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Contents

MORPHOMETRIC STUDY OF TEETH IN AGE CALCULATION

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ABSTRACT

The diagnostic usefulness of some morphometric parameters of teeth in age determination were studied . In the first series 173 central incisors from 13-83 year-old individuals were examined and in the second series 72 teeth from 30 individuals (aged 39 to 80 years) . Root transparency and dentinal tubule diameter were the most reliable parameters on the basis of image analysis (IBAS system) of scanning electron microscopic images. These variables were used in multiple linear regression analyses which led to the exclusion of secondary dentine as it did not improve the fit and therefore did not help to explain the dependent variable. The precise measurement of the morphometric variables we used facilitates age determination, reducing the mean error reported by other authors who used subjective estimates. Our results document the limited effectiveness of these parameters in age estimation due to individual variations caused by genetic factors and chewing habits.

Key words: age determination, IBAS system, scanning electron microscopy, tooth.

INTRODUCTION

Since the appearance of Gustafson's paper[1] a number of studies have questioned the effectiveness of the parameters and the precision of the measurements used to estimate age. Earlier studies in our laboratory[2-3] suggested that fewer parameters could be used and more precise measurements designed to exclude subjectivity on the part of the researcher.

Using these previous studies as a starting point we investigated the usefulness of automatic image analysis (IBAS) in quantifying some dental parameters. The results of these measurements were analyzed statistically to obtain a regression formula that could be used to calculate age from a single tooth.

Of the 22 parameters studied, those selected as most informative were root transparency, pulp diameter at the cemento-enamel junction, crown length, secondary dentine deposition, periodontal attachment and total pulp area. These data yielded 18% of the subject's age. To assess the possible use of error in determinations of a single tooth as a corrective factor, we analyzed several teeth from the same subject, a procedure that succeeded in reducing observational error, but at a nonsignificant level.[2-3]

Of all variables studied those that yielded the most precise results were root transparency which contributed to more than 12% of the variable "age". In agreement with a number of authors[4-6] we consider root transparency to be the feature most closely associated with tooth aging.

To analyze this phenomenon further (the result of gradual mineralization of the peritubular dentine which leads eventually to obliteration of the dentine tubules) we used SEM and the IBAS image analysis system to examine the number of tubules and tubule diameters, and tested the usefulness of these parameters in age determination.

MATERIAL AND METHODS

Two samples of human anterior teeth (incisors and canines) showing no structural disease were fixed in 10% buffered formaldehyde. Each tooth was cut in half through the midsagittal plane and each half sliced and polished down to a 1mm-thick section[4] with a carborundum coated disc cutter. The medial face (Fig 1) was examined by direct projection with a IBAS-I image analysis system connected to a video-camera which transmitted the images to a PC monitor.In the first series 173 central incisors from individuals aged 13 to 83 years were examined. A total of 22 variables was measured (Table 1) and these data were used to develop a regression equation based on the variables that significantly influenced age determination as follows: $56.4837 - 0.2757\ (X_1) + 7.3547\ (X_2) - 4.632\ (X_3) - 0.844\ (X_4) + 1.0961\ (X_5)$, where X_1 is pulp diameter, X_2 is root transparency, X_3 is total pulp area, X_4 is crown length and X_5 is periodontal attachment.

The second series consisted of 72 teeth from 30 individuals (aged 39 to 80 years). In this sample we studied the parameters required to apply the regression equation in order to determine whether the use of more than one tooth from a single individual decreased the error of prediction (Table 2).These teeth were prepared in a manner that allowed us to assess peritubular dentinal deposition and to count the dentine tubules. A 1mm-thick slice of each tooth was cut through the midsagittal plane and a 0.25 to 0.50mm-wide piece from the cemento-enamel junction to the apex was removed by cutting inward horizontally at the neck to a depth of 0.25 to 0.50mm then downward at right angle to the apex. The specimens were placed in an ultrasonic bath with 0.5% NaC10 for 15 min then in a 35% orthophosphoric acid solution for 2 min. The sections were dried and gold sputter-coated for observation in a scanning electron microscope.[8]

Once we had observed the specimen in the SEM we photographed the deep surface of the cut at right angle in order to assess its depth. The tubules within the field of observation were observed in the medial third of the length of the root at 2000X, a magnification found in earlier studies to provide optimal images of the area of interest[8]. Photographs of the images thus obtained were subjected to image analysis to count the number of tubules and to measure their diameter (Fig.2).

RESULTS

In order to attempt to determine age and to find which variables were the best predictors of age, simple linear correlation analyses were performed for age and each of the remaining variables (Table 1). The variables found to be statistically significant predictors were pulp crown diameter, root transparency, pulp area, crown length, periodontal attachment and secondary dentine. These variables were used in multiple linear regression analyses which led to the exclusion of secondary dentine as it did not improve the fit and therefore did not help to explain the dependent variable. The goodness of fit of the regression equation was $r = 0.425$ with $p < 0.0002$ and r^2 : 18.1%.

The results of measurements of several different teeth from the same individuals are given in Table 2. The findings of the morphometric analysis of SEM images are summarized in Table 3. According to the correlation matrix there was a statistically significant correlation between age and the number of tubules, with $r = -0.2046$, $p < 0.05$. The number of tubules also correlated with maximum tubule diameter, with $r = -0.3246$, $p < 0.01$. Multiple regression analysis using age as the dependent variable yielded a multiple r value of 0.2814 and $r^2 = 0.0792$ for 64 degrees of freedom; these results failed to contribute significantly to age determination.

DISCUSSION

The measurement of the morphometric variables we used facilitates age determination, reducing the mean error reported by other authors who used subjective estimates. Of the 22 variables tested, the most useful was root transparency which determined 12.45% of the variable age, a result similar to previous findings.[4-6]

Although our technique improves predictive capacity the finding that only 18% of the dependent variable was accounted for suggests that many other factors disrupt the dependence of age on the tooth parameters we studied.In spite of the fact that analyzing more than one tooth from a given individual decreased the mean error there was still considerable variability in the morphometric values obtained both within and between subjects. As shown in Table 2 the errors in measuring central incisors, lateral incisors or canines did not differ significantly. Although we used a technique that eleminated subjectivity in age determination and provided exact measurements of the morphometric parameters by image analysis the method failed to yield satisfactory results. It is therefore clear that alternative methods must be found to cope with the complexities of genetic or environmental influences on the variables and to improve their predictive potential.

Detailed consideration of root transparency by SEM analysis of the number and diameter of dentinal tubules revealed a statistically significant relationship between age and the number of tubules although the correlation was too weak to be of use in age determination. This finding corroborates one of the conclusions given by Kvaal.[8] The poor relationship between these two variables may be due to individual variability, as influenced by the factors such as eating or parafunctional chewing habits. Other possible factors may be those causing progressive tubular obliteration in a given individual.

The applicability of morphometric analyses of teeth in age determination must therefore remain a controversial issue as the method is still awaiting development in the problem of individual variability.

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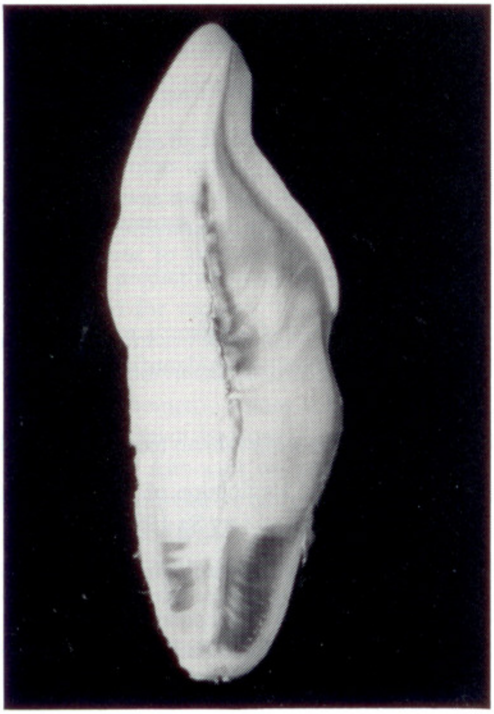

Fig. 1. Midsagittal slice (1-mm thick) of an upper central human incisor from a 58 year-old individual, showing root transparency, attrition and narrowing of the pulp cavity.

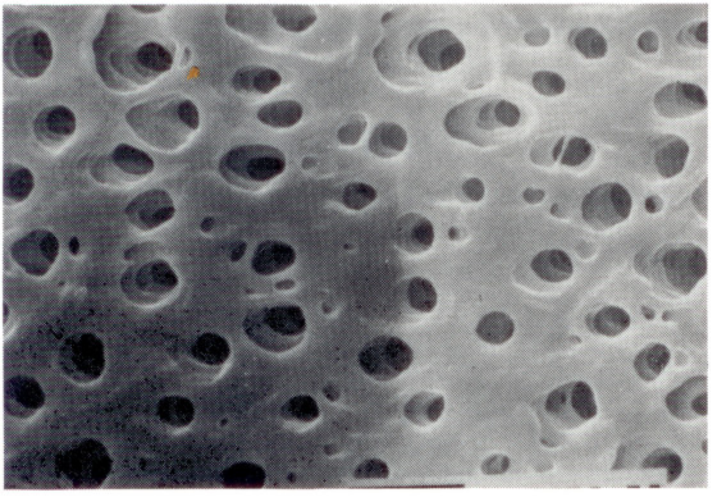

Fig.2. Scanning electron microscopy image of a tooth prepared for dentinal tubule counting and measurement (2000 X).

Table 1

Simple linear correlation between the variable "age" and each of the morphometric parameters.

Age	Parameter	R	R^2	P	D.F.
X_2	Central crown width	0.0884	0.0078	0.2771	1.151
X_3	Width at the cemento-enamel junction	0.1393	0.0194	0.0780	1.159
X_4	Root diameter halfway between the neck and the apex	0.0308	0.0009	0.6887	1.170
X_5	Pulp canal width at the neck	0.2423	0.0587	0.0031	1.145
X_6	Pulp canal width halfway between the neck and the apex	0.0175	0.0003	0.8211	1.167
X_7	Distance from end of pulp to aplical foramen	0.0233	0.0005	0.8528	1.64
X_8	Area of secondary dentinal deposition	0.1858	0.0345	0.02	1.166
X_9	Root transparency	0.3525	0.1243	0.00001	1.149
X_{10}	Total pulp area	0.1715	0.0294	0.0281	1.162
X_{11}	Pulp area above neck	0.0576	0.0033	0.4972	1.139
X_{12}	Area of aplical root resoption	0.1646	0.0271	0.3168	1.37
X_{13}	Cementum thickness	0.1511	0.0228	0.1460	1.92
X_{14}	Area of ideal crown	0.1205	0.0145	0.1404	1.149
X_{15}	Attrition	0.0738	0.0054	0.3863	1.138
X_{16}	1st observer	0.2397	0.0575	0.0015	1.171
X_{17}	2nd observer	0.2122	0.0450	0.0051	1.171
X_{18}	Total length of tooth	0.1219	0.0148	0.1102	1.171
X_{19}	Crown length	0.2018	0.0407	0.0078	1.171
X_{20}	Maximum crown width	0.0602	0.0036	0.4315	1.171
X_{21}	Periodontal attachment	0.1841	0.0339	0.0153	1.171

Table 2
Errors obtained in age estimation in different types of teeth.

Tooth (FDI)	Mean Error (YEARS)	SD	NUMBER OF SPECIMENS	RANGE
11/21	12.8160	+ 5.1900	15	(5.00 - - 20.50)
31/41	7.3529	+ 5.1020	24	(0.36 - - 20.39)
32/42	8.4800	+ 6.0190	13	(0.41 - - 19.78)
12/22	12.0650	+ 5.1538	9	(5.17 - - 19.56)
33/43	10.9116	+ 5.3008	6	(4.73 - - 17.00)
13/23	16.4260	+ 11.1244	5	(6.81 - - 29.99)

Table 3
Statistical results for variables studied in 70 human teeth.

No.	VARIABLES	MEAN	STD.DEV.	MINIMUM	MAXIMUM
1	Age	62.7714	8.9914	39.0000	80.0000
2	Depth cut	0.3954	0.1871	0.1400	1.1300
3	Number of tubules (total)	36.3571	14.0486	4.0000	80.0000
4	Number of tubules (measured)	14.8571	4.1012	3.0000	27.0000
5	Minimum diameter	0.7593	0.7912	0.1400	3.1500
6	Maximum diameter	4.8390	1.4602	2.6900	10.2500
7	Medium diameter	3.2970	0.9076	1.8200	6.6100

DENTAL ROOT SURFACE STRUCTURE AS AN INDICATOR OF AGE

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ABSTRACT

The purpose of this investigation was to examine the relationship between the root surface structure of human teeth and the age of the individual and also to evaluate whatever contribution this relationship might give to multiple regression methods for age estimation. The material, consisting of 1000 permanent teeth, excluding molars, was examined by means of a new scoring system (Surface Roughness Scores, SRS) for surface roughness, in addition to the scoring systems of Gustafson (RG) and Johanson (RJ) for root resorption. Statistical analyses using the SPSS package indicated a symmetric left/right distribution of root surface structure. The Pearson correlation between age and RJ varied from -0.02 for maxillary central incisors to 0.54 for mandibular central incisors and was approximately the same for RG. These two scoring systems seem to be of little value in methods for age estimation. Correlations between age and the new scoring systems SRS were significant for all teeth and varied from 0.44 for maxillary second premolars to 0.68 for mandibular first premolars. There was no detectable influence of gender or reason for extraction. However, the SRS could not be assessed with sufficient reproducibility, and the estimates were therefore too subjective to be used as the sole criterion for age estimation. This scoring system could, however contribute positively to a multiple regression method.

Keywords: Dental root surface; dental root resorption; age.

INTRODUCTION

To estimate its age may be an important part of the investigation in forensic dental identification of a human corpse. The amount of external resorption of the dental root was one of the independent variables used in Gustafson's original method for human age estimation.[1] The contribution of this factor to the reliability of the method was, however, not assessed and its inclusion in methods for age estimation has been criticized in later works as being insufficiently age-related to add value to the results.[2-7] Even though Dalitz[8] found the correlation beween age and root resorption to be 0.4, his method discarded resorption. That the number of resorption areas increased with age was also found by Henry and Weinmann[9]. On the other hand, Miles[2] found that resorption might have an adverse effect on the age estimate and a negative correlation between resorption and age has also been reported[10].

One reason why root resorption may not have contributed to the results in methods of age estimation might be that the amount of resorption has been found to be related to the degree of periodontal disease.[11-13] Kronfeld,[14] however, claimed that resorption was not caused by periodontal disease unless the tooth was traumatized. Being more strongly correlated with disease than age, resorption has been considered to be of no value in methods for age estimation[4]. Johanson[15] used a multiple regression method for age estimation and included resorption as one of the factors; the value of which was particularly emphasized in estimates on teeth from elderly individuals.

The amount of root resorption has previously been assessed in a scoring system,[1,15] but no objective measurement for this possibly age-related change has been described. It has also been observed that the root surface becomes more rough and uneven with age.[16-19] As well as being caused by resorption, this may also be the result of a tendency towards mineral deposition in the surface along the periodontal fibres. Futhermore an uneven deposition of cementum may also contribute to the roughness of the surface. A new scoring system for estimation of the surface roughness, taking into consideration the previously mentioned factors, has therefore been designed for this study.

This investigation set out to examine the correlation between age and the conventional scoring systems for root resorption as applied to each type of tooth, and to compare these results with those from the new scoring system for surface roughness. Futhermore, the investigation aimed at examining the influence on surface roughness scores of other factors, namely gender and reason for extraction. Finally, the value of these scores in methods of age estimation was assessed.

MATERIALS AND METHODS

The material, described in previous reports[20,21] consisted of 1000 teeth from a Caucasian population, comprising 100 of each type of tooth, excluding molars.

The teeth were sectioned according to the "half-tooth" technique,[22] and the cut surfaces were examined in a stereomicroscope to assess resorption scores according to the criteria of Gustafson (RG)4 and Johanson (RJ),[15] the latter score being doubled to avoid halfunits. In addition, after careful removal of the remaining periodontal fibres with a finger nail, the juxta-apical root surface was studied in a stereomicroscope under low magnification and scored according to a new system for evaluation of the surface roughness (SRS).

The five scores (SRS) of this new system were defined as follow:

0 = an almost completely smooth surface.

1 = an almost even surface with microscopic roughnesses (10 fm) and only a few larger roughnesses and no external resorption defects.

2 = a less even surface with a number of larger roughnesses, but with no or only a few resorption defects.

3 = an uneven surface with both smaller and larger roughnesses and some resorption defects.

4 = a very uneven surface with large roughnesses and resorption defects.

Photographs and drawings (Figs. 1 and 2) exemplify the new scores. Score 0 was never registered in this investigation, as every tooth seemed to have microscopic roughnesses in the root surface.

The reproducibility of SRS (first scoring : TS) was tested by a second examination (TS2) of the root surface of maxillary lateral incisors. In addition, another examiner (SK) performed registrations after studying the score definitions and inspecting the photographs of typical examples of teeth with different scores (Fig. 1).

STATISTICAL METHODS

The data were entered into files in a Sanyo MBC-17plus[5] microcomputer, using the Wordstar word processor program. Statistical analyses were performed in the microcomputer, using the SPSS/PC+ statistical package.[22]

A paired t-test for left/right differences was performed on contralateral teeth from the same individual (20-28 pairs of each tooth type). Since no differences were detected at the $P<0.01$ level, left and right teeth were pooled for the final analyses. As these were made with the tooth, not the individual as the unit, only one from each pair of contralateral teeth from each individual could be included in this study. The right tooth was chosen, and thus the number of teeth for the final analyses was reduced from 100 to between 72 and 80 for the various types.

Squared and logarithmic (base 10 logarithm) transformations of the independent variables were made by the computer. The transformations served as a test for non-linear relationship between age and surface structure.

Both the inter- and intra-individual variations in the assessment of the surface roughness scoring system were tested on 50 maxillary left lateral incisors, using the subprogram Crosstabs and calculating the tau-b and gamma statistics.[23] In addition, the kappa statistics were calculated, using a special computer program.[24]

For each type of tooth a descriptive analysis was run. The relationship between the different ways of measuring surface structure and age, tooth-age, gender and reason for extraction was analysed, using the Correlation subprogram. In addition, partial correlation analysis between these variables were made, using the Regression subprogram. By including age in the regression, partial correlation between gender and reason for extraction and surface structure could be read while age was controlled for. Likewise, by including gender and reason for extraction as independent variables, partial correlation between age and surface structure was found while these two factors were controlled for.

Multiple regression analyses were run, using the Regression subprogram. Age and tooth age were used alternately as the dependent variable. A stepwise procedure was employed with inclusion level at $P<0.05$ and exclusion level at $P>0.055$.

RESULTS

The mean scores for the root surface structure in the different scoring systems are shown in Table 1. Variation in the mean score for the various types of teeth did not seem to be related to age.

For maxillary left lateral incisors the test of the new scoring system (SRS) resulted in the following correlation with age: TS: $r = 0.52$, TS2 (repeated examination by TS): $r = 0.53$, SK: $r = 0.40$. Tau-b, gamma and kappa statistics shown in Table 2 revealed that the SRS had a rather poor reproducibility.

The correlation with age for SRS was positive and significant for all tooth types (Table 3), with correlation coefficients varying from 0.48 for maxillary second premolars to 0.69 for mandibular first premolars (Fig 3). SRS for central incisors and first premolars were more strongly correlated to age than for the other types of teeth. Neither the squared nor the log transformation of SRS had stronger correlation with age. The use of tooth age as an alternative to the age of the individual did not result in a significantly different correlation with SRS.

For some types of teeth, Pearson correlations between age and scores for external resorption (RG and RJ) (Table 3) were weak and for the remaining teeth insignificant. For maxillary centrals alone a negative but insignificant correlation was found when using RJ.

Partial correlation coefficients between SRS and age calculated after controlling for gender and the reason for extraction (Table 4), resulted in only minor deviations from the Pearson correlation coefficients. No significant correlations were found between SRS and gender or the reasons for extraction (Table 4). Partial correlations between SRS and RJ[15] indicated a weak relationship for some types of teeth and no significant relationship for others (Table 4).

No significant correlations were found between SRS and extraction for periodontal reasons. For some teeth a small but significant negative correlation was found between SRS and the width of the pulp in the cervical area.

For all types of teeth the SRS was included in the regression (Table 5). In addition, RG was included for mandibular central incisors and second premolars and LRG (logarithmic transformation of RG) for maxillary second premolars. The correlation coefficients for the regression varied from 0.51 for maxillary lateral incisors to 0.69 for mandibular central incisors and first premolars.

DISCUSSION

The teeth in this study originated from heterogeneous sources and might to a greater or lesser extent be affected by pathological conditions which could result in a wider variation in the changes studied and in a weaker correlation with age. However, it has also been claimed that teeth from different sources may be more suitable for the study of age changes as they reflect the biological variation better than teeth from a homogeneous source.[25]

For all teeth the roughness scores (SRS) showed a significant correlation with age. The criteria for this scoring system are more complex than for the scores according to Gustafson[1] and Johanson.[15] In addition to resorptions it also takes into consideration the appearance of the cementum surface, including calcification along the periodontal fibres.

Assessment of the roughness scores (SRS) is, of course, based on a subjective judgement, as the reproducibility test showed. Moreover, the score may vary from one area to another on the same root. Another disadvantage is that mechanical cleaning of the surface may have smoothened away remnants of periodontal fibres. The possibility of chemical cleaning was not explored in this study.

In the case of only a few types of teeth were the scores according to Gustafson (RG)[1] and Johanson (RJ)[15] found to be positive but weakly correlated with age. One reason for this may be that the scores could be more difficult to assess from half-sectioned teeth using a stereomicroscope than from conventional thinly ground sections in an ordinary light microscope; this could explain the small, and for most teeth insignificant, correlation with age. However, Maples[10] arrived at a negative correlation with age, using ground sections. Therefore the scores of Gustafson[1] and Johanson[15] are apparently unable to contribute to age estimates either alone or in conjunction with other types of age related changes.

The use of tooth age instead of indvidual age did not improve the correlations. If SRS had varied between the sexes, which was not the case, an improved correlation with tooth age might have been demonstrated. The observed lack of correlations between SRS and extraction for periodontal reasons in contrary to other reports.[11-13] An explanation may be that periodontal disease is a clinical diagnosis not based on an exact measurement of the actual destruction of the periodontal ligament. Futhermore, teeth with severe periodontal destruction may have been extracted for other reasons, e.g. pulpitis.

When the age was controlled for, a tendency was found for more irregular surfaces in teeth with narrower pulp canals. This could be due to a congenital tendency for increased production of mineralized tissue in some individuals or to external influences such as greater mastication forces. The latter is however unlikely, since no differences were found between genders, although the chewing forces are weaker in females than in males.[26]

In summary, the correlations between SRS and age were not so strong that this factor can be recommended for use by itself in age estimations and its use is even contradicted because of the low reproducibility in scoring. However, when employed together with other parameters in a multiple regression formula these scores might contribute to increased accuracy in age estimates.

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Table 1

Means of age of individuals and dental root surface scores.

TOOTH TYPE	AGE YRS	RG SCORES	RJ	SRS
11/21	51.1	0.6	0.9	2.2
12/22	52.6	1.0	1.9	2.6
13/23	53.6	0.5	0.8	2.3
14/24	43.9	0.6	1.2	2.3
15/25	47.3	0.5	0.9	2.3
31/41	57.9	1.1	2.3	2.8
32/42	57.6	0.3	0.6	1.9
33/43	53.6	0.8	0.6	2.7
34/44	47.3	0.8	1.6	2.6
35/45	52.9	1.2	2.5	2.8

RG = resorption scores according to Gustafson (1).
RJ = resorption scores according to Johanson (15).
SRS = surface roughness scores (see text).

Table 2

Tau-b and gamma statistics for the reliablity of scoring made by the same examiner at different times (TS-TS2) and by different examiners (TS-SK, TS2-SK). Kappa statistics for the three observers jointly.

Statistics	TS-TS2	TS-SK	TS2-SK
tau-b	0.47	0.41	0.45
gamma	0.70	0.59	0.61
kappa = 0.2			

Table 3

Pearson correlation between age and root surface structure for various types of teeth. Significance limit at P>0.01 for r>0.29 (n=78).

TOOTH TYPE	AGE/RG	AGE/RJ	AGE/SRS	AGE/SRS2	AGE/LSRS
11/21	.01	-.02	.62	.62	.59
12/22	.30	.28	.51	.50	.50
13/23	.13	.15	.55	.54	.55
14/24	.30	.31	.62	.63	.57
15/25	.08	.15	.48	.44	.50
31/41	.50	.54	.66	.63	.67
32/42	.12	.17	.60	.58	.54
33/34	.40	.40	.58	.57	.57
34/44	.45	.44	.69	.68	.66
35/45	.39	.36	.53	.52	.52

SRS2 = SRS SQUARED.
LSRS = BASE 10 LOGARITHM OF SRS.
For other abbreviations see Table 1.

Table 4

Partial correlations between age and surface roughness scores (SRS) controlling for the effects of gender (1) and reason for extraction (2). Partial correlations between gender, reason for extraction and the scores of Johanson (RJ), and SRS after controlling for the effect of age (3). The Pearson correlation between SRS and AGE is included for comparison.

TOOTH TYPE	1 SRS/AGE	2 SRS/AGE	3 SRS/SEX	3 SRS/EX	3 SRS/RJ	Pearson corr. SRS/AGE
11/21	.58	.60	.05	.23	.31	.62
12/22	.49	.53	.21	.13	.01	.51
13/23	.54	.55	.13	.03	.11	.55
14/24	.58	.62	.05	.18	.32	.62
15/25	.47	.48	.10	.17	.46	.48
31/41	.68	.62	-.14	.12	.38	.66
32/42	.57	.58	-.04	-.07	.29	.60
33/43	.58	.58	.08	-.16	.18	.58
34/44	.66	.69	.04	-.19	.31	.69
35/45	.48	.53	.08	.18	.10	.53

EX = reason for extraction.
For other abbreviations see Table 1.

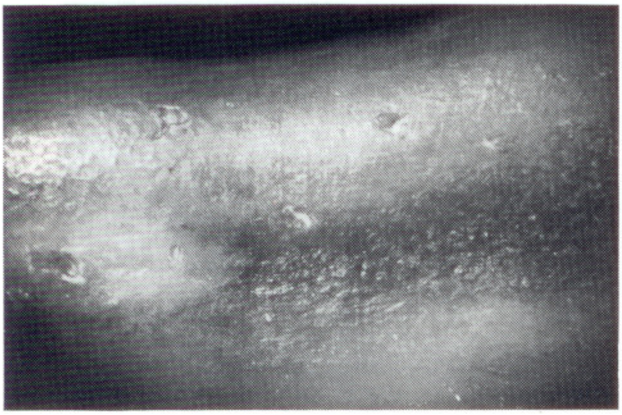
Table 5

Multiple regression formula with age and tooth age as dependent variables.

Maxillary teeth.			
1.	AGE =	19.7 + 14.2 SRS	(r = 0.62)
	TAGE =	9.4 + 14.3 SRS	(r = 0.62)
2.	AGE =	18.6 + 13.2 SRS	(r = 0.51)
	TAGE =	8.2 + 13.1 SRS	(r = 0.51)
3.	AGE =	24.8 + 12.3 SRS	(r = 0.55)
	TAGE =	12.7 + 11.7 SRS	(r = 0.54)
4.	AGE =	11.4 + 13.9 SRS	(r = 0.62)
	TAGE =	-1.6 + 13.8 SRS	(r = 0.62)
5.	AGE =	15.7 + 14.6 SRS - 58 LRG	(r = 0.62)
	TAGE =	2.3 + 14.5 SRS - 59 LRG	(r = 0.62)
Mandibular teeth			
1.	AGE =	14.1 + 13.0 SRS + 6.5 RG	(r = 0.69)
	TAGE =	5.1 + 13.1 SRS + 6.7 RG	(r = 0.69)
2.	AGE =	31.8 = 13.7 SRS	(r = 0.60)
	TAGE =	22.1 + 13.8 SRS	(r = 0.60)
3.	AGE =	24.5 + 13.1 SRS	(r = 0.58)
	TAGE =	11.1 + 13.5 SRS	(r = 0.58)
4.	AGE =	9.8 + 15.7 SRS	9r = 0.69)
	TAGE =	-2.7 + 15.7 SRS	(r = 0.69)
5.	AGE =	10.0 + 11.3 SRS + 9.0 RG	(r = 0.60)
	TAGE =	-3.5 + 11.2 SRS + 9.1 RG	(r = 0.60)

TAGE = tooth-age
AGE = age of individual
SRS = surface roughness score
RG = Gustafson's estimate of external resorption
LRG = Logarithmic transformation of RG

Score 1



Score 2

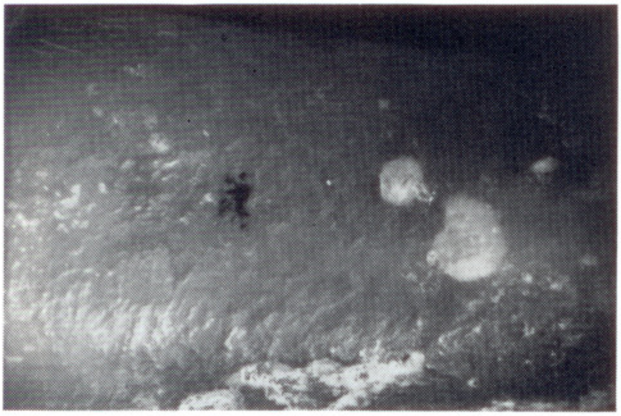
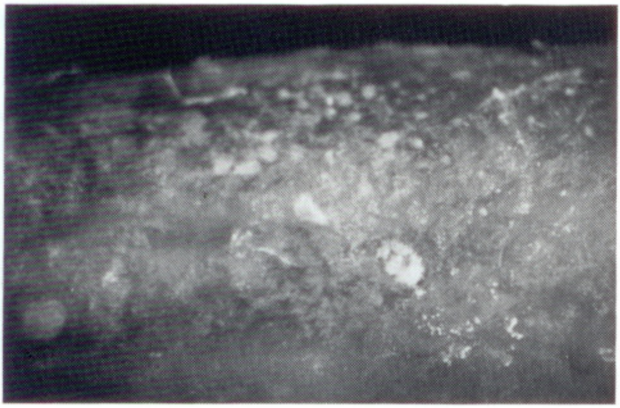


Fig. 1a - Photographs of tooth surfaces presenting the different scores (1-4) in the new system for surface roughness scores (SRS) showing the scores 1 and 2.

Score 3



Score 4

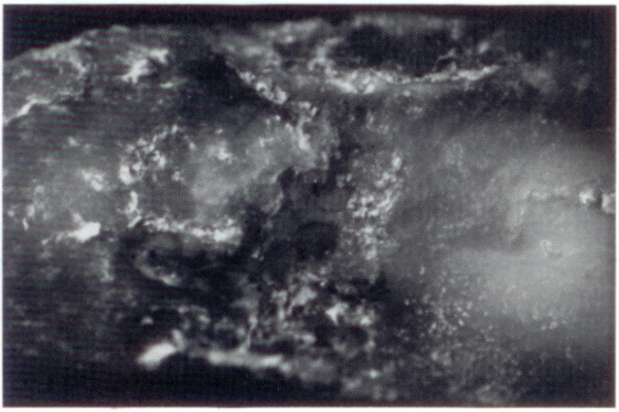


Fig. 1b - Photographs of tooth surfaces presenting the different scores (1-4) in the new system for surface roughness scores (SRS) showing the scores 3 and 4.

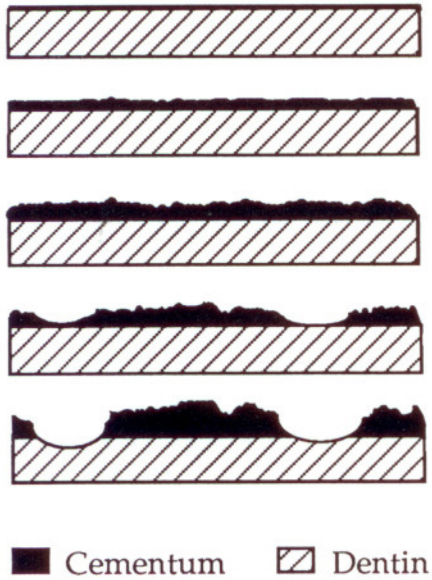


Fig. 2 - Diagrammatic representation of the different scores in the new system (SRS).

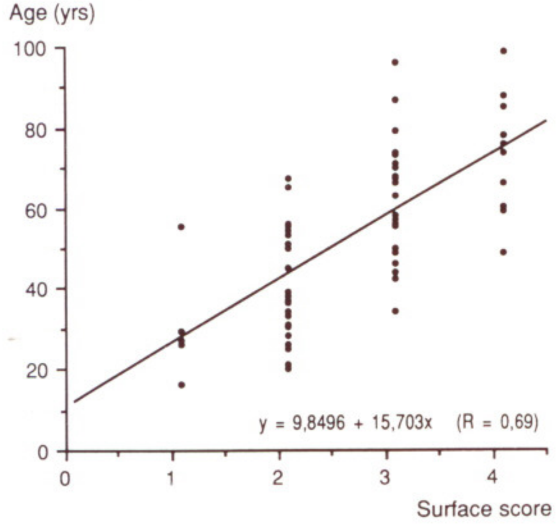


Fig. 3 - Plot of age versus surface roughness scores (SRS) in mandibular first premolars (r = 0.69).

DENTAL RADIOGRAPHIC IDENTIFICATION UTILISING COMPUTERISED DIGITAL SLICE INTERPOSITION: A CASE REPORT

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Abstract: A pair of ante- and post-mortem periapical dental radiographs of an individual were digitised on a personal computer with the aid of an X-ray scanner. The radiographs were appropriately prepared and compared using image editing software. In this case, dental restorations, root morphology, periodontal ligaments, pulp spaces, bony trabeculation and a retained root fragment were features used for comparison. The results showed that all the features were consistant in ante-mortem and post-mortem radiographs except for two points. Both discrepancies were related to dimensional differences found in dental restorations and the retained root fragment. Nevertheless, there were acceptable explanations to account for each discrepancy.

Keywords: radiography, computerised digital slice interposition, dental identification

INTRODUCTION

Identification of missing persons or unknown human remains can be a complicated task. Conventional methods of identification include visual recognition, clothing and personal artifacts, DNA "fingerprinting", fingerprints, skeletal, serological, medical and dental examination.[1-4] In cases where bodies are severely decomposed, skeletonised, burned or otherwise mutilated, dental identification is often the method of choice.[1,5-7] Schuller[8] was the first to suggest the use of radiographs for identification, while Culbert and Law[9] and Law[10] were the first to conduct a positive identification of a body through comparisons of the mastoid sinuses in ante-mortem and post-mortem radiographs. Comparisions of skeletal structures, frontal and other paranasal sinuses have also been employed as landmarks for identification.[2,11,12]

The human dentition with a broad spectrum of individual characteristics is a convenient site to obtain relevant informantion for comparison. Sprawson[13] and Simpson[14] were among the first to recognise the use of dental radiographs for forensic identification. Examination of the post-mortem dentition visually and radiographically may enable the forensic odontologist to establish a general history of the individual's age, sex, and race.[15] Missing and impacted teeth, bony trabeculation, caries, periodontal or periapical pathosis, endodontic therapy, dental prosthesis, tooth morphology and other anatomical structures in the oro-facial region are features commonly compared during a dental identification. [1,3,14-17] These features are readily available in ante-mortem dental casts, radiographs, and charts from dental practitioners.

The purpose of this paper is to describe an alternative method of dental identification. It incorporates the concept of computerised interposition on digitised ante-mortem and post-mortem dental radiographs as an accurate technique for identification.

CASE REPORT

A 55 year-old female with a history of bipolar affective disorder was reported missing from her rural home. Five weeks later, a body was discovered hanging by the neck in a barn, some distance from the missing subject's home. Unfortunately, the body was already in an advanced state of decomposition (Fig. 1). The suspected female subject had been a resident of another jurisdiction and her dental records were obtained by police and forwarded to forensic pathology for identification purposes.

The teeth of the unidentified subject were intact and many had a pinkish hue around their cervical areas. Although several dental restorations were present in the oral cavity, only the mandible was presented to the forensic odontologist because no clinical or radiographic ante-mortem records were available for the maxilla. The mandible was largely skeletonised with minimal remaining soft tissue attached. It was cleaned of maggots by the pathology staff prior to examination. Only a single ante-mortem periapical radiograph of the left mandibular permolar or molar region was provided by the subject's dentist. Three separate dental restorations were shown on the six year-old radiograph. There was a distoocclusal amalgam restoration on the left mandibular first premolar, a mesio-occluso-distal amalgam restoration on the left mandibular second permolar, a mesio-occluso-distal amalgam restoration on the left mandibular first molar and a retained root fragment distal to that same molar. The ante-mortem dental chart was available but unfortunately the dentist had failed to record any information pertaining to the subject's teeth.

Numerous post-mortem radiographs of the left mandibular premolar and molar regions were taken by the forensic odontologist. One post-mortem dental radiograph was carefully selected on the basis of its similarity to the projection geometry of the ante-mortem radiograph. The ante-and post-mortem radiographs were subjected to futher comparison and analysis with a new identification method described in a previous *in-vitro* study.[18] The radiographs were digitised on a Macintosh*IIci computer* with an X-ray scanner* and transferred to graphics analysing software.* The images were enhanced with respect to density and contrast with the aid of the *Levels* and *Brightness/Contrast* function in the software. No dimensional changes were made to the radiograpic images except for magnification, in which case both the ante- and post-mortem radiographic images were magnified at the same time by the same factor (Fig 2). The type of restorations found on the left mandibular first and second premolar, and the left mandibular first molar matched exactly in both ante- and post-mortem dental radiographs (Fig 2). A thin horizontal slice of the root structures was excised from the ante-mortem radiograph and laid over the root structures of the post-mortem radiograph using the *Cut* and *Paste* functions of the image analysing software (Fig 3). Similarly, a comparison of the retained root fragment found in both the ante- and post-mortem radiographs was made (Fig 4). Additionally, five other sections of the ante-mortem radiograph were cut and pasted over the post-mortem radiograph for comparison (Fig 5). Based on these points of comparison, a definitive identification of the suspected individual was accomplished. The identity of the subject was accepted by the coroner responsible for the case based on the dental identification report.

* Apple Computer Inc., 20525 Mariani Avenue, Cupertino CA 95014-6299

* XRS model 3CX, 4030 Sepncer Street, Torrance, CA 90503.

* Adobe Systems Inc., 1585 Charleston Road, Moutain View, CA 94039-7900

DISCUSSION

The human dentition and dental restorations that may accompany it are often regarded as one of the most durable parts of the human body and are highly resistant to post-mortem changes.[1,3,6] Since the subject's body was discovered in an advanced state of decomposition, visual identification of the body was not possible. Formal documents such as a driver's licence and personal artifacts which would normally be used for identification purposes were absent and the case exemplified the importance of dental identification. However, the limited ante-mortem dental records made it challenging as the dental chart proved to be useless since no records of the subject's teeth were made. There was only a single ante-mortem intra-oral radiograph provided by the dentist and this radiograph alone served as the basis for identification.

There were several areas of agreement between the ante- and post-mortem dental radiographs. During a comparison of the ante- and post-mortem radiograph, the pattern of dental restorations was a definite match, despite subtle differences in the size of the restorations. This inconsistency can easily be accounted for by differences in vertical angulation between the two views (Fig 2). Several studies have shown that the specific combination of an individual's decayed, missing and filled teeth (DMFT) could serve as a meaningful method of identification with 95.7% accuracy.[19] Unfortunately in this case, the subject's teeth were not charted by the dentist so no pertinent information could be gathered.

This is the first known occasion in forensic dentistry that the concept of computerised digital slice interposition has been applied to a case of identification. Comparison of the horizontal slice of the ante-mortem radiograph with the post-mortem radiograph has shown the root size and curvature to be a positive match. The shadows of the alveolar bone, periodontal ligaments and dental pulps all aligned precisely to provide futher proof of a definitive match (Fig 3). The same method was employed previously in an *in-vitro* study where ante-and post-mortem radiographs of 39 hemi-mandibles were made and all of them matched perfectly.[18] In another set of duplicates, five other sections of the ante-mortem radiograph served as the foci for comparison. They showed that there was a direct matching of the pulp chamber of the first mandibular molar, the trabecular bone pattern and the root structure of the second mandibular premolar. (Fig 5).

Unique dental features such as impacted teeth, dilacerated or retained roots, endodontic therapy, crowns and bridges and other dental restorations are often important landmarks for a positive radiograph identification.[3,16,20] Keiser-Nielsen[21] suggested that certain dental features deserved to be classified as "extraordinary features" because their frequency in the oral cavity is low. Sometimes, these "extraordinary features" alone may be sufficient to provide a conclusive identification.[21] In this case, a retained root fragment was located distal to the left mandibular first molar on both ante- and post-mortem radiographs. Although the same feature could be found on both radiographs, the actual dimension of the post-mortem root fragment was smaller than that of the ante-mortem. This discrepancy in size can be attributed to several factors. One is the slight distortion of the images due to the differences in projection geometry between ante- and post-mortem radiographs. It is difficult for the forensic odontologist to duplicate the original angulation of the X-ray beam used to expose the ante-mortem radiograph.[20] The time lapsed between ante-mortem and post-mortem radiographs can allow for certain remodelling processes to occur. Assuming the root fragment was exposed to the oral environment (which it was when viewed clinically), it is entirely possible that over a span of six years caries contributed to its reduction in size. The retained root fragment may also have undergone some form of external resorption which could have affected its size.

In the authors' opinion, significant benefits would be gained from adding this technique to the forensic odontologist's armamentarium. It enables the forensic odontologist to maximise the amount of information that can be extracted, even from a single ante-mortem radiograph in cases where ante-mortem radiographic records are limited. In most cases however this will involve periapical or bitewing radiographs that are readily available from dental offices and will serve as important sources of information even if dental charts are unavailable. This technique may become extremely useful in the future because traditional dental identification methods have relied heavily on the presence of matching dental restorations found in both ante- and post-mortem records. With the general reduction in the incidence of caries and dental restorations[22] the technique allows a concentration on analysis of comparisons of anatomical features other than resorations, such as pulp chamber and root morphology. This may be crucial for future dental identification.

CONCLUSION

During a comparison of the ante- and post-mortem radiographs it is necessary to determine several points of concordance in order to establish a positive identification. The case described is the first to incorporate the technique of computerised digital slice interpostion as the sole method of identification. This technique proved useful in this case for providing several points of agreement from a single pair of ante- and post-mortem periapical radiographs. The only two points of discrepancy were the differences in size of the retained root fragment and dental restorations in the ante- post-mortem radiographs. The first point of disagreement could be accounted for by oral environment influences in the six years between the ante-mortem and post-mortem dental radiographic examinations and the second inconsistency could be attributed to differences in projection geometry when exposing ante- and post-mortem radiographs.

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FIGURES AND FIGURE LEGENDS

Figure 1: Post-mortem photograph of the subject showing the advanced state of decomposition.

Figure 2: The pattern of dental restorations is a match between the ante-mortem (top) and post-mortem (bottom) radiographs. There are slight differences in the vertical angulation between the two views.

Figure 3: A thin slice of the root structure from the ante-mortem radiograph (top) is cut and pasted over the root structure of the post-mortem radiograph (bottom). This revealed a direct match in the root sizes and curvatures, lamina dura, periodontal ligament spaces and dental pulps.

Figure 4: The retained root fragment (right box) in this post-mortem radiograph has been highlighted and the ante-mortem view of this root (left box) is present just left of the post-mortem view.

Figure 5: Five regions of the ante-mortem radiograph (top) have been cut and pasted onto the post-mortem radiograph (bottom) as a further illustration of the match.

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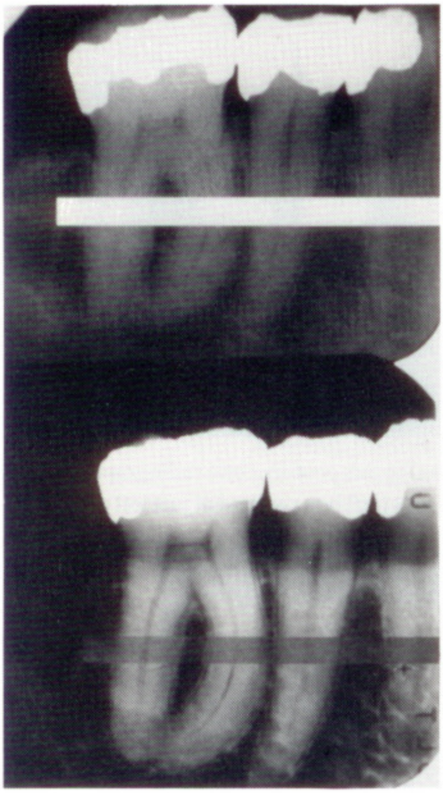
Figure 1: Post-mortem photograph of the subject showing the advanced state of decomposition.



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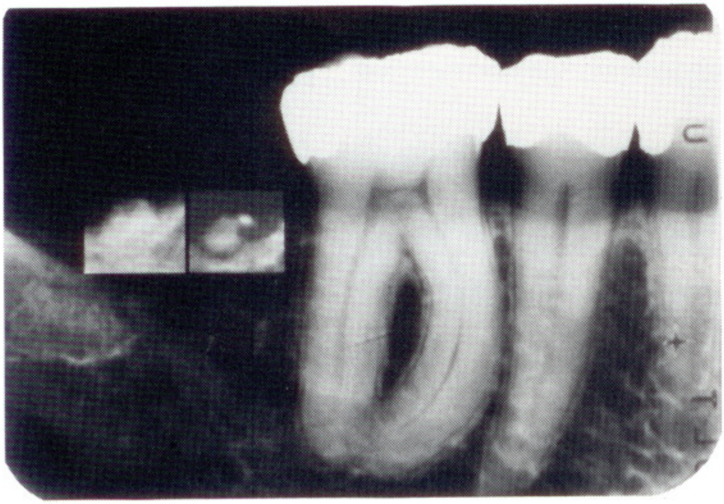

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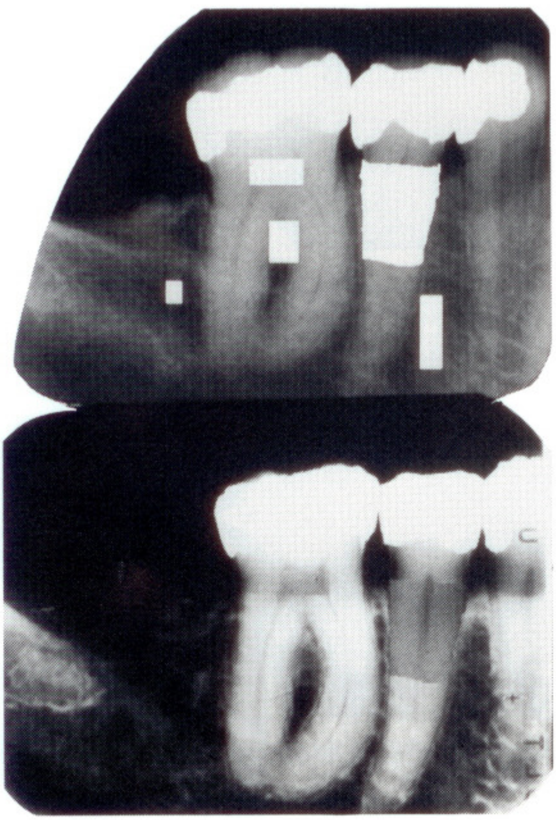

Figure 5: Five regions of the ante-mortem radiograph (top) have been cut and pasted onto the post-mortem radiograph (bottom) as a further illustration of the match.

BITEMARKS IN FORENSIC DENTAL PRACTICE: THE RUSSIAN EXPERIENCE

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INTRODUCTION

Examining and analysing bitemarks presents many problems. They may occur in human skin or in foodstuffs and in all cases may change rapidly as time passes. In food particularly, ambient conditions such as temperature and humidity can cause changes in the mark's characteristics while bite marks in human skin can deteriorate when haematoma and viscoelastic deformation in the skin disappear. It would be beneficial therefore to capture the mark in a fixed medium for later examination at leisure. Methods of doing this may be classified as follows:

1) Photographs using correct lighting to highlight all features of the bite.

2) Casts of the jaws and teeth of the offending individual.

3) Casts of the bite of the offender in experimental materials, including, if any, prostheses that may be worn.

4) Casts of the actual bitemark after impression, a description of the way the bite was caused and photographs of an arrangement of teeth in an articulator to simulate the original dentition could also contribute positively.

Choosing the correct medium to record the mark or the correct sequence of several media is important. It is necessary in the first instant to do it in a non-destructive way and to do so without delay while the mark is still fresh and has not undergone any degenerative change.

The technique used for recording a bitemark depends on its character and on the severity of the bite. In the case of a superficial bite the anterior teeth display a linear arrangement with the distances between individual teeth and characteristics such as fissures, attrition and other defects observable. The premolars are revealed as double points caused by the cusp tips. In the case of a stronger biting force incisors are not so easily identifiable and only outlines and general size are visible. The occlusal surfaces of premolars are better visualized and in general the configuration of the occlusion is more obvious. When a bite is deep and tearing the marks are mirror image tracings of the teeth and contain all the detail and microrelief of the incisal edges. Important are the localization, width, depth of grooves, their sequence and form. Any record taken of these marks should faithfully reproduce the linear nature of the bite and the irregularities in the teeth.

The difference between sliding bites and non-sliding is that the microrelief in the teeth is shown up in the lines whereas in the non-sliding bite the microrelief is clearly visible but the smaller details are hidden in the depth of the mark. The result is that a sliding bite gives more detail than a non-sliding and this should be recorded. Records are of course necessary and photographs in addition to casts are useful for later comparison.

Mathematical methods for analysing bitemarks are well known and include the dimensions of the marks which are an advantage because a qualitative description only is not sufficient to establish a complete picture of the marks. Mathematical analysis allows observations to be made which are independent of physical records.

The mathematical description which can be supported by statistics lends authenticity to the observation of bitemarks. It is also useful where individual tooth marks are not clear but where the dental arch as a whole is clearer and the length of a group of teeth is measurable. This way of recording a bitemark was particularly useful in a case of murder of a minor (JM) where test bitemarks from the suspected offender were compared with a bitemark and quantification using a statistical mean combined with other details allowed a conclusion to be made that the suspected offender was innocent. The true offender was later convicted.

RADIOLOGY IN BITEMARK INVESTIGATION

An aspect of tooth marks that has not been investigated is the volume of the mark left by the tooth. Only the form and size of the bite have hitherto been described. The existing methods of recording bitemarks, photographic and casts, do not always allow an image character of the incisal/masticatory surfaces because the base of the mark is difficult to observe. It is in fact impossible to analyse all the features of form and size of the crown of each tooth. Photography also fails to highlight all unevenness. In fact, photography can be misleading because shadows and highlights can be incorrect. Making impressions can be damaging to the mark and the resulting cast inaccurate.

In order to overcome the above disadvantages a method was attempted which would capture the mark quickly, totally and non-destructibly. Radiology was used together with a contrast medium in order to create an image of the tooth mark. The consistency of the contrast medium was important as was the radio-lucency of the bitten object. Different carriers were radiographed such as cheese, wax, bread, soap. These are all relatively common carriers for bitemarks and they were all found to be sufficiently radiolucent. The contrast medium first used was barium sulphate in different consistencies of liquidity. The photographs were clear but the results not satisfactory because the casts did not correspond to the radiographs and the bases of the marks were not sharp.

Other contrast media were then tried. Urotrast and jodolinol were found to give good contrast and good radiographic results. These materials were also non-destructive and were easy to remove with syringe or filter paper.

The useful views obtained were frontal, in which the form and size of the teeth and the interdental distances were observable and the lateral veiw, in which the shape of the floor of the bite and the shape and detail of the occlusal/incisal surfaces of the crowns were visible. Casts are complementary and can be used in a comparative manner.

The advantages of radiology are:

(1) an immediate and permanent record of the bite mark.

(2) a full reproduction of the dentition of the offender.

The use of bitemarks is a well recognized technique to identify an offender. Teeth can yield information about age, gender, occupation, diseases and other characteristics. Personality may be deduced and bitemarks and the teeth that cause them can lead to complex forensic evidence.

In another case of a murdered female body, bitemarks were found on breast, face and shoulder which led to identification of the culprit. The marks clearly showed two upper left incisors missing and it could be verified that one month before the murder the murderer attacked a man who, in self-defence knocked out the upper left central and lateral incisors. The bitemarks clearly showed the absence of these incisor teeth.

REVIEW

Manual of Forensic Odontology

Ed. D C Averill

American Society of Forensic Odontology, 1991

This handsome manual is a step-by-step journey through the complexities of practical forensic odontology. It is so complete that it begins with a chapter for the new forensic dentist, providing suggestions for beginning in the field such as finding an involved colleague, being available at any time, providing letters of introduction and brief resumes to interested agencies and so on to no. 15 which recommends working towards forensic board certification. The manual is of course American and has an inevitable slant throughout but there is much that is of international interest.

There are further chapters dealing with dental identification, dental jurisprudence, bite mark analysis, child abuse and neglect, computer use in forensic dentistry, mass disaster dental identification, forensic photography and a final chapter titled "Reference" which contains comparative tooth designation charts, charts of artificial teeth and documentation from the National Crime Information Centre.Chapters 3, 4, 5, 6 and 8 are in the reviewer's view the best. In "Dental Jurisprudence" the reader is prepared in their role as expert witness, always a traumatic experience and for which traditionally there is very little material to which to refer, temporo-mandibular joint trauma is explained and its implications in legal matters fully discussed and the whole question of malpractice from the practitioner's point of view, the role of adequate record keeping, trial testimony, presentation of trial exhibits, failure to diagnose and much else are reviewed. Although seen from an American view point this valuable material is for all practitioners. The chapter on bite marks is comprehensive and opens with some historic examples. Recording, studying and comparisons with casts and other techniques are simply and clearly dealt with. Child abuse is a brief chapter with the least words but with very helpful lists of diagnoses, characteristics and action to be taken. The use of computers in forensic dentistry like in all aspects of modern life has assumed great importance. This chapter not only starts with basic information for even the most computer illiterate but goes on with elementary statistics and into identification programmes giving step-by-step procedures for operating the programme. Finally, forensic photography deals with all aspects of this most important medium for recording, archiving and building up evidence. An interesting inclusion is a section on restoration of damaged radiographs. Damaged, inadequate or missing radiographs are surely the bane of the life of a forensic odontologist!

The limitations of the manual are few. The chapter on mass disaster dental identification is rather rudimentary but perhaps this was intentional. Chapter 2, dental identification, the foundation of forensic odontology has less material relatively than other less important sections. It is thin under age determination of decedent, does not take into consideration the considerable modification of Gustafson's method that has taken place recently and does not touch on age determination by epiphyses and sutures in bones. The use of sinuses for identification should also be included. It would have been beneficial to describe procedures for recovery of remains in the field. Emergency teams and police often overlook small items such as individual teeth at the site, which could be vital in an identification. The last chapter containing tables could have been extended by including the times of tooth eruption, apexification, epiphysis and suture closure etc. The last criticism is levelled at the editorial office which has overlooked many typographical errors, looseness of grammar and inconsistent reference formating. This reviewer wonders whether the president of IOFOS, Dr Klaus Rotzscher's name has been misspelt (p.24) and whether International Society of Odonto-Stomatology should read International Organization for Forensic Odonto-Stomatology (IOFOS) (p.3).

In spite of the limited criticisms this manual is a valuable addition to the forensic odontological literature. It's usefulness lies in its down-to-earth practicality, ease of reading and comprehensive coverage. The illustrations are clear and it should be a great help to all forensic odontologists, both novice and experienced as they attempt to help identify the unknown and unrecognizable of this world.

CJT