the previous figure*

interpreting the images and comparing them with those of the supposed individual when alive. It is not always possible to reproduce the exact radiographic technique used before, especially if a radiograph was made by the bisecting plane technique of intraoral films. Obviously, the best results are obtained when the angle of the film is the same as that of the original film. Therefore, several attempts should be made by varying the angle, as described. Greater approximation will be possible if the size of the canal and the shapes of the restorations are used as parameters.[25]

The time interval between the antemortem and the postmortem radiographs may lead to a number of changes in both the teeth and the supporting bone.[3] Although the dental crown may be modified by surgical procedures, or by a pathological process such as dental caries or attrition, the pulpal outlines often remain intact.[26] Due to recent preventive techniques there has been a reduction in restored teeth in the population, leading to considerably fewer parameters for comparison.[27]

It is also important to note that the beam may travel through structures with different thickness when comparing the antemortem to the postmortem exposure, i.e. an inflammatory process or increased cheek thickness may cause a change in the density of the image obtained in the antemortem radiograph as compared with the post mortem radiograph. Teeth and bones that have been incinerated or immersed in water for a long period of time, or that have been subjected to other effects of nature, may show variation in structural density, or in the material used to restore the teeth.[25] Therefore, when the density of the radiographed structure is greater, the kVp to be used should also be greater, and vice-versa.[28] That way, the radiograph will qualitatively approximate the antemortem radiographic image.

A dry skull has a lower density than a live skull; therefore, the kVp to be used should be lower. Skulls with vestiges of soft tissue should be exposed with half to two-thirds of the normal exposure time.[21,29] Obviously, in machines having fixed kVp and milliamperage (mA), the only variable factor is the exposure time. If it is increased, the radiograph becomes denser.

Better film processing results are obtained when the visualisation technique[25] is used, since various time settings may be used according to different bone densities, unlike that afforded by the automatic process. It must further be stressed that old radiographs that are very dense (dark) may be "improved" using Farmer's manipulated solution[29] (distilled water-1 litre, potassium ironcyanide 30 gr, sodium hyposulphate), which lightens radiographs. This toxic solution should be handled carefully. The technique of washing, fixing, rewashing and drying helps decrease the incidence of radiographic discolouration.

Another resource available today is radiograph scanning and digitalisation techniques. Mathematical treatment of the image can alter the initial appearance of the radiograph, especially in terms of contrast, brightness and density. Other numerous software features as noise reduction filter, highlight, inversion or zoom can be used looking to improve the image. This treatment results in change to the original image and must be carefully documented in order to withstand legal scrutiny.[30] Several different measurements may also be made of both antemortem and postmortem radiographs, comparing them by way of the image subtraction technique.[31] New technologies may open new avenues for this type of identification. The Internet may be useful in international cooperation efforts to identify bodies by allowing the efficient transfer of images.

CONCLUSIONS

1. The teeth, their natural anatomical characteristics and those introduced by dental treatment, as well as the way they are implanted and the bone architecture, are fundamental to individualisation in human identification.

2. Intraoral and extraoral radiographs are an effective, cheap and safe method of human identification by comparison.

3. Radiographic comparisons may be carried out using several radiographic adapted techniques, aided by devices that make dry skull fixation easier, in order to obtain correct positioning.

4. In order for the comparative technique to be effective, multiple exposures should be made using several different angles, and using canal size and restoration shape as parameters of comparison for approximate identification.

5. kVp or exposure time may have to be changed depending on the density of the structure to be radiographed.

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