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RESEARCH

HISTORICAL REVIEW

FORENSIC IMPLICATIONS OF THE VARIATION IN MORPHOLOGY OF MARGINAL SERRATIONS ON THE TEETH OF THE GREAT WHITE SHARK

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ABSTRACT

The teeth of the Great White Shark have been examined to ascertain whether there is any commonality in the arrangement or number of the marginal serrations (peaks) or, indeed, whether individual sharks have a unique pattern of shapes or size of the peaks. The teeth of the White Shark are characteristic in size and shape with serrations along almost the entire mesial and distal margins.

This study has revealed no consistent pattern of size or arrangement of the marginal serrations that was sufficiently characteristic within an individual shark to serve as a reliable index of identification of a tooth as originating from that particular shark. Nonetheless, the serrations are sufficiently distinctive to enable the potential identification of an individual tooth as having been the cause of a particular bitemark. (**J. Forensic Odonto Stomatology 1996 14:1, 3-9**).

Keywords: Sharks, *Carcharodon carcharias*, teeth, shark bites, identification.

INTRODUCTION

The Great White Shark (*Carcharodon carcharias*, Order Lamniformes, Family Lamnidæ) is a formidable predator combining large size, powerful jaws and efficient locomotion.[1-3] Like the Hammerhead sharks (Order Carchariniformes, Family Sphyrnidæ) and Requiem sharks (Order Carchariniformes, Family Carcharinidæ), it possesses a highly efficient dentition[1-4] and is ideally suited to preying on larger fish and aquatic mammals. It is the largest flesh-eating shark and is responsible for the majority of shark attacks on humans.[1,2,5]

The teeth are monocuspid with enameloid crowns shaped as flat triangles with particularly sharp cutting edges, resembling saws, made up of minute serrations along the margins. The function of such teeth is to allow cutting and shearing of large chunks of flesh since these sharks often prey on animals too large to be swallowed whole.

The marginal serrations (denticulate cutting edges) of the teeth of the White Shark, which appear regular to the naked eye, were found to be quite varied in their peak-sizes when photographs of the teeth were enlarged.

In forensic investigations of shark attacks it is sometimes necessary to identify the species, or even the individual shark within a species, which caused the bite or to ascertain whether the marks were made by a shark at all.[1,2] It is therefore of interest to know whether there is a consistency in the arrangement or number of marginal serrations on a tooth within a shark species or whether individual sharks have a unique pattern of shapes, sizes or arrangement of the serrations or peaks. In this study we have attempted to determine whether there is any commonality in the arrangement and sizes of the peaks on the tooth edges within a single White Shark specimen or across the species.

MATERIALS AND METHODS

The dried and preserved jaws of three White Sharks were used in this study. One was a contribution from a local fisherman (Shark 1 = 3.27 m long), the second was a museum specimen (Shark 2 = 4.34 m) and the third a juvenile shark (Shark 3 = 1.75m) which was captured during the period of this study and made available to us.

Photographic Procedures

Photographs of the teeth were taken on 35 mm monochrome film format. A 55 mm camera lens, usually used for close-up photography, was employed in this study because its 'macro' lens function allowed higher magnification of the image within the film frame. Despite the depth of field of some lenses being shallow, an acceptable plane of critical focus could be obtained because these shark teeth are relatively flat. A good plane of focus ensures that the cusp tip and sides of the base are in focus (i.e. the three points of the triangular tooth are parallel to the film plane). For printing, images of the teeth were enlarged by a standard factor of 3.5 times with the aid of accurately printed metric scales laid on each tooth. The factor of 3.5 was chosen because it allowed even the largest shark tooth to be printed on the 127 mm by 178 mm (5 in. by 7 in.) photographic paper.

Nomenclature

A system of notation has been devised[1,2] in which the teeth of the shark are numbered sequentially for easy identification. This Shark Tooth Identification Notation System (S.T.I.N.S.) has been modelled on the Federation Dentaire Internationale (F.D.I.) system of notation which is currently used by the dental profession for classifying human teeth, with that system being modified to include the greater number of teeth present in the shark (Fig.1)

An imaginary line is drawn through the midline (corresponding to the symphysis) of the upper jaw to a point midway between the jaw articulation points, thus dividing it into two equal parts. The lower jaw is similarly divided into two so that the whole jaw is effectively divided into equal quadrants. A two digit number is employed to identify an individual tooth in each quadrant

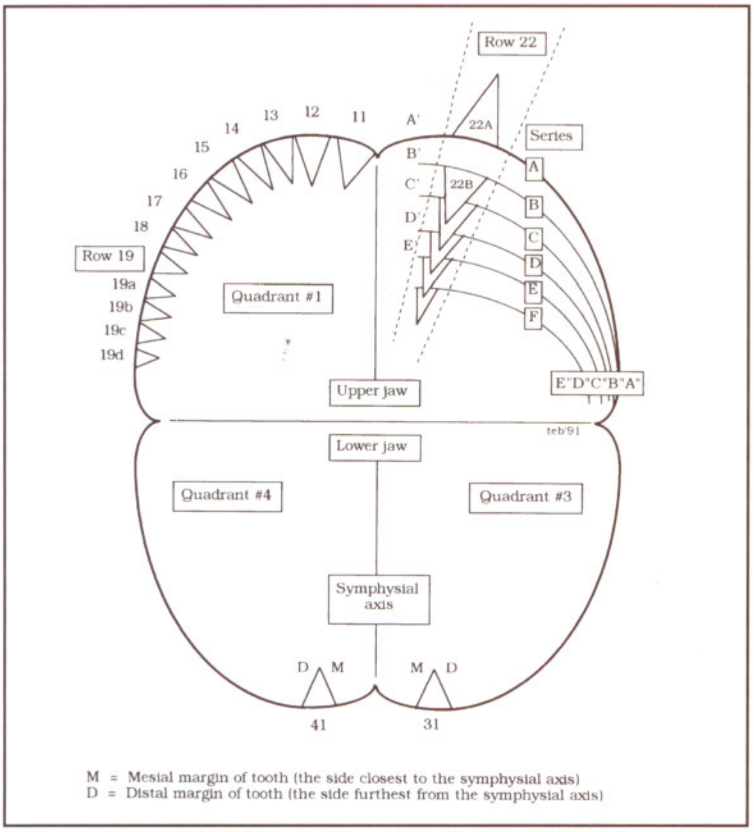


Fig 1 Diagram of the shark jaw illustrating the Shark Tooth Identification Notation System (S.T.I.N.S.) which has been developed to categorise individual teeth and the arrangement of the rows and series of teeth.

of the jaw. The first digit of the system identifies the particular jaw quadrant, so that the upper right quadrant is numbered as 1, the upper left quadrant as 2, the lower left quadrant as 3 and the lower right quadrant as 4.

The second number denoted the actual tooth with the number starting from the tooth nearest to the symphysis (mid-line) and then proceeding sequentially in a distal direction towards the jaw articulation of upper and lower jaws (e.g. 11, 12, 13 etc). To avoid confusion with the use of a third Arabic numeral in the notation, the posterior teeth after the ninth tooth in any quadrant are denoted with the ninth tooth number plus a lower case letter (also distally in ascending order, e.g. 19a, 19b, 19c, 19d, etc). Teeth on either side of the jaw midline or symphysis (i.e. teeth numbered 11, 21, 31 and 41) have been termed 'symphyseal' teeth.

Definitions used

Functional teeth are those teeth in an erect or semi-erect position that are sufficiently developed (i.e. advanced forward) to participate in a bite.

Replacement teeth are those teeth, ranked in a row behind the functional teeth, that are still developing (i.e. are in a recumbant position).

A row of teeth is defined as a line of teeth which is approximately at right angles to the arc of the jaw and is derived from a single developmental unit. It includes one or more of the functional teeth plus the subsequent replacement teeth which exist at various stages of development. The rows are thus arranged in a columnar fashion with each tooth ranked immediately behind the preceding tooth.

A series of teeth is defined as a line of teeth parallel to the arc of the jaw, all of them in a particular rank within the different rows.

Serrations. All functioning teeth of the White Shark are finely serrated on the margins with the tips being smooth. However serrations were either extremely small or absent on some of the lower teeth of the juvenile shark examined in the present study. Serrations consist of altering elevations and depressions. To distinguish them, the elevations have been termed peaks and the depressions have been termed notches. The summit of the tooth has been termed the tip. Detailed study of the peaks was feasible with the use of enlarged photographs of the teeth.

Measurements carried out in this study

The measurement of various tooth parameters was facilitated by tracing the enlarged photographic image of the tooth on to tracing paper.

1. The length of the mesial and distal margin of the tooth was determined from the tracing. The computerised digitising system* (using X, Y coordinates) was employed to describe the distance which represents the sum of all individual peak-to-peak distances from the first basilar peak to the tip of the tooth (Fig.2).

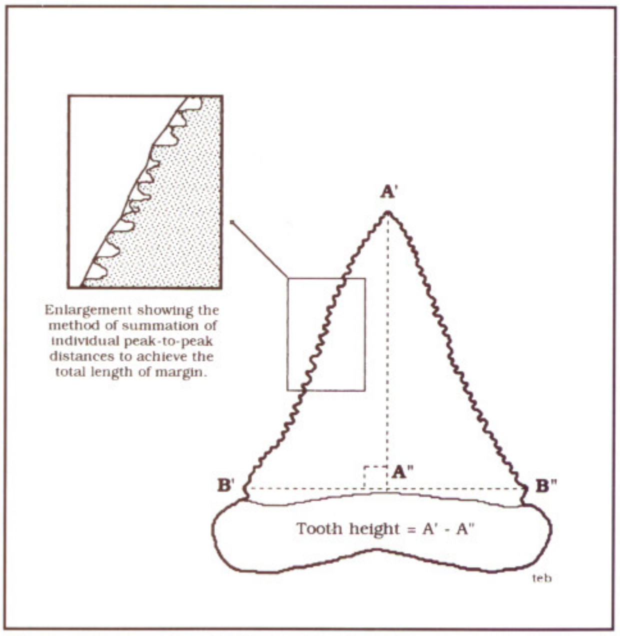


Fig 2 Digram showing the method used to measure height and the length of the mesial and distal margins of a shark tooth, using a tracing digitiser on a photographic enlargement of the tooth

2. The number of peaks was established from the photograph. Sometimes a magnifying glass was used directly on the shark teeth to determine whether a peak was fractured or not. This also helped in locating the notches when peaks were badly fractured.

Non-metrical criteria recorded in this study

1. Damage to teeth

As with all predators, the teeth of White Sharks are subjected to attrition, wear, fracture or loss when the powerful biting force is used during attack. The condition and type of damage on individual teeth of the sharks used in this study was categorised as follows:

A	=	No damage.
B	=	Damage to primary cusp tip.
C1	=	Minor damage to the peaks on the mesial margin of the tooth; the existence of intact notches enabling counting of the peaks.
C2	=	Minor damage to the peaks on the distal margin of the tooth; the existence of intact notches enabling counting of the peaks.
D1	=	Major damage to the serrations of the mesial margin.
D2	=	Major damage to the serrations of the distal margin.
E1	=	Damage to the base of the tooth on the mesial margin.
E2	=	Damage to the base of the tooth on the distal margin.
F	=	Serrations completely absent from the margin of tooth.

With D1 & D2 categories the counting of discrete peaks was not possible since notches were absent. An attempt to estimate the number of peaks missing from a section of the tooth margin was not deemed advisable due to the wide variation in the width of existing peaks.

2. Peak Types

It was clear from initial observations that there was a variety of peak-types along the margin from the base of the tooth to the tip. An attempt was made to differentiate these peaks into six general categories and to ascertain the number of peaks in each category.

To avoid the need to measure accurately the height and width of each peak on the tooth a method of categorising peaks into a set of size-categories was developed. A template representing the categories was drawn and photocopied on to a transparent plastic sheet (Fig. 3). The various peak-types were categorised according to their best 'fit' within the margins of an overlaid template. If a notch bisecting a peak extended below an imaginary line drawn halfway up the peak, then that peak was classified as two separate peaks (Fig. 4). If the notch did not extend below this line the peak was described as *bifid*. Some peaks had two notches and were termed *trifid* (Fig. 4).

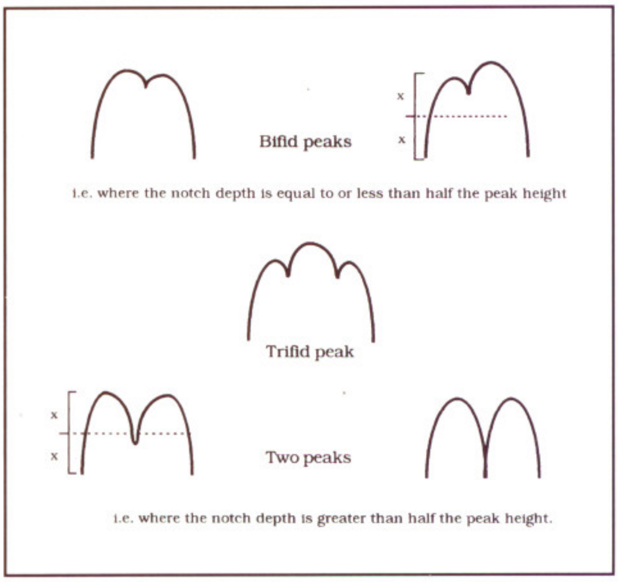


Fig 4 Diagram illustrating the criteria used to classify peaks on the margins of a shark tooth.

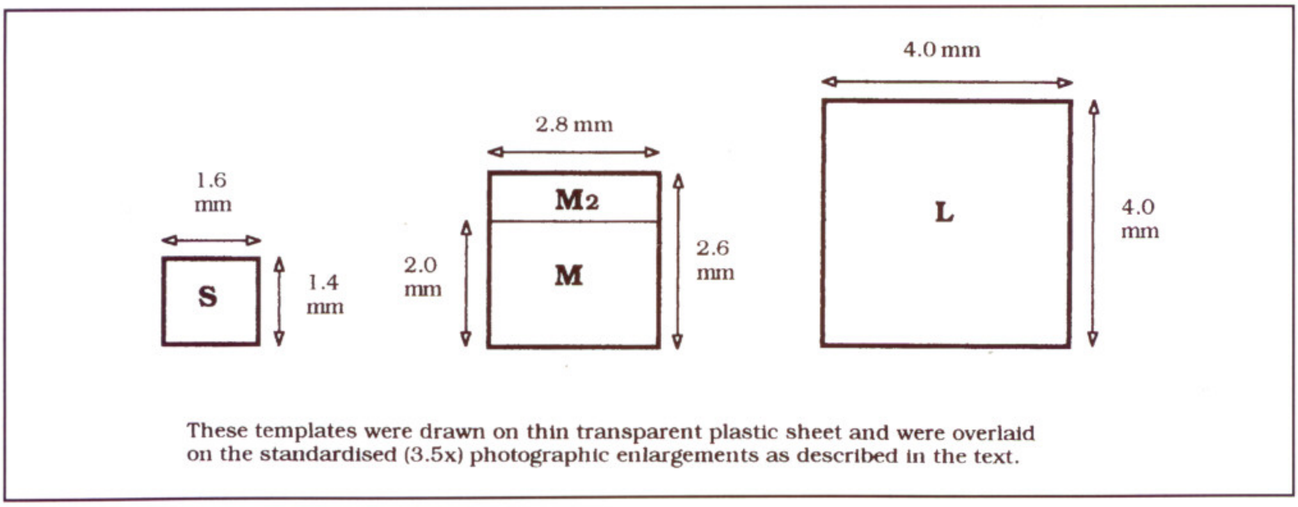


Fig 3 Diagram showing the dimensions on the transparent overlay template used to categorise the types of peaks on the margins of a shark tooth.

Thus, for the purposes of this study, peak-types have been classified as follows (see Figs. 3 and 4):

- S = small peak (<1.6 mm wide at base and <1.4 mm high)
- M = medium peak (<2.8 mm wide at base and <2.0 mm high)
- M2 = medium-large peak (<2.8 mm wide and <2.6 mm high)
- L = large peak (<4.0 mm wide at base and <4.0mm high
- B = bifid peak
- T = trifid peak

3. Relative frequency of peak-types

The categorisation of various peak-types has been outlined above. A study was undertaken to determine if the spectrum of peak-types varied between mesial and distal margins of the teeth, between left quadrant and right quadrants, between upper and lower jaws and between the three sharks. This was done by counting the various peak-types and recording their total as the relative frequency (i.e. percentage of the total number of peaks). This was repeated for each margin (mesial and distal) of the teeth in each quadrant. The relative frequencies of occurrence of the peak-types in each quadrant and for the entire jaw (i.e. per shark) were also determined.

RESULTS

Tooth height[1,2,6] and length of tooth margins[1,2] in the White Shark have previously been shown to be proportional to body length. An idea of the relative sizes of these parameters can be gained from taking the averages of values for the symphyseal teeth, 11 and 21 (Fig. 1). The heights and margins were found to be, respectively: 26.7 and 29.5 mm for shark 1, 35.4 mm and 40.2 mm for shark 2 and 14.5 mm and 15.9 mm for the juvenile shark 3. Serrations were either extremely small or absent in some of the lower teeth of the juvenile shark examined in this study. The maximum number of peaks counted on a tooth margin varied between sharks but also occurred on a symphyseal tooth. The symphyseal teeth of shark 1 had a mean of 39 peaks with shark 2 having 46 and shark 3 having 29. These values are related to the length of the tooth margin upon which they are suited and thus increase with the size of the shark. The minimum number of peaks on a tooth was, as expected, associated with the smaller, i.e. most distal, teeth near the jaw articulation but the numbers were similar i.e. not related to the shark size, values being 17 for shark 1, 16 for shark 2 and 17 for shark 3.

Relative frequency of peak-types

A small selection of the collected data, illustrating the results for the two symphyseal teeth of the upper jaw of the 3 sharks, is shown in Table 1. It can be seen that there was a tendency for the largest peaks to be situated more centrally along the margin. There appears to be a reasonable degree of similarity (about 50% commonality) between the arrangement of the peaks on mesial and distal margins of the same tooth. Overall, however, there was no consistent pattern to the actual arrangement of the various peak-types on the tooth margin. Apart from the tendency towards bilateral (left-right and mesial-distal) symmetry, the occurrence of any type in a particular position appeared to be a rather random phenomenon. When the data for all teeth in a quadrant was collated, it was clear that, when position was ignored, the frequency of occurrence of peak-types was very similar between the left and right quadrants of the jaw within a shark but quite different between upper and lower jaws and between sharks (Figs. 5, 6 and 7).

Shark 1: In the upper jaw, the L peak-type mostly occurred in the middle of the mesial and distal tooth margins. The M peak-type occurred randomly on the margin with the infrequent S peak-type found closer to

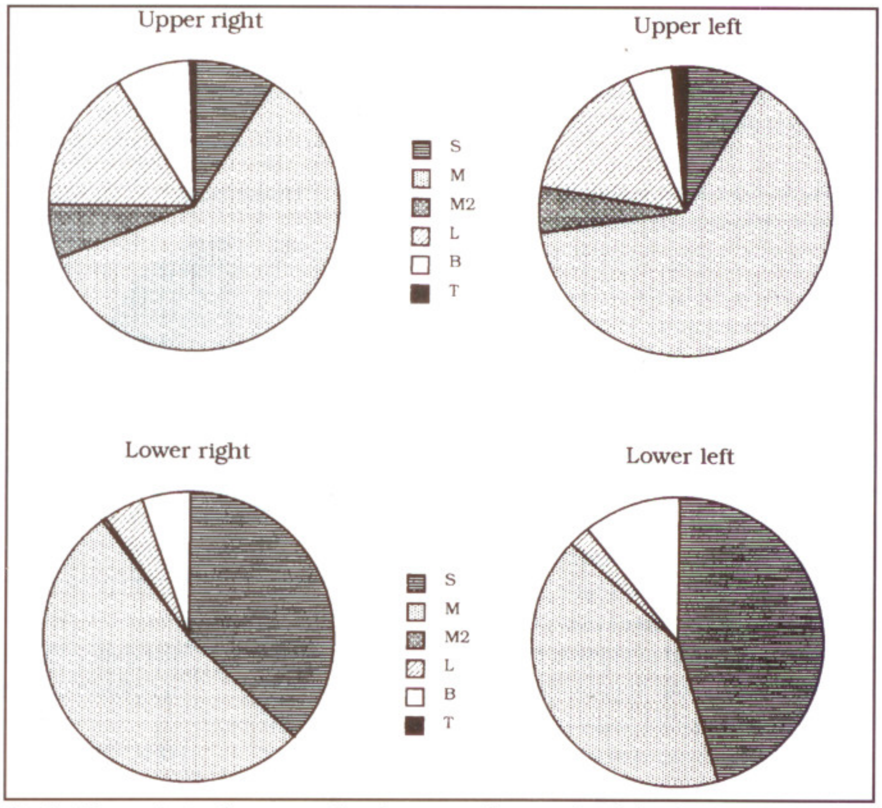


Fig 5 Mean relative frequency of peak types on the mesial and distal margins of all teeth in each jaw quadrant of shark 1. The code letters refer to the classification of peak types as described in the text and illustrated in Figures 3 and 4. S = small peak, M = medium, M2 = medium-large, B = bifid peak and T = trifid peak.

the tip and base of the tooth. In the lower jaw, most of the basal peak-types and those at the tip of the teeth were of the S variety whilst M peak-types and the infrequent L peak-types were found mostly at the centre of the margin of the teeth. There was a reasonable degree of similarity of peak-types between the margins (mesial and distal) of teeth, and between left and right quadrants of each jaw, but there were appreciable differences between the upper and lower jaws. It was observed that in all quadrants peak-type M was the most frequent with peak-type L in the upper and peak-type S in the lower being the second most frequent. Peak-type M2 was found to be comparatively more common in the upper than in the lower jaws (Fig. 5).

Shark 2: This shark also showed a random pattern in the arrangement of the peak-types. However, similar trends towards the larger peaks being in the centre of the margin were noticed. In the lower jaw, S peak-type occurred in increased frequency toward the tip of the teeth. Data were similar to Shark 1 in the bilateral symmetry and in the relative frequency of peak-types and their occurrence. Peak-type M2 was again more frequent in the upper jaw than in the lower jaw (Fig. 6). The L peak-type was significantly more common in this, the largest of the three sharks.

Shark 3: The L peak-types were rare with the M peak-type, as the larger peak-type present, being concentrated in the middle of the margins of the teeth. The increased frequency (as compared with Sharks 1 and 2) of S peak-type at the base and the tip of the teeth was evident. In the lower jaw the teeth exhibited peaks that were too small to be studied qualitatively. Moreover, peaks were absent or had been stripped off the teeth probably because of the enormous biting forces generated in the shark jaw. This shark, probably because it was a juvenile, exhibited a highest frequency of the S peak-type followed by the M peak-type. A similar relationship in the frequency of the peak-types on the mesial and distal sides of the teeth was observed. M2 peak-type was absent and L peak-type was significantly lower in frequency than with the more mature specimens (Fig. 7). There was a significantly lower fraction of bifid and trifid peaks than in the larger sharks. An example of the extensive raw data collected is shown in Table 1. All other data have been depicted graphically in Figs. 5 to 7.

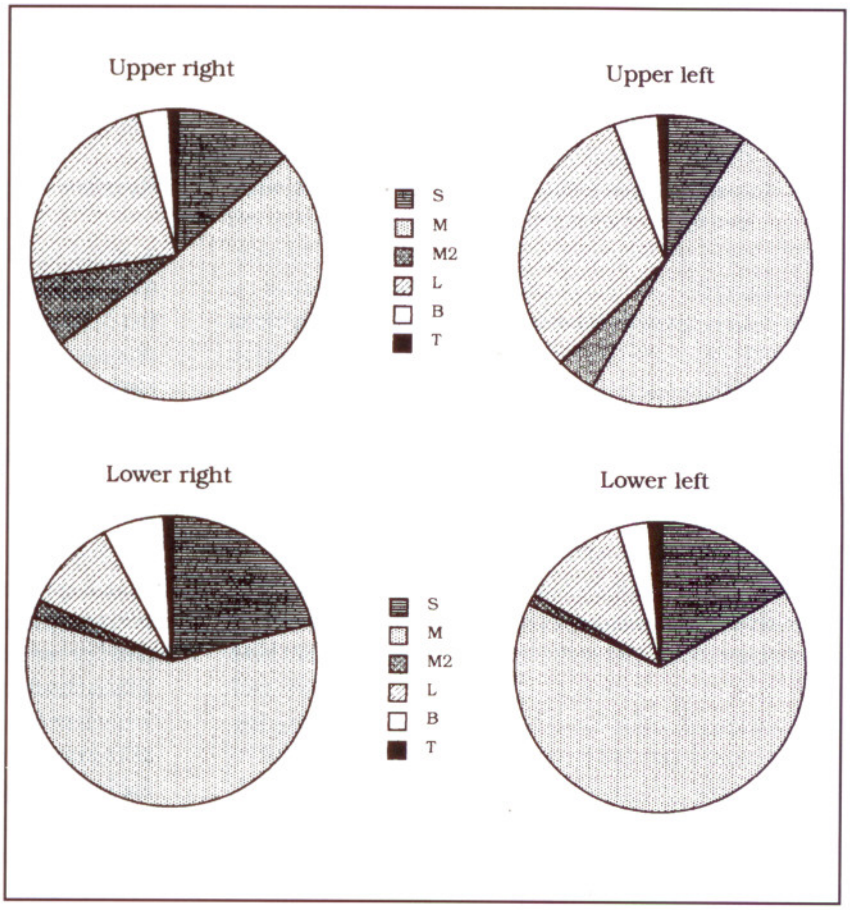
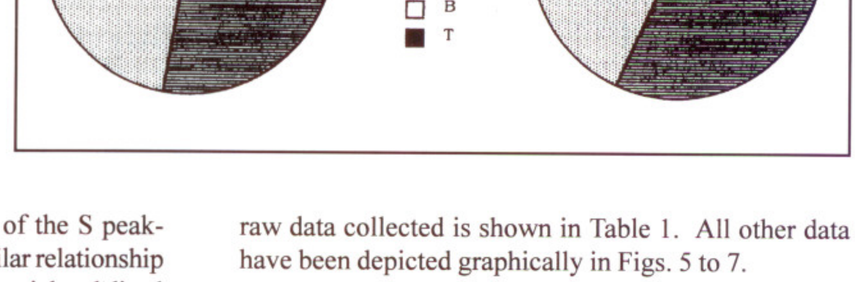


Fig 6 *Mean relative frequency of peak types on the mesial and distal margins of all teeth in each jaw quadrant of shark 2. The code letters refer to the classification of peak types as described in the text and illustrated in Figures 3 and 4. S = small peak, M = medium, M2 = medium-large, B = bifid peak and T = trifid peak.*

Fig 7 *Mean relative frequency of peak types on the mesial and distal margins of all teeth in each jaw quadrant of shark 3. Insufficient data was available to construct such a chart for the lower jaw. The code letters refer to the classification of peak types as described in the text and illustrated in Figures 3 and 4. S = small peak, M = medium, M2 = medium-large, B = bifid peak and T = trifid peak.*



DISCUSSION

We have previously shown[2] that the teeth of the Great White can be identified by their size, shape and presence of multiple serrations along the entire margin excepting

TABLE 4: A selection from the collated data showing the comparison between the number and types of peaks on the symphsial teeth in the upper jaw of the three sharks. Peaks are numbered from the base of the tooth towards the tip. The overall data is summarised in Figs. 5-7.

	Shark 1				**Shark 2**				**Shark 3**			
Tooth No.	11		12		11		12		11		12	
Peak No.	Mes	Dis	Mes	Dis	Mes	Dis	Mes	Dis	Mes	Dis	Mes	Dis
1	S	S	S	M	B	S	S	S	M	B	M	S
2	B	M	S	M		M2	M	M	M		S	S
3		L	M	M	B	M2	M2	M	B	S	S	M
4	M	M	M	M		M	M	M2		S	M	S
5	M	M2	M	M2	M2	S	M	M	M	S	M	M
6	M2	M	M	M	L	S	M2	M	S	S	M	M
7	M	M	M	M	L	S	M2	M	M	S	M	M
8	M	M	M	M2	M	M	M2	L	M	S	M	M
9	M	M	M2	M2	M2	M	M	M2	M	S	M	M
10	B	M	M	M	M	M	M	L	M	S	S	M
11		M	M	L	M	M	M	M	S	S	S	M
12	L	M	M	M	M	M	M	M2	S	S	S	S
13	M	B	M	M	M	M	M	M	M	S	S	M
14	M		M	L	M	M	L	M	M	M	M	S
15	M	B	L	M	S	M	L	M	M	M	M	M
16	M		B	L	S	M	M2	M2	M	S	M	M
17	M	L		M	S	M	L	M	M	M	M	M
18	M2	M	L	M	M	L	M	L	S	L	M	M
19	M	L	M	L	M	M	M	M	M	S	S	S
20	M	M	M	L	M	L	M	M	M	M	S	M
21	M2	M	M2	M	L	L	L	L	S	L	S	M
22	M	B	L	M	L	L	L	B	S	M	S	S
23	M		L	M	B	L	S		S	S	S	S
24	L	M	L	M		M	M	L	S	S	S	S
25	L	T	L	S	L	L	L	L	S	S	S	
26	L		M	M	M	M	M	L	S	S	S	
27	S		B	L	L	L	M	M	S	S	S	
28	M	M		L	L	L	L	M	S		S	
29	M	M	L	M	L	M	M	L				
30	M	M	M	M	L	M	M	M				
31	M	M2	M	M	L	M	M	M				
32	M	M	M	M	M	M	M	M				
33	M	M	M	M	M	M	M	L				
34	M	M	M	M	M	S	S	M				
35	M	M	M		M	M	M	M				
36	M	M	M		M	L	M	M				
37	S	M	L		L	L	M	L				
38	S	S	M		M	M	M	L				
39		M			M	M	M	L				
40					M	M	S	M				
41					M	L	M	M				
42					M	L	L	S				
43					L	L	L	M				
44					M	L	M	M				
45					M	M	S					
46					L		M					
47					M		S					
48								S				

Mes = mesial margin of tooth, Dis = distal margin. Peak sizes and shapes were categorised, using overlay templates (see the text and Figs. 3 & 4), as follows: S = small peak, M = medium, M2 = medium-large, L large, B = bifid peak, T = trifid peak at the tip of the tooth. The symphyseal teeth are the largest and tooth size decreases progressively from the anterior to the posterior part of the jaws.[1,2] The size of the symphyseal teeth (and of the other teeth in proportion) is predictably related to the body size of the shark.[1,2,6] These parameters have proved useful in forensic investigations of shark attacks on humans.[2]

Now it has been shown that the greatest number of serrations per tooth occurred on the largest teeth and that these larger teeth have a relatively higher frequency of the larger peak types. The distal teeth were of more uniform size in all the sharks and their margins carried similar numbers of peaks. There was a tendency for the larger peaks to be concentrated towards the centre of the tooth margins, with the smaller peaks occurring more at the base and tip of the tooth. This arrangement may confer benefits to the cutting efficiency of the teeth.

Despite there being some similarity in the arrangement of peak-types on the mesial compared with the distal margins of the same tooth there was little similarity between teeth, even adjacent ones. If one ignores their actual position on the margins the frequency of occurrence of the different types of peaks exhibits a bilateral symmetry being similar between left and right segments of the upper jaw. Bilateral symmetry was also manifest in the lower jaw but the actual frequencies of occurrence were quite different from those of the upper jaw. There was also no obvious similarity in the frequencies of occurrence in any shark.

CONCLUSION

Apart from the characteristic shape and size of the teeth of the White Shark and the fact that serrations occur along almost the entire tooth margin, there does not appear to be a consistent pattern in the size or arrangement of these serrations on or between teeth in the shark that is sufficiently characteristic to enable the identification of a tooth to a particular position within the dental arch or even to a particular specimen of White Shark. This, of course, does not preclude the possibility of identifying a particular shark from marks made by a tooth of that shark.

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APPLICATION OF DIMORPHISM IN TEETH TO AGE CALCULATION

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ABSTRACT

The objective of this study was to determine which teeth provide the most reliable data for use in age estimation. We studied 170 teeth from the anterior region (central and lateral incisors, and canines) and used an image analysis technique to analyse a number of morphometric features in thin sections of tooth. Our results showed root translucency to be the variable most clearly related to the subject's age, and the canine teeth to provide the most reliable information on this variable. (**J. Forensic Odonto Stomatology 1996 14:1, 10-13**).

Key Words: Incisor and canine teeth, root translucency, age estimation, IBAS system.

INTRODUCTION

Dental features determining the age of a person have been researched extensively in recent years. Notable aspects of this work have been studies of attrition, and Takei[1] was amongst the first to consider dental deterioration and to establish different categories of attrition, but without quantification. In a technique to measure attrition directly by means of a stereo microscope, using a millimetre grid,[2] different results were obtained according to the type of tooth analysed. There was a weaker correlation between age and attrition in canines and maxillary central incisors compared with observations on premolars. In a study[3] investigating attrition in molars a clearer result was obtained for the first molar than for the second, although correlation with age was still rather low. The method used by Takei was improved by applying a stepwise regression analysis,[4] although it contained some errors. On the other hand a wide variation of attrition was found in one individual,[5] but age determination was made easier by observing the number of attrition facets as well as the attrition area.

Root translucency has been investigated as a means of determining age and the dentine translucency volume, without cutting the tooth,[6] utilised as a parameter, while measuring the length and the area of translucency by carrying out a multiple regression analysis[7] displayed a strong correlation between age and translucency. A quantification of translucency in relation to the total length of the tooth revealed a strong correlation with age and a study of translucency with a negatoscope (an instrument also utilised for studying radiographs) helped to simplify the use of Gustafson's method.[9,10] In studies of the relationship between radicular translucency and age, measurements of secondary dentine according to the method of Johanson[8,12] showed a significant correlation with age while a greater incidence of translucency was found in non-vital, as compared with vital, teeth at any given age.[11] Impacted canine teeth, free from environmental influences were found to develop an increase in secondary dentine with increasing age and a reduction in volume of the pulp chamber.[13] On the other hand the width and height of the pulp chamber, measured by x-ray was found not to correlate with age.[14]

In earlier reports[16,17] we described the possible explanations and limitations of morphometric studies of teeth with computerised image analysis (IBAS) in estimating a subject's age, and these results correspond with those of Xiaohu *et al.*[15] These findings showed the most useful parameter in predicting age to be root translucency,[6,7,18-23] but the usefulness of this approach is compromised not only by technical considerations, but also by the considerable variablity between individuals, influenced by genetic and environmental factors, such as chewing and eating habits.

The object of this study was to investigate the usefulness of uniradicular teeth (central and lateral, and canines) in age estimation.

MATERIALS AND METHODS

The experimental sample consisted of 170 anterior teeth (Table 1) 45 lateral incisors (subject mean age 53 years), 73 central incisors (subject mean age 57 years) and 52 canines (subject mean age 51 years), with a subject age range of 12-80 years. All teeth were extracted in the course of clinical treatment in different stomatological services in the city of Murcia. Because of the small sample size, neither gender nor intra-oral location (maxilla or mandible) were isolated as variables in the statistical analysis and no apparent difference between

TABLE 1: Distribution of the sample according to age of subjects.

	n	Subject Mean age Years	Range Years	S.D.
Central incisors	73	57	31-81	±10.079
Lateral incisors	45	53	16-73	±11.149
Canines	52	51	12-80	±19.165

TABLE 2: Results of multiple linear regression analysis with age as the dependent variable.

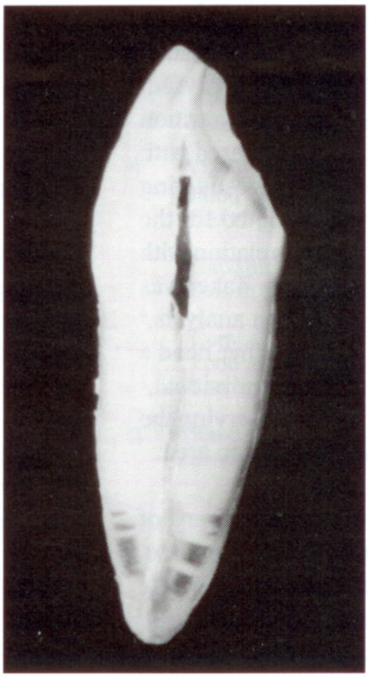
	DF	r^2	Multiple r
Central incisors	64	0.25	0.543
Lateral incisors	36	0.32	0.5699
Canines	42	0.55	0.7419

TABLE 3: Results of step-wise regression analysis with age as the dependent variable.

	DF	r^2	Multiple r	Variable entered
Central incisors	64	0.1988	0.4368	Root translucency Periodontal attachment
Lateral incisors	36	0.243	0.4929	Root translucency Secondary dentine
Canines	42	0.5367	0.7326	Root translucency

teeth from males or females, or between upper and lower jaws were detected. After each tooth was extracted it was fixed in 10% buffered formaldehyde and reduced on a carborundum powder disk cutter to a thin sagittal slice measuring 1 mm in thickness. The following measurements were made (Figures 1 and 2): secondary dentine, total pulp area, root translucency, mesiodistal width of the crown, pulp diameter, crown length, periodontal attachment and total tooth length.

The non-lineal variable area was calculated by a logarithmical transformation. A video-camera was used to convey the image of the specimen to the monitor of the computerised image analysis system Microm Image Processing, IMCO 10* where the distances and areas noted above were measured and stored for subsequent statistical analysis. The relationship between age and other variables was investigated by simple linear correlation and simple linear regression. The correlation and determination coefficients were calculated as well as the level of significance and the appropriate comparisons were used to express age as a function of each of the other variables.



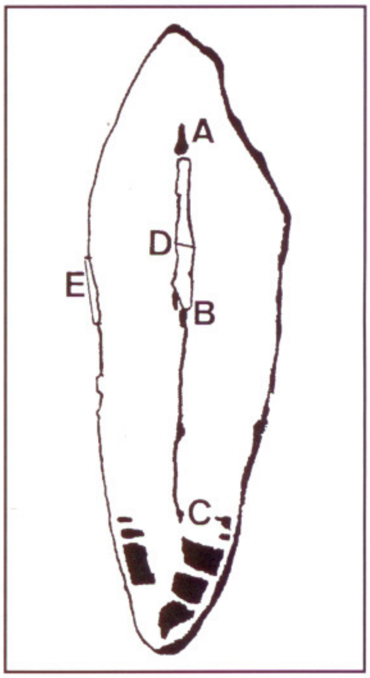


Fig 1 (left) Midsagittal slice (1mm thick) of an upper central human incisor. The following morphometric parameters were measured on the medial surface L : secondary dentine, total pulp area, root translucency, mesio-distal width of the crown, pulp diameter, crown length, periodontal attachment and total tooth length.

Fig 2 (right) Schematic diagram based on Fig 1 of an upper central human incisor.

A = reactive dentine, B = total pulp area, C = root translucency, D = pulp diameter, E = periodontal attachment.

RESULTS

The results confirmed our previous finding that root translucency is the parameter that most reliably predicts age (Tables 2, 3 and 4). In the step-wise regression analysis within the sample of central incisors, periodontal attachment also showed a statistically significant relationship with age but the greatest predictive power was found in canines, which yielded r^2 and multiple r values much higher than those found for central or lateral incisors.

DISCUSSION

In a study of 1000 teeth[25] in which periodontal recession, attrition, colour, secondary dentine translucency, cementum and surface were observed it was recommended that for age estimation it is advisable to avoid the use of teeth with the weakest relationship between the variables and age, such as mandibular canines and secondary premolars. Our results differ from those of this author, as they show uniradicular teeth, especially the canines, to have a higher statistical correlation with age. The discrepancy between the two studies may be due to the selection of material and the method of analysis (quantification of the parameters). From a theoretical point of view at least it seems that the hypothesis, which considers the canines the most reliable tooth to predict age, is valid, because the influence of environmental factors on the tooth (for example, chewing and diet) is not as strong, although there must be individual variation. The canines are the most stable teeth in the dental arch, owing to their anatomical features and firm attachment.[24] In addition, the canines are less susceptible to the effects of mechanical overloading and functional factors, and so ageing of canines is likely to be more closely

LATERAL INCISORS	Regression Coeff	Std Error	F (1.42)	P	r^2
Secondary Dentine	5.1931	2.6509	3.838	0.05677	0.0837
Root Translucency	7.5288	2.9455	6.533	0.01429	0.1346
Constant	30.5422				

CENTRAL INCISORS	Regression Coeff	Std Error	F (1.70)	P	r2
Root Translucency	3.896	1.322	8.686	0.004	0.1104
Periodontal Attachment	2.4907	0.8916	7.883	0.0067	0.1003
Constant	38.1325				

CANINES	Regression Coeff	Std Error	F (1.50)
Root Translucency	15.3927	2.0225	57.925
Constant	18.7903		

TABLE 4: Results of step-wise regression analysis in different teeth

dependant on the subject's age. In our analysis, root translucency was the parameter most closely related to tooth ageing, and was sufficient in itself to provide useful age estimates [6-8,26-29] In an earlier study,[17] we noted that there were considerable differences between individuals, as well as between teeth from a single individual. This makes it necessary to select those teeth for analysis that show the closest correlation with age, and which are the least vulnerable to functional overloading and environmental influences which would affect the morphometric parameters studied, making them independent of the subject's age. No account was taken of whether the teeth were from the upper or lower jaw, because in functional terms there appear to be no significant differences between the two locations.

* *Kontron Bildanalyse - Germany.*

The findings of this study clearly suggest that the canine is the most suitable of the uniradicular teeth for age estimation. Canine root translucency predicted 55% of the variable age, in contrast with only 25% predicted by central incisors and 32% predicted by lateral incisors. Moreover, statistical error was significantly lower in calculations based on canine data than when incisors were included.

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THE FORENSIC IMPLICATIONS OF PALAEOPATHOLOGY OF THE CRANIUM AND JAWS. PART I. A TECHNIQUE FOR RADIOGRAPHY OF MUMMIFIED AND SKELETAL REMAINS.

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ABSTRACT

Radiography of dried skulls presents two major problems: the lack of soft tissue which usually leads to overexposure, and difficulty in maintaining the cranium, with or without mandible, in correct position. The first problem can be alleviated by suspending a one litre drip bag containing Hartman's solution across the X-ray tube head and angled to give a fluid thickness of 10cm. Satisfactory positioning of the skulls and relating the mandible to cranium was achieved by construction of a spinal column substitute and acrylic hooks and rubber bands. Exposure of 50KV and 10mA at 15 seconds for orthopantomographic views and 70KV at 1.5 seconds for lateral and 65KV at 1.5 seconds for postero-anterior views gave an optimal, clinically acceptable image. The perfused fluids of living tissues exert a strong, modifying influence on the X-ray beam. (**J. Forensic Odonto Stomatology 1996 14:1 14-20**).

KEY WORDS Dried bones, Mummified remains, X-ray technique

INTRODUCTION

In 1982, the Royal Australasian College of Surgeons founded Interplas within its section of Plastic and Reconstructive Surgery. This organisation sends plastic surgeons, on a voluntary basis, to remote areas of Oceania to provide a surgical service that is otherwise unobtainable. Simple cases such as cleft palate, hand surgery or head and neck cancer which require the facilities of a large, modern hospital, are brought back to the Australian mainland.

In 1988, the Australian and New Zealand Association of Oral and Maxillo-facial surgeons, of which one author (G.T.) is a member, formed a committee to investigate the extension of Oral and Maxillo-facial services to the Oceanic region.

Meanwhile, several Oceanic governments have sent dental graduates to Australia, to enter maxillo-facial surgical training programmes, in recognition of the need for such services in their national populations. While the provision of treatment for acute conditions is based on obvious necessity, the management of complex maxillo-facial disorders requires a detailed epidemiological data base, and an understanding of regional norms, which may be at variance with those of predominantly Caucasian Australia.

Although there are some general studies considering racial variation in craniofacial relations[1] and specific groups such as South African Negro[2] and American Negro women[3], such a data base for Oceanic populations. particularly Melanesian does not seem to exist.

In addition to surgeons seeking a standard data base, anatomists, physical anthropologists, archaeologists and experimental radiologists have a need, from time to time, to radiograph dried and/or mummified skeletal remains. In such a project to establish the incidence of osteopathology and cephalometric data which would be of assistance in reconstructive surgery of the jaws in a Melanesian population, the first task was to develop the radiograph technique, a preliminary abstract of which has been published.[4] There are two major differences between living and dried bones: lack of soft tissues and inability to position the bone where required. Likewise, the sample size is often quite large and needs to be radiographed in a short period of time. Cost of materials is also a limiting factor in this type of study.[5]

This paper is a report of the first part of the project and presents a simple technique to meet these problems.

METHODS, MATERIALS AND APPARATUS

Skeletal specimens

The skulls examined in the study were selected from the Melanesian collections housed in the Shellshear Museum, Department of Anatomy and Histology, University of Sydney and the Australian Museum, Sydney. Special permission was obtained from the Aboriginal Land Council of NSW to include a small sample of Aboriginal skeletal material that had been scheduled for re-burial. The selection criteria for specimens suitable to this study were as follows:

1. both cranium and mandible were required.

2. the mandible must have been able to articulate with the skull in a reasonable centric occlusal realtionship. This required the presence of at least one mandibular

condyle, a contralateral occlusal contact between teeth, and alignment of the dental midlines for maxillae and mandible.

3. edentulous specimens were not excluded if a reasonable explanation of vertical dimension was possible and

4. the following cephalometric reference points must have been evident: sella, nasion, basion, subspinale (A point), supramentale (B point), porion, menton.

A total of 221 complete skulls fulfilled the above criteria and were used in this study.

The number of complete specimens, i.e. cranium and mandible, in the Shellshear collection totalled 114 skulls. Of these, 97 met all of the above criteria. Seven mandibles were found to be mismatched to the cranium of the same specimen catalogue number, seven were too badly damaged to be articulated and three were incorrectly articulated by raffia cords or clay masks, which could not be disturbed without damaging the specimen.

The number of complete Oceanic specimens in the Australian Museum collection totalled 110. Of these, 94 met all the required criteria. Three specimens were too fragmentary, two were mismatched and 11 complete skulls were incorrectly articulated by raffia cords or clay masks. The Australian Aboriginal sample consisted of 36 specimens, of which 30 satisfied the criteria. The remaining six were too fragmented to use. Each specimen was radiographed in three standard views; orthopantomogram, lateral cephalometric and postero-anterior cephalometric.

Mounting of skulls for radiography

In order successfully to articulate the mandibles to the crania and then position them correctly in the machine, some artificial substitutes were required for the missing suspensory muscles and supportive spinal column. In addition, the substitutes had to be radiolucent so as not to interfere with the radiographic image. The material chosen was dental acrylic resin (polymethyl methacrylate), as it can be fashioned to any desired shape and is radiolucent in thin section.

Fixation of the mandible to the cranium was achieved by the use of acrylic hooks joined by elastic bands, to mimic the action of jaw elevator muscles (Figs.1a & b). The hooks were fabricated in two sizes, the smaller designed to engage the zygomatic arch or infra-orbital rim and the larger to engage the lower border of the mandible.

Intact specimens with good occlusal contacts needed only two sets of hooks to firmly secure the mandible in place. Specimens with insufficient occlusal contacts or damaged rami were given additional support by dental cotton wool

Fig. 1(a) and (b) Mandibles held to crania using acrylic hooks and rubber bands.

rolls to substitute for missing teeth (Fig. 1b). These rolls are equivalent in thickness to the average height of tooth crowns as well as being translucent on x-ray. Some of these specimens required four sets of hooks to provide a stable articulation. Where the articulation of the mandibular condyle to the glenoid fossa was unstable, temporary fixation was achieved by the use of a thermoplastic dental luting wax ("Sticky Wax").

The cephalostat used for cephalometric views, efficiently supported the skull, while the hooks and rubber bands held the mandible in position (Fig. 2). The orthopantomogram craniostat however did not provide support for the cranium, so a spinal substitute was devised using an intravenous drip-stand base and pole, the top of which was fitted with an acrylic platform (Fig. 3). The platform was moulded with a graduated vertical extension, shaped to fit snugly in the foramen magnum and prevent the skull slipping from the platform. Height of the platform could be adjusted by the drip-stand pole clamp.

Radiographic Apparatus and Materials

All radiographs in this study were taken with the same machine, a FIAD ROTOGRAPH 230 S* (Fig. 4). This machine is capable of both orthopantomographic (OPG) and cephalometric functions, converting from one function to the other by three switches which adjust the position of the tube head and filters. All conversion switches are relayed so that any omissions will not permit normal function.

The technical specifications are as follows:

Working Voltage	240V+/-10%, 50/60Hz
Maximum Power Required	1.8KW
Tube Head Tension	50-85KV, in 5KV increments
Current	10mA
Exposure Time (OPG)	15 Seconds
Filter	2mm Al. equivalent
Focus	0.8mm
Film Size	Panoramic 12.7 x 30 cm
	Caphalometric 18 x 24 cm

In orthopantomographic mode the subject (or specimen) is positioned with the chin resting on a platform and the forehead against a vertical rest which also carries an adjustable clamp to fix the head, once positioned. The head is centered and focused by means of a cruciform light beam diaphragm, with a variable horizontal to ensure correct alignment. A digital read-out showing the final head position ensures reproducible films of any subject.

In cephalometric mode the subject is held in a craniostat with fixation in the external auditory meati. The head is oriented in the Frankfort horizontal plane by an adjustable positioning rod which fits against the nasion. The tube-film distance is 1.53 metres to provide a 1:1 image with minimal magnification. Both lateral and postero-anterior views are achieved by rotating the craniostat through 90°.

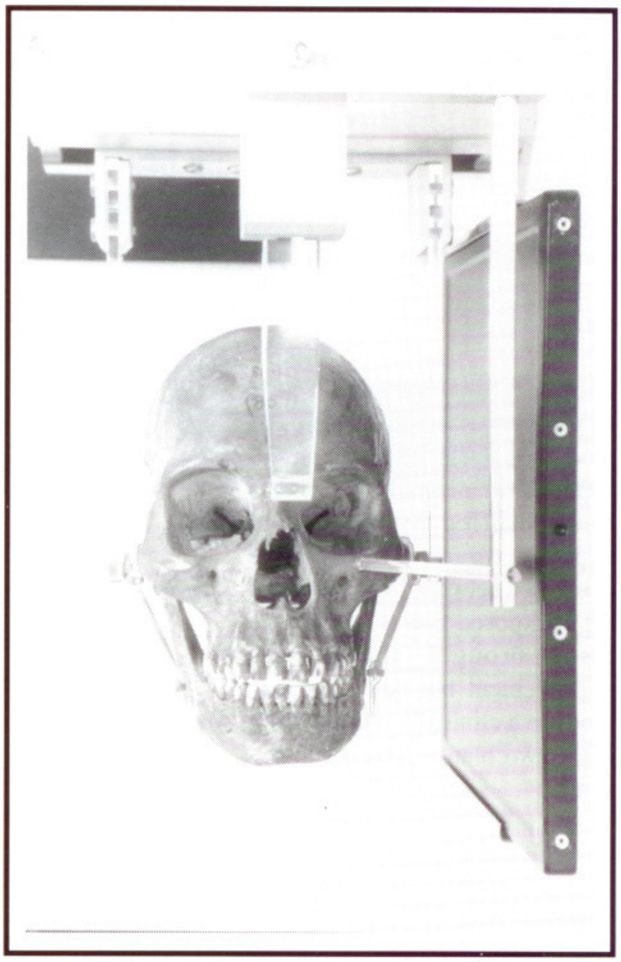

Fig. 2 *Skull located in cephalometric craniostat.*

Films and Cassettes

The film used was *Konica SR* (Super Rapid), in the film sizes stated above. Both OPG and cephalometric cassettes were fitted with *Konica KR* high speed, rare earth intensifying screens, green-light-emitting with a factor of 400.

Film Processing

All films were processed in a *Velopex Extra-X* developing machine, under darkroom conditions using *Velopex* ready mixed, high temperature, low oxidising developer and fixer. The machine has a processing time or four minutes and will accept a maximum film width of 260mm.

RESULTS and DISCUSSION

Film Density and Contrast

Specimen 84-250 from the Shellshear collection was chosen at random on which to test the optimum kilovoltage and exposure times for OPG, lateral and postero-anterior views. It was found that all views failed to render satisfactory images, even at minimal kilovoltage, when taken in the standard way for living subjects. The films were too dense, that is, too dark and of too high contrast with too little differentiation between structures (Fig. 5). It was apparent that the missing soft tissues exerted a modifying influence in absorbing or scattering some of the x-ray beam to produce the correct contrast.

The use of aluminium filters only served to 'harden' the beam and produce high density images. The effect of the intensifying screens was modified by the use of exposed, dark blank films interposed between the screens and the unexposed film (Fig. 6). One blank brought about some improvement but not enough to produce a clinically useable film, while two blanks gave no image at all.

A study by Austin[6] and a preliminary report by the authors[4] made reference to a similar problem when x-raying an isolated, dried maxilla and used a rubber latex glove filled with water to a thickness of 10 cm placed over the exit of the beam from the machine. This simulated the water and fat content of the missing soft tissues and produced a well contrasted image. The present study had the problem of simulating not only the thickness of soft tissue on one side of the skull but had to allow for the tissues between each side and those on the opposite side of the skull. We used a one litre drip bag of Hartman's solution which contains approximately the same constituents as human tissue fluid. The bag was suspended across the flat tube head and angled to give fluid thickness of 10cm (Fig. 3). The resultant images were of suitable clinical contrast (Fig. 7).

Kilovoltage and Exposure time

The OPG is taken at a fixed exposure of 15 seconds and the

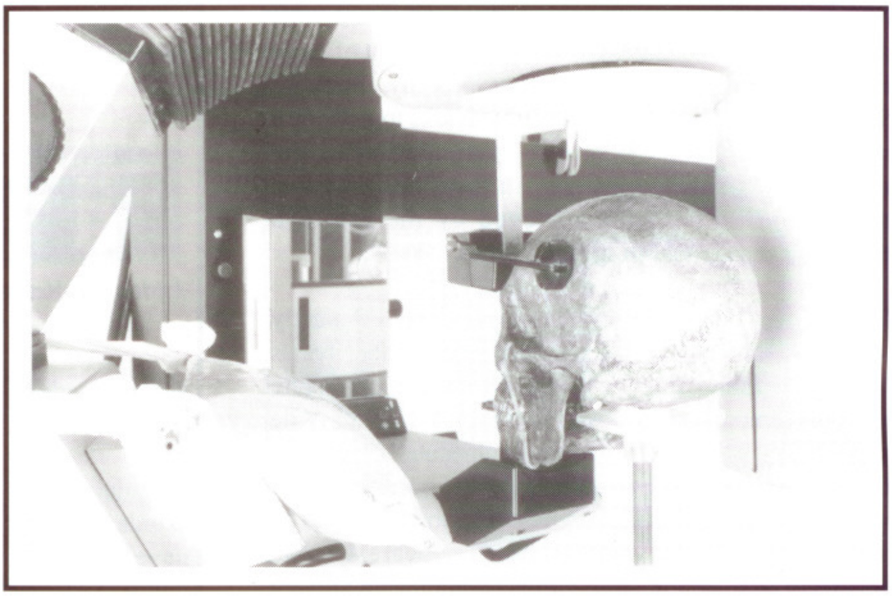

Fig. 3 *OPG craniostat augmented by specially constructed spinal support substitute. Note position of drip bag over x-ray outlet.*

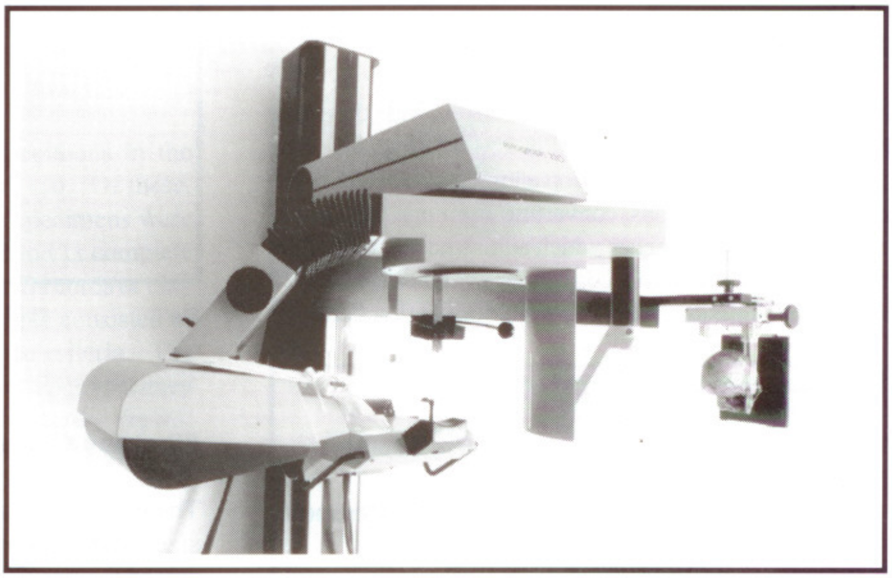

Fig 4. *Fiad Rotograph 230 S x-ray machine.*

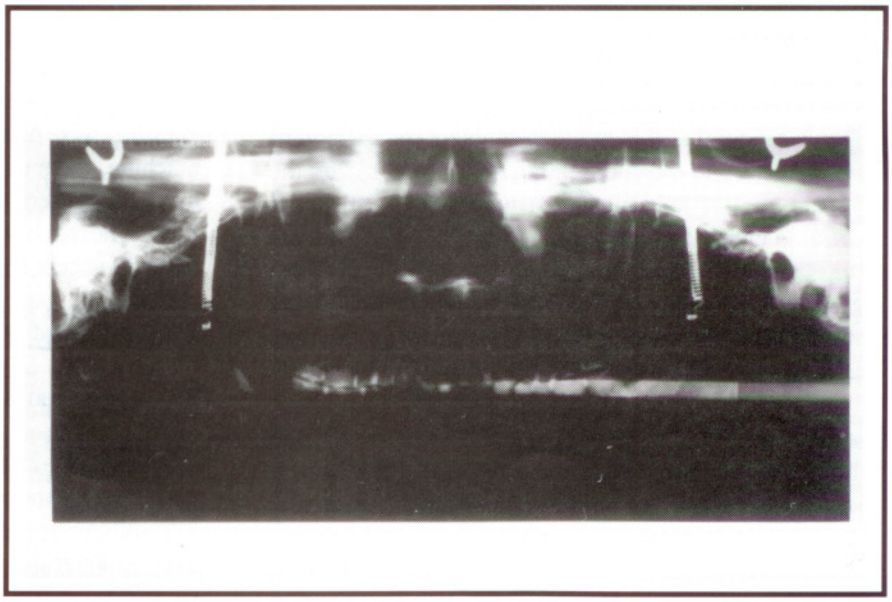

Fig. 5 *OPG taken at standard setting for living subjects.*

milliamperage of the *Fiad 230* is fixed at 10mA for all exposures. The only variable for an OPG is the kilovoltage, and trial films demonstrated that 50KV gave the optimum image (Fig. 8). Cephalometric views are plain, full thickness exposures and therefore allow variation in exposure time and kilovoltage. The greater tube-film distance required a higher kilovoltage for both P/A and lateral views. In the latter this was due to the superimposition of the two facial halves. The optimim results after trial were obtained using 70KV at 1.5 seconds for postero-anterior views (Figs. 9 & 10).

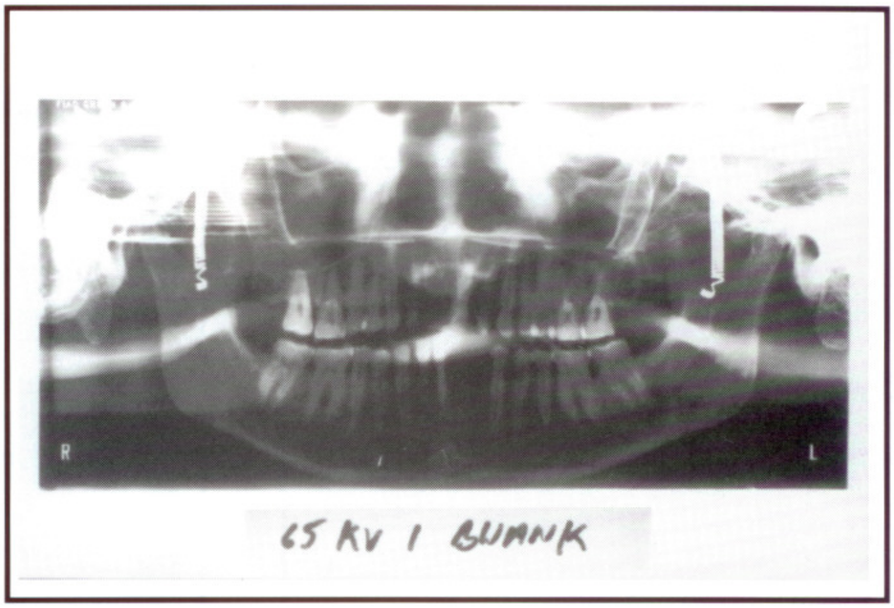

Fig. 6 *Same skull as Fig. 5 at 65KV with one exposed, blank film interposed between screen and test film.*

Fig. 7 *Same skull as Fig. 5 at 65KV and using drip bag of Hartman's solution.*

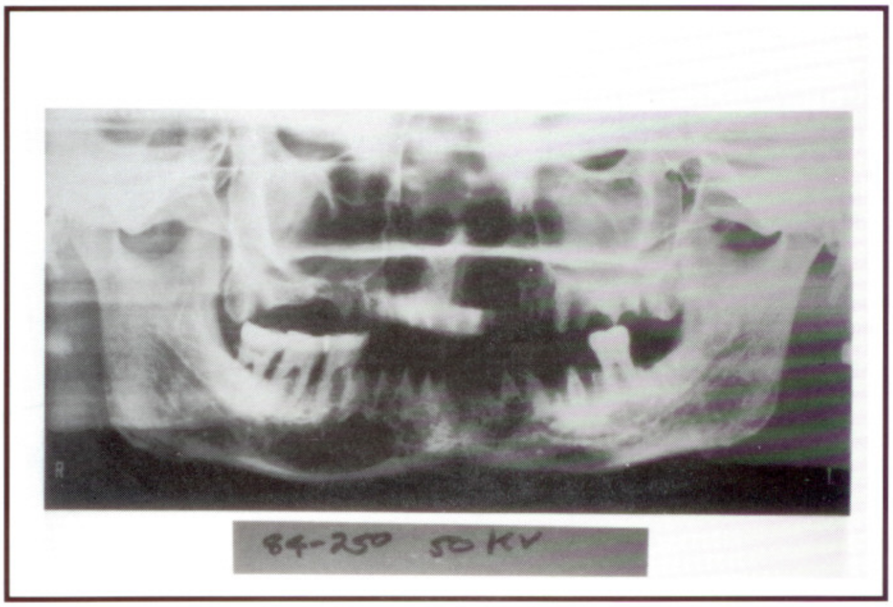

Fig. 8 *OPG of specimen skull at 50KV plus drip bag showing optimum image for diagnostic purposes.*

Experiment Utilising a Mummified Head

Specimen E59269 from the Australian Museum collection was a decapitated head that had been mummified. The specimen was radiographed using the settings for dried skulls (above) resulting in an image which was 'washed out', that is, of very low contrast and density, and clinically unreadable (Fig. 11).

Maintaining the same kilovoltage and exposure time, while removing the fluid bag, produced an image of similar density and contrast to that of a living subject but less than that for dry bone. The image was clinically readable but too dark for detailed diagnostics such as osteopathology.

Raising the kilovoltage for the OPG by 15-20KV and for the cephalometric views by 10KV, plus using the fluid bag, produced an image of good clinical density and contrast (Fig. 12). These settings closely approximate those used for living subjects and indicate that it is the perfused fluids of living tissues which exert a strong modifying influence on the x-ray beam.

Fig. 9 *Lateral cephalogram of mummified head. 70KV at 1.5 seconds plus drip bag.*

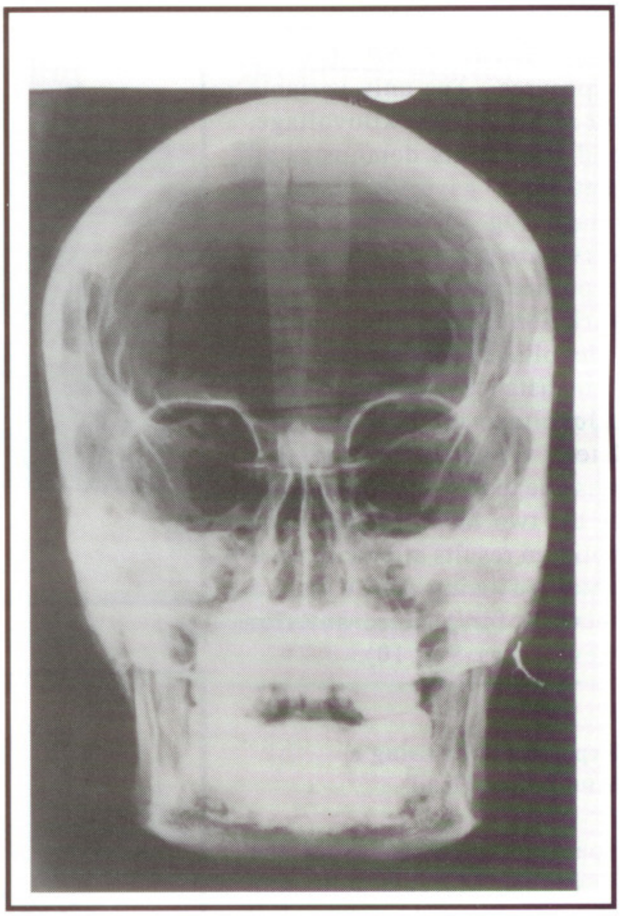

Fig. 10 *Postero-anterior cephalogram of mummified head. 65KV at 1.5 seconds plus drip bag.*

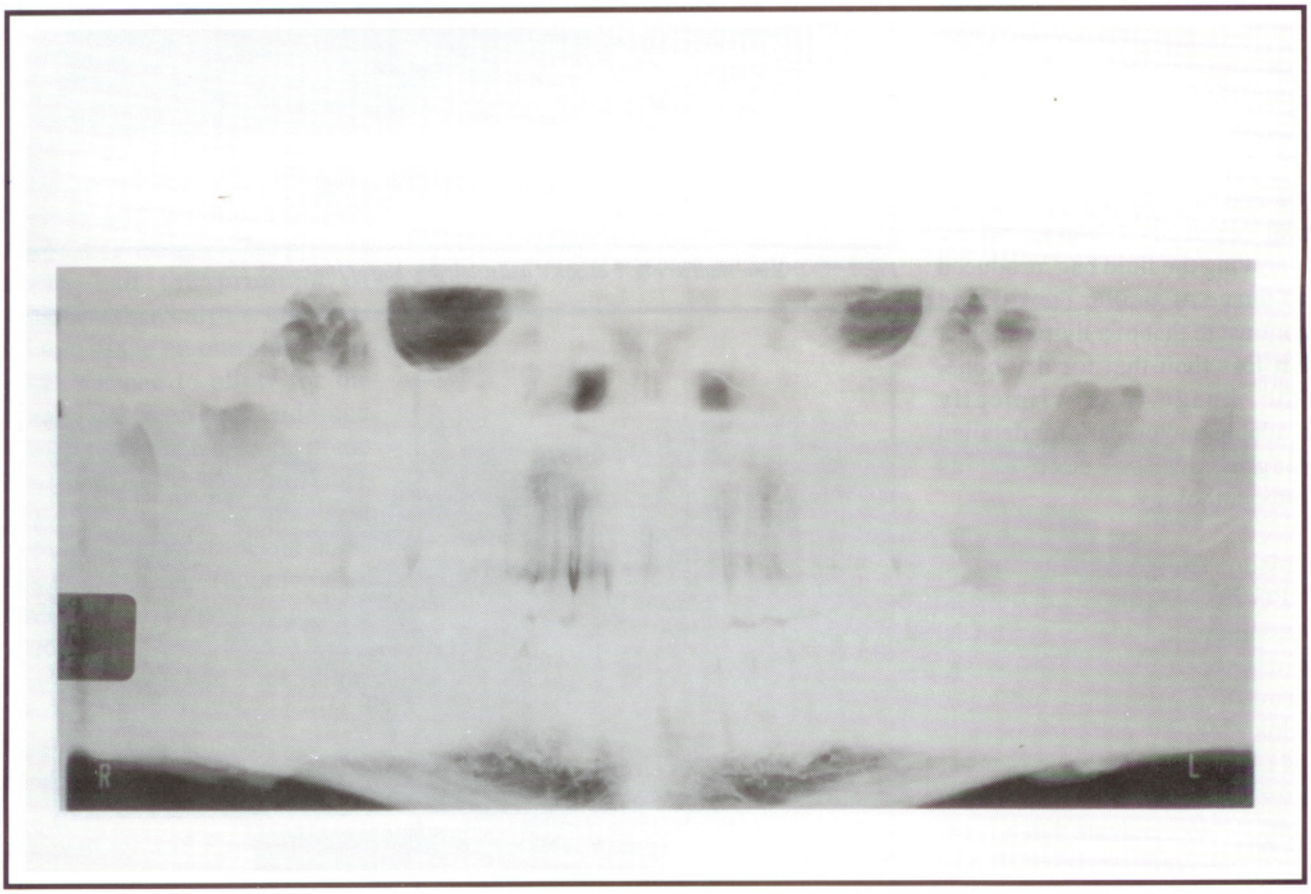

Fig.11 *OPG of mummified head at standard setting for dried skulls plus drip bag.*

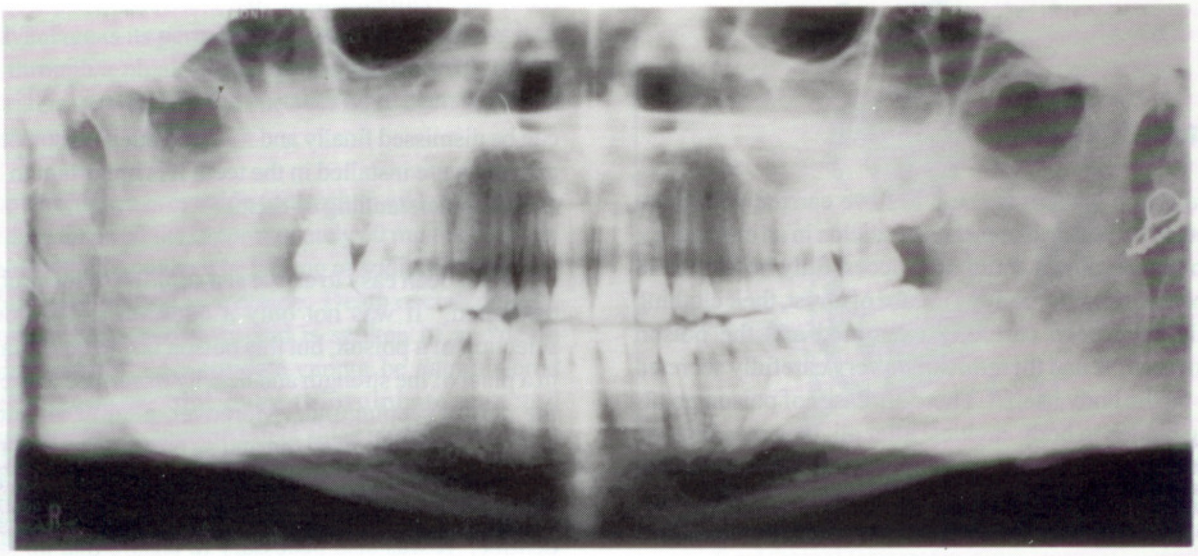

Fig.12 OPG of mummified head using drip bag and raising kilovoltage by 15KV.

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* *All trade names used refer to equipment purchased from J. Whisby & Associates, Sydney. (Australian Agents).*

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TEETH AS A POISON DEPOT

E. Von Skramlik

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INTRODUCTION

Third Reich leaders are said to have carried with them constantly a poison as a means of suicide in an emergency. Such poison phials could not successfully be hidden in clothes worn on the body as in case of arrest, their clothing would have been carefully examined and the poison discovered. It had therefore to be very carefully secreted in or on the body itself.* There are cases of poison phials being hidden in body cavities[1] after all, they may be used to hide rings, or jewellery generally, so why not poison phials? This method was, however, unsuitable for suicide by poisoning since in an emergency quick action was required and such a hiding place did not allow easy access. "Pockets" in folds of the skin were equally poorly suited for the purpose as in a strip search such "containers" would have been detected. Nevertheless, it is said that Hermann Goering had such a pocket created which contained a phial which was overlooked in the search and which he then used to put an end to his life.

Teeth also are said to have been repositories for such poison phials (this is an imitation of the poison reservoirs in the teeth of snakes). In such a case the poison phial is successfully hidden and as there is not usually the opportunity to check a person's teeth thoroughly, in a comparatively short time, the cache goes undetected. It is reported of Heinrich Himmler that he carried such a poison depot in a tooth, and that he made use of it after his arrest. He was, at the time, observed to be manipulating his teeth in some way, and it was also established that he bit on something and swallowed it, being impossible to prevent him from doing so.

A scientific examination of such "reports" has so far not been undertaken but if they were more than mere fiction, and that poison depots were worn in the teeth, how were they installed, and what was their nature? So far, nothing has been established and it seems desirable to examine the subject further. If we are dealing with fiction then it can be dismissed finally and for good but if poison depots can and were installed in the teeth it is important to have a clear understanding of them.

It has not been easy to arrive at a solution of the problem described. It was not only a question of the correct selection of a poison, but this poison had to be contained in a phial of the strength and density of surface to prevent the poison seeping out. Moreover, a tooth of suitable size had to be hollowed out and so prepared as to contain the poison with perfect safety for the user. It was, after all, necessary to prevent the poison from permeating the dentine. It was also necessary to ensure that no saliva could enter the cavity and thus possibly carry the poison into the mouth, thus posing an unintentional and severe threat. The whole installation, therefore, had to be sufficiently large, well sealed, and easily accessible at any time.

The poison

The poison to be used for such a purpose should be highly efficient, of which even minute quantities would be fatal. Moreover, it is desirable to have death occur not only very rapidly, but also quite painlessly.[2,3]

One of the strongest possible poisons is aconitine of which a quantity of 4 mg is sufficient to cause the death of an adult (Table 1). Unfortunately, however, death is delayed for a number of hours and severe physical symptoms (asphyxia) accompany it together with acute mental agony. There is no antidote once aconitine has entered the body and its "advantage" (in the present sense) lies in the small quantity required for suicide.

TABLE 1: Effects of various poisons.

poison	Q mg	t mins	MD	AD
Aconitine	4	230-300	agonizing	none
nicotine	60	10	easy	none
NaCN	113	<10	rapid	thiosulphate
KCN	150	<10	rapid	thiosulphate
E 605	500	45-60	agonizing	atropine, O2 ventilation

Q = minimal fatal dose. t = time from application of the poison until occurrence of death. MD = manner of death. AD = antidote.

A second possible poison would be nicotine which, in quantities of 60 mg will be fatal to an adult within a relatively short time. So far as is known death occurs without any particular physical pain and within a maximum of 10 minutes if the necessary quantity has been ingested. There is no known antidote to nicotine. As a liquid it has advantages, particularly the ease of filling a phial and its small fatal quantity. Its main disadvantage is its permeative power which allows it to pass through a phial's walls unless the porosity of the material is very low, or the surfaces have been sealed in some way.

A popular poison is cyanide (potassium and sodium). A fatal dose for an adult is approximately 60 mg of hydrogen cyanide which is present in 113 mg of sodium cyanide or in 150 mg of potassium cyanide. Death occurs rapidly, almost entirely painlessly and is spoken of as "death within seconds". An antidote cannot be administered quickly enough, and even thiosulphate injected intravenously can have no effect since its decomposition interval is too long to permit the formation of harmless hydrogen rhodonite.[¥] Cyanides are required in greater quantities than nicotine but death occurs sooner. Cyanides do have disadvantages, however, as they are difficult to obtain in pure form, especially sodium cyanide and are subject to decomposition under the influence of carbon dioxide. Harmless sodium or potassium carbonate will be formed while hydrogen cyanide gas will dissipate. Therefore, unless these preparations are stored in completely dry and airtight conditions they will eventually become entirely ineffective.[§]

Finally, the insecticide E 605 has lately attracted attention as having been repeatedly used for murder and suicide. It will cause the death of an adult if used in quantities of 500 mg, within a comparatively short time and usually very painfully. Atropine and oxygen appear to be effective antidotes. E 605 is an oily liquid with an odour of leeks, which is not readily subject to decomposition and this preparation could have been used by Third Reich leaders since it has been known since 1944, but was not then commercially available. It is, however, outside the scope of this review since the quantities required are too great for storage in small phials.

The quantities

The choice of poison will chiefly depend upon the size of cavity which can be created in a tooth to accommodate it. It has also to be kept in mind that the space in the cavity is not totally available for storing the poison. The tub inlay (Fig. 1), which will have to be cemented in the tooth cavity in order to protect the dentine against fracture, and the phial will take up some of the available space in the dental cavity. Its size, therefore, determines the extent of the tub inlay which, in its turn, determines the size of the phial. Phial size, in turn, however, depends on the quantity of the poison to be used and also on a loose fit, necessary to allow for rapid removal from the tooth by means of only the tongue. It is, therefore, impossible to make use of the total cavity in the tooth.

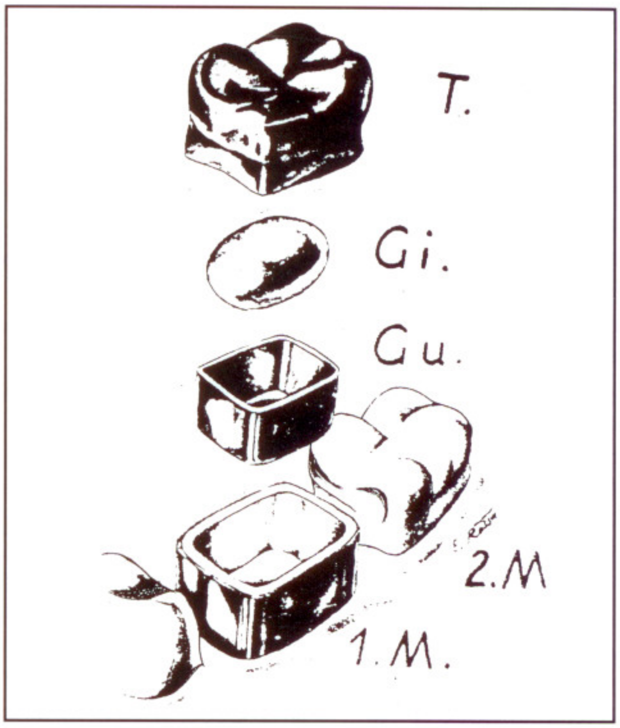

Fig 1 Schematic drawing of a molar surrounded by protective collar with telescopic crown, tub inlay and poison depot.

T = telescopic crown; Gu = tub inlay; Gi = phial; 1M = first molar; 2M = second molar.

The phial

After selection of the poison it was necessary to find a material suitable for the manufacture of the phial. Essentially, it was to have properties indispensable for the safe storage of the poison (Table 2), ease of processing and moulding and a certain strength, without offering too great a resistance to the bite; in other words, chewing pressure was to be able to crush it. Swallowing the phial whole would not induce death for it is unlikely that the stomach juices would dissolve it. In fact the material must be resistant to chemical corrosion, otherwise the poison might be lost, or else destroyed. It was also necessary for the completed phial to be easily filled with the liquid and sealed. Finally, the material of the phial had to possess sufficient density as porosity would allow passage of substances through the walls in both directions.

Metal was out of the question. It was of course easy to process at high temperatures and phials could be made thin enough to be crushed by a bite. However, in general, metals are corroded by nicotine and the cyanides and sealing would present difficulties since the high temperatures required for this purpose might easily have destroyed the poison.

Glass is easier to process and mould than metal and also

TABLE 2: Characteristics of materials to be considered for the manufacture of poison phials in teeth.

Material	P	M	St	R	C	F	S	D
metal	d	s	great	not good	great	not d	d	great
glass	e	s	great	good	s	d	d	great
porcelain	d	s	great	good	s	d	d	great
vulcanite	e	d	s	good	s	not d	d	s
celluloid	d	e	s	good	?	not d	e?	s
perspex	e	good	great	good	s?	good	not d	s
Piacryl SH	good	good	great	good	s?	e	e	s

P = processing, M = mouldability, St = strength, R = bite resistance, C = corrodibility, F = fillability, S = sealability, D = density, d = difficult, s = slight, e = easy.

has sufficient strength. It is, however, fragile and is not easy to seal after filling. The phial can be filled by heating and then immersed in the liquid poison, e.g., nicotine, which will then be drawn into the cooling chamber by partial vacuum. The heat of the sealing operation on the other hand may easily destroy the poison and it has frequently been observed that nicotine begins to burn during such an attempt. Conversely, the steam pressure inside the sealed phial can rise to the point where it causes it to burst. Generally, the same is true of porcelain but is more difficult to process than glass. Vulcanite and celluloid are not strong enough and too porous which leaves only the synthetic materials of which there are several examples and which are generally easy to process and mould.

It has taken a great deal of effort to find a suitable synthetic material. Perspex was taken into consideration but it does have a number of disadvantages. Piacryl SH (rapid hardening) has proved to be much more suitable. A polymer and monomer are combined by stirring until the material hardens in a very short time, After the polymerisation process is completed, drilling produces a phial with very thin walls. The drill opening allows the introduction of the poison into the phial, regardless of whether it is in liquid or in powdered form. The phial cavity is sealed by adding Piacryl SH over the opening and this provides a very effective seal since the liquid portion of the Piacryl will saturate the dry part. No heat is necessary, as would be the case for glass, which is an advantage. With Piacryl, therefore, there is neither a vaporisation of nicotine nor an escape of cyanides in gaseous form as would always occur in the processing and use of glass.

Preliminary tests with Piacryl SH have shown, however, that within a space of approximately 14 days, nicotine will permeate the phial walls in small but significant quantities. Piacryl, therefore, does not completely satisfy the requirements for a material in this context. However, it was difficult to discard this material since it has the advantage of easy processing and of mouldability, sufficient strength on the one hand, and is crushable by biting on the other and also is not in general, corroded by poison. Furthermore, sealing off the capsule after filling it with the poison offers no particular difficulty.

Our own tests have shown that the disadvantage of the permeability of this material may be overcome by sealing the empty phial in a high-percentage solution of sodium silicate. After drying, the poison is poured into the phial which is then sealed and the entire phial is coated on the outside with sodium silicate solution. Sodium silicate has good adherence characteristics particularly to the roughened Piacryl surface.

The tooth

Having established the types of poison which might be placed in a depot and which would be suitable to induce rapid death, and having identified the material for the phial to hold the poison, at least for a time without danger to the user, it is now necessary to select a suitable tooth and to prepare it to receive the depot. Not all teeth are suitable; the choice is really limited to the first two molars in the lower jaw. The upper jaw should not be considered for this purpose since the effect of gravity, jolting by standing or sitting and other movements may disengage the capsule. The first two mandibular molars have the advantage that their two roots are easily accessible, they are usually well formed and permit a thorough root treatment and filling. A good root treatment should precede the preparation of a cavity for the depot, if only for prophylactic reasons. After all, one should not, with a tooth bearing the poison, run the risk of tooth decay setting in later. The other four mandibular molars are also suitable for the installation of the depot but their more posterior location would complicate the process somewhat and reduce accessibility to the poison when needed.

Having treated the root the bottom of the pulp space is thoroughly cemented over and the preparation of the cavity may be commenced. Naturally, the tooth wall must not be ground away excessively, running the risk of collapse. A wall thickness of less than 1.0 mm is not sufficiently resistant to occlusal pressure, and it is wise to surround the tooth with a protective ring to support it (Fig. 1). The chewing surface is then ground back sufficiently to receive the required telescope crown.

After drilling, a tub inlay is cemented into the tooth to secure the dentine against fracture from the inside. After fashioning the telescope crown, the poison depot is installed in the cavity which is sealed from the top with the crown. Care should be taken to prevent entry of saliva, and of course, food particles, into the cavity. The telescope crown must, however, only be sealed to the extent that the wearer can remove it without great difficulty and with as little manipulation as possible. Circumstances will in fact probably require that the phial be removed very quickly. The following manipulations must be taken into account: removal of the telescope crown, removal of the phial, possibly with the aid of the tongue or a small pin, crushing (biting) of the phial and swallowing it. All that should be done very quickly and imperceptibly. The operation should be commenced by inserting a finger between the lips to remove the crown which should not particularly attract the attention of bystanders.

In order to ascertain the optimum size of the cavity, various molars were prepared in the manner described above.[4] On average, the cavity in the larger molars measured 310 cubic mm and after cementing the tub inlay in place, a cavity of 225 cubic mm remained. Within the capsules (Fig. 2) there was a space averaging 120 to 130 cubic mm. Such a space can readily accommodate approximately 15 mg aconitine or 120 mg nicotine. These quantities greatly exceed the fatal dose but for cyanides this cavity is insufficient.

Much more space is gained, of course, by manufacturing a hollow bridge.[5] By fashioning a suitably large space in the prosthesis, cosiderably larger phials and therefore larger amounts of poison may be deposited than in a single tooth. In such a case, not only cyanides, but also E 605 could be used. It is necessary for the bridge to be removable but anchored sufficiently by precision attachments to prevent it from disengaging and being swallowed prematurely with the phial (Fig. 2). Fitting the poison depot in a denture presents a similar situation as with a natural tooth where the cavity destined to receive the poison has to be artificially created (Fig. 3).

DISCUSSION

This investigation has shown that it is possible to fit a poison depot in the teeth. Nicotine is the best choice of poison given that a cavity of suitable size can be fitted in a molar. The poison container should be a phial made of Piacryl SH which has been sealed inside and out with sodium silicate. Much better possibilities are offered by the use of a bridge. A denture would only be used for this purpose if the wearer was actually in need of a removable prosthesis.

Wearing a poison depot in the teeth does not remain an audacious decision; this fact must not be overlooked. Even biting on a hard object, e.g. a fruit stone, may dent the telescope crown (despite a recessed positioning of the occlusion by 0.5 mm), and cause a rupture of the phial. There is thus a constant and immediate danger to life. Saliva may enter the cavity and allow the poison to leach out and unintentional poisoning may occur. Moreover, at any time, unintentionally and unnoticed, the telescope crown may dislodge, and while serious

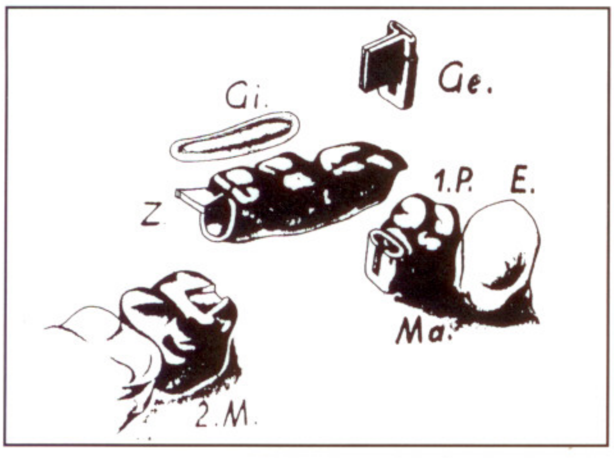

Fig 2 Schematic drawing of a bridge containing a cavity to carry a poison vial.

Ge = precision attachment; Gi = poison phial; Z = bridge with movable dovetail rest; 1P = first premolar; 2M = second molar; E = canine; Ma = crown carrying matrix of precision attachment.

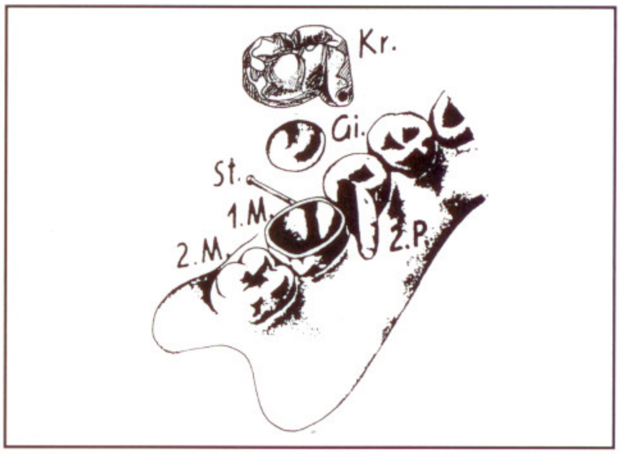

Fig 3 Schematic drawing of a denture prepared to accommodate a poison phial.

Kr = telescope crown; Gi = poison phial; St = pin holding crown in place; 1M = first molar; 2M = second molar; 2P = second premolar.

during daytime, would be disastrous during sleep or a spell of unconsciousness. This danger could be minimised by only inserting the poison phial at a critical time or when danger is threatening. In any case, the depot should be inspected periodically, if only to make sure no saliva or food debris have entered the tub inlay. It is also advisable for a person contemplating suicide to have the poison renewed periodically and/or to have the phial resealed with sodium silicate.

Returning to the initial question of whether leading personages of the Third Reich did in fact carry such a poison depot in their teeth, the verdict must be that the technique is possible and that we are not dealing with fiction; teeth can be modified to accommodate poison. For the time being however we remain ignorant of the material used for the phials since Piacryl SH is a more recently developed material which was probably still unknown in 1945. Nor can we readily ascertain which poison was used . Nicotine is an unlikely choice, as we favour the cyanides with the most popular receptacle being the cavity of a bridge, suitably anchored to the teeth and easily accessible.

Finally, it should be remembered that such a poison cache in the teeth need not be exclusively intended for suicide. It is possible that a poison phial in a tooth could have been intended to kill another person.

** It is of historical interest that the respected natural scientist and chemist, Francois Marie Caritat Baron de Condorcet, poisoned himself with potassium cyanide during the night of his arrest in 1794. The poison was kept in a ring which he always wore on his finger.*

† In this paper the possible poisons used by the Third Reich leaders are described and discussed, and techniques that might have been employed to store the poison in the teeth simulated and their feasibility established. - Editor's note.

¥ The enzyme rhodanese facilitates the reaction of thiosulfate with cyanide to form nontoxic hydrogenthiocyanate - Editor's note.

§ The classic example of an unsuccessful suicide attempt involving potassium cyanide which had already changed to potassium carbonate, is provided by Napoleon. In 1814, at the time of his abdication, he attempted to poison himself in Fountainbleau.

¶ Approximately one third of the dental cavity remains for the poison. Justifiably, the question will be raised why thePiacryl should not be used to make an inside cast of the tub inlay. In this way the space inside the cavity would be used most efficiently and more space would be left inside the phial for depositing the poison. It must be remembered, however, that the phial must be removable from the tooth in an emergency. It should therefore not fit too tightly, nor should it adhere exactly to the walls of the inlay; much space is thus lost.

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