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QUANTITATIVE FORENSIC EVALUATION OF BITE MARKS WITH THE AID OF A SHAPE ANALYSIS COMPUTER PROGRAM : PART 1; THE DEVELOPMENT OF "SCIP" AND THE SIMILARITY INDEX

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ABSTRACT

Bite marks left on human tissue and bitten material have become an important aspect of scientific evidence used for the conviction or acquittal of a suspect. Expert opinion has often been based on subjective comparisons rather than any objective metrical analysis and many experts will agree that there is a need to employ additional comparative tests to achieve unbiased objectivity in their investigation.

In this study, an interactive shape analysis computer program ("SCIP" - Shape Comparison Interactive Program) has been employed in an attempt to derive experimentally a quantitative comparison, in the form of a Similarity Index (S.I.), between the "offender's" teeth and the bite marks produced on a standard flat wax form. The S.I. values obtained using "SCIP" were evaluated in a variety of experimental bite mark situations. It was found that in no case could the S.I. values produced by comparison of the bite mark with the dental casts from non-perpetrators be confused with the much lower S.I. from comparison of the bite mark with the dental cast of the perpetrator. The use of the Similarity Index derived using the "SCIP" program is recommended as a simple, accurate and objective means of comparing bite marks in suitable forensic cases.

Keywords: Quantitative shape analysis, "SCIP", bite marks, Similarity Index, person identification

INTRODUCTION

Bite marks left on human tissue and various other materials have become important elements of scientific evidence used for the conviction of a criminal suspect. These bite marks should not be evaluated merely by subjective comparison but must be analysed using scientific principles and procedures so that the validity of this evidence will not be challenged.

Forensic odontologists usually interpret a bite injury qualitatively by associative comparison, where similarities or dissimilarities with the dentition that have produced it are compared with the bite mark. It is inevitable that this kind of evidence will introduce a subjective bias and provoke questions in the court room regarding its reliability. In recent years, mathematical techniques employing complex computer programs to determine general recognition, quantification and comparison of analogous shapes have received much attention. A method of forensic identification utilizing such computer technology for shape analysis would seem to be desirable. When a high degree of correlation between teeth and bite pattern can be achieved, a match to a particular individual would be possible.

Accurate bite impressions can be produced in soft wax which is a reliable method for simulating a bite mark. In a study by Whittaker[1], two examiners were able to match subjectively 98.8% of the impressions in wax to study casts of the subjects involved. Incorrect matching was found in only one case in which the incisal edges of the anterior teeth had not registered in the wax bite. When photographs of wax bites with photographs of study casts of the subjects' dentitions were used for subjective visual comparison however, the accuracy fell to 68% for one examiner and 67% for the other. When measurements of arch curvature and tooth width, angulation and spacing were utilised when comparing these photographs, an accuracy of 96.0% was achieved by one examiner and 95.5% by the other. It is evident from this experiment that visual matching using subjective criteria was found to be less accurate than when objective measurements were also taken.

In the present study, an interactive shape analysis program was employed in an attempt to derive experimentally a quantitative comparison between a subject's teeth and the bite marks produced on a flat piece of wax. Values of indices obtained, in a variety of comparisons, using this shape-fit program were then evaluated, such that statistical limits of individuals could be determined from bite marks produced under optimum conditions. Subsequently these indices were compared with those from studies of bite marks made on curved surfaces. The reliability of using this program in identifying bites on the skin and foodstuffs in experimental situations was investigated.

METHODS AND MATERIALS

The shape comparison interactive program "SCIP"

This computer program is useful in identifying and measuring the location and extent of relative deformation of two shapes. It was adapted* from an original Fortran shape analysis program[2] with

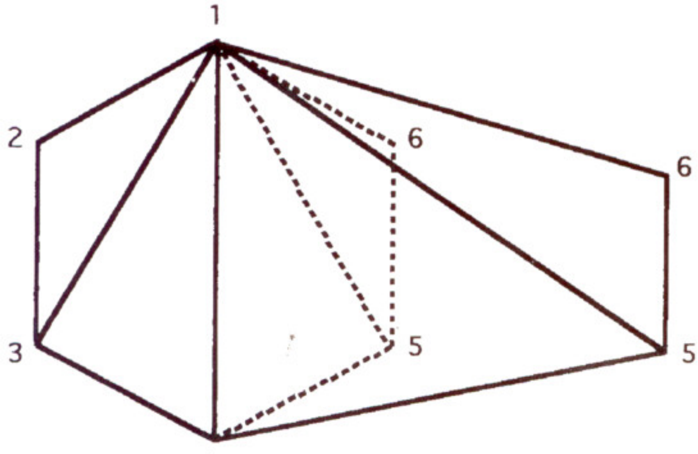

Fig. 1 (a)

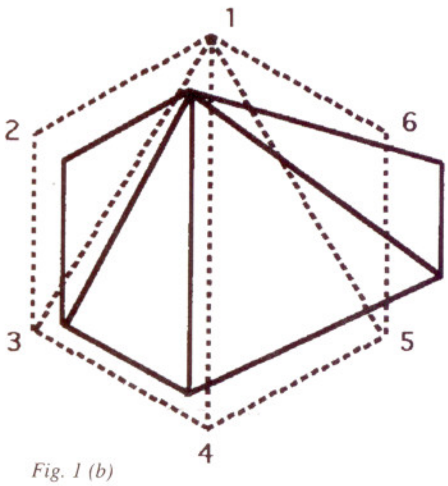

Fig. 1 (b)

Diagrams illustrating the different 'fits' that are achieved between two shapes, using the Shape Comparison Interactive Program ("SCIP"), by applying a) the "least squares" method and b) the "robust" method of shape comparison.

provision for analysis in two ways - the "least squares" and "robust" methods[4].

The robust method (Fig.1a) is useful in the detection of any localized shape differences when present. It will demonstrate close fit in similar regions and poor fit in relatively deformed regions. In our preliminary assessments for this project, it was not possible to get more than half the analogous points to match by the robust method and it did not promise to be a very useful technique.

The least squares method (Fig.1b) is used to find the common location and orientation of two shapes in order to compare their similarities and differences. The method relies on the matching of coordinates obtained from sets of analogous points selected to describe the shapes under study. The degree of matching is an expression of the similarity between two shapes.

Residual length (R) = distance between homologous points of shapes 1 and 2, e.g. A1, A2.

Average residual length = $\frac{\Sigma R}{N}$ = Similarity Index (S.I.)

Root mean square = $\sqrt{\frac{R^2}{N}}$

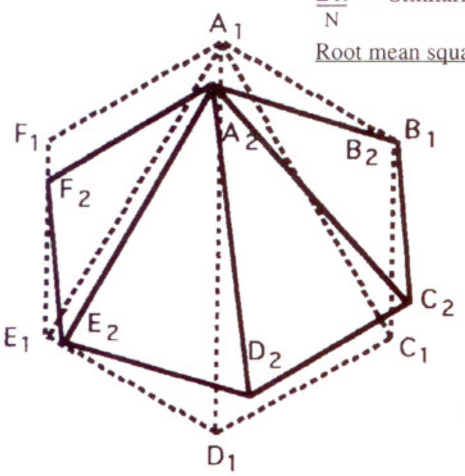

Fig. 2 The use of residuals to derive two indices of similarity (the average residual length and the root mean square) by using "SCIP" and applying the "least squares" method and b) the "robust" method of shape comparison.

It was decided to employ the least squares method as it produces an overall fit, the residual value of which is a useful single number measure of the degree of difference between two specimens. Although the program allowed two methods of estimating least square fit, it was decided to employ "average residual length" rather than "root mean square residual length" because the values obtained with the former were comparatively lower (Fig.2). Average residual length (mm) is obtained when the sum of the distances between homologous points of shape 1 and shape 2 is divided by the number of points.

In this study, the "average residual length" value is used as the numerical indicator of similarity between two shapes and has been termed the Similarity Index (S.I.).

Production of experimental wax bites

Bites were made in such a way that impressions of the incisal edges of the upper and lower incisors, and cuspal penetrations of canines, premolars and molars were recorded. Each subject was instructed to bite a warmed flat wax specimen in centric relation (i.e. biting with the mandible in the most retruded position). This was considered to produce relatively good tooth marks with a standardised biting procedure. A thin aluminium kitchen foil† was pressed between two layers of the wax (except with "Coprwax", see below) to provide added strength and the sandwich was trimmed to a standard dental arch-shaped wafer. Under lighting, the exposed shiny surface of the foil clearly revealed the penetration of the incisors and the cusps of the posterior teeth.

Bites were produced in three types of wax.

(a) Surgident "Coprwax" bite wafers

(b) Investo "Dental Modelling Wax"

(c) Moyco "Beauty Pink-X-Hard Dental Wax"

(a) Surgident "Coprwax"¥ provided satisfactory photographs because of its coppery-brown colour. This wax is impregnated with copper powder which provides uniform heat transmission during the warming and cooling process. It is supplied in the form of precut, arch-shaped wafers containing a layer of aluminium foil to increase strength, prevent the teeth from cutting through and reduce distortion. It softens readily in warm water (52-57°C) and after the bite is registered it should immediately be chilled with cold water (19-24°C). However, these wafers distort easily because of insufficient width of biting surface, and their use was discontinued.

(b) Investo "Dental Modelling Wax"§ is supplied as sheets (160mm x 80mm with a thickness of 1.25mm). It could not be satisfactorily bitten as uniform warming was not possible (melting point 55-60°C). Even with the use of flexible arm, fibre optic spot lights¶, this red wax, due to its translucency, did not deliver clarity of detail (especially on photographs).

(c) Moyco "Beauty Pink-X-Hard Dental Wax"# was then assessed. "Beauty Wax" is an opaque pink wax, supplied as sheets of 14.5mm x 7.3mm with a thickness of 1.5mm, and gave clear incisal and cuspal marks. It could be easily warmed to uniform softness (melting temperature approximately 66°C) due to the presence of thermally conductive fillers. This wax was therefore selected for this study being superior to the other waxes, particularly in its resistance to distortion, ease of manipulation and suitability for photographing.

Each flat wax bite was photographed alongside a scale using standardised lighting conditions. The impression was boxed, cleansed with a wetting agent and cast in dental stone** with the aid of vibration to ensure a bubble-free model. Each cast (positive) was given a separate code from the original cast of the dentition of the subjects.

Photographic procedures

From the departmental collection of dental stone casts of dental students, eleven were randomly selected (six males and five females) and the students themselves invited to produce "test bites" on wax. Four from this group were then selected to perform "test bites" on foodstuffs.

Photographs of the casts were taken under "ideal" standardised conditions[4] with single-lens reflex Hasselblad 500EL/M camera††, fitted with 80mm lens and a "Proxar-F:1m" lens extension. The camera was set vertically in a fixed plane and set about 390mm above a metal stage on which two laboratory jacks were placed within a rectangular box-like framework carrying a horizontal metric scale. As standardized lighting procedures were employed, all photographs were taken using the same exposure parameters (aperture size f11; shutter speed 1/30 s; exposure value 13) with oblique lighting. Lighting was provided by two adjustable photographic flood-lights fitted with 150 watt photoflood globes.

Parallelism between the scale and film plane was accomplished by placing a mirror in the plane of the scale, then adjusting the camera until the reflected image of the camera lens was centred without distortion in the focussing screen.

The casts were orientated on a dental cast surveyor table with a levelling tripod. The two points of the tripod were located in the central fossae of first molars with the arm resting on the incisor teeth. The plane thus created was levelled with a spirit level on the tripod. If either or both first molars were absent, the tripod points were placed on the second molars and this plane was levelled and adjusted as before. The camera lens-scale distance was set at 725mm. Test photographs using floodlights failed to reveal full cuspal indentations and improved illumination was devised (Volpi "Intralux 6000" fibre optic spotlight) which solved the problem. The bitten wax was placed on a black velvet cloth, kept parallel to the measurement scale, with spotlights focussed on the indentations, and then photographed. Photographs were taken on 120mm film format¥¥ suitable for the Hasselblad camera and enlarged to life size using the scale measurements.

Selection of reference points

As the incisal edges and cusp tips cause the initial penetration during a bite, the mesio- and disto-incisal angles were chosen as reference points for the incisor teeth, with cusp tips as reference for the canines. For the posterior molar and premolar teeth, cusp tips were chosen as reference points, which also provide an indication of the sizes of the teeth involved and the shape of individual arches. In situations where the cusp tips were not present (e.g. owing to attrition), the centre of the cusp surface was used as the reference point. Missing points due to anatomical anomalies, fracture or extraction of the teeth were recorded as "missing".

In an actual bite mark it is the anterior teeth which are usually impressed into the "bitten" material. In this study however, the posterior teeth (except the third molars) were included in the bite analysis, since a greater number of reference points will increase the accuracy of the match and give a potentially lower numerical value for greater discrimination.

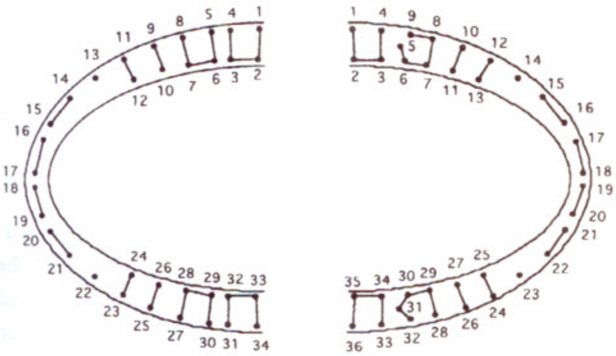

Fig. 3 Diagram showing the sequence used when digitising reference points marked on photographs taken of dental casts, bitemarks or casts of bitemarks (for explanation, see text).

In total, 34 reference points of discrimination in the upper arch and 36 in the lower were employed (Fig.3). These were:

Upper arch: 2nd molar - 4 points, 1st molar - 4 points, 2nd premolar - 2 points, 1st premolar - 2 points, canine - 1 point, lateral incisor - 2 points, central incisor - 2 points

Lower arch: 2nd molar - 4 points, 1st molar - 5 points, 2nd premolar - 2 points, 1st premolar - 2 points, canine - 1 point, lateral incisor - 2 points, central incisor - 2 points.

The digitising of reference points

All dental casts, wax bites and wax bite casts were photographed under standard conditions. Digitising was performed on an overlay upon which the reference points were marked by tracing over the photographic prints. Each dental arch was described by coordinates of the reference points located within a Cartesian system of orthogonal x and y axes. The reference points on both upper and lower arches were marked on all teeth except the third molars.

Digitising was performed by a Calcomp 2300 digitiser[§§] connected to a Laser 386 SX computer[¶¶]. Direct digitising from photographic prints was avoided as the conductivity of the silver compound on the latter can affect the accuracy of digitising via the platen. All digitising was done in a systematic manner, characterising molars, premolars, canines and incisor teeth (Fig.3). The first tooth recorded on the maxillary cast was the left second molar and on the mandibular cast it was the left second molar.

For recording of wax bites or bite lesions, the overlay carrying the marked reference points was inverted and then digitised, because the wax bites are a mirror image of the dentition producing them. It should be noted that, when two shapes are being compared, the computer program edits out missing points and only matches analogous points.

Table 1 shows the parameters which were compared and the subjects involved. The first comparisons were made within each subject's own casts and impressions, and for ease of description, were termed as "self" (Table 2). Subsequently, wax bite impressions were also compared with dental casts between subjects (i.e. non-perpetrators) and labelled as "non-self" (Table 3).

Table 1: Reference table of the comparisons which have been made (•) in this study between dental casts, bite impressions and positive casts of bite impressions, within single subjects ('self'). The overall results are summarised in Table 2.

SUBJECT CODE	CAST OF DENTITION		BITE IMPRESSION	POSITIVE CAST OF BITE IMPRESSION	
	A	B	C	D	E
	Cast photographed and points marked on overlay.	Points marked on cast. Photographs taken and points traced on overlay.	Flat wax bite photographed and the points marked on overlay.	Positives photographed and points marked on overlay.	Points marked on positives and photographs taken. Points then traced on overlay.
B-S	•	•	•	•	•
J-Y	•		•	•	
K-U	•		•	•	
L-K	•	•	•	•	•
H-S	•		•	•	
C-N	•		•	•	
W-U	•		•	•	
Z-L	•	•	•	•	•
S-K	•	•	•	•	•
R-I	•	•	•	•	•
A-D	•		•		

Table 2: Similarity Indices (S.I.) resulting from the forms of comparison, described in columns A - E in Table 1, made between casts, bite impressions, and positives of bite impressions within single subjects ("self").

Subject Code	Column C with Column A		Column D with Column A		Column C with Column B		Column E with Column A		Column D with Column B		Column E with Column B	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
B-S	1.140	0.814	0.661	0.582	1.367	1.588	1.934	0.836	0.627	0.786	2.728	0.658
J-Y	0.816	0.689	0.604	0.734								
K-U	1.048	0.728	0.860	0.862								
L-K	0.975	1.966	0.668	1.550	1.246	2.716	0.741	0.690	0.736	2.311	0.491	0.694
H-S	1.048	1.104	1.304	0.775								
C-N	1.669	0.818	0.828	1.787								
W-U	1.133	0.861	0.869	0.725								
Z-L	0.875	0.761	1.016	1.382	0.824	2.301	0.948	0.984	0.702	0.684	0.753	0.474
S-K	1.372	0.876	0.682	1.095	1.148	0.774	0.859	2.356	0.509	1.011	0.514	2.156
R-I	0.696	1.123	1.308	0.718	0.680	1.056	0.595	2.043	1.351	0.650	0.389	1.637
A-D	0.880	1.579										
MEAN	1.06	1.03	0.88	1.02	1.05	1.69	1.02	1.32	0.79	1.09	0.98	1.12
± SEM	0.08	0.12	0.08	0.13	0.13	0.37	0.24	0.34	0.15	0.31	0.44	0.33
RANGE: H	1.669	1.966	1.308	1.787	1.367	2.716	1.934	2.356	1.351	2.311	2.728	2.156
L	0.696	0.689	0.604	0.582	0.680	0.774	0.595	0.690	0.590	0.650	0.389	0.474
MEAN S.I. VALUE FOR ALL 'SELF' DETERMINATIONS = 1.09 ± 0.27 (SEM). n = 84 Range = 0.39 to 2.72												

RESULTS

(1) Evaluation of the Similarity Index using flat wax bite comparisons (Table 2).

The initial determination of Similarity Indices was from the comparison of flat wax bites with the casts of the perpetrators. It was found that the mean Similarity Index (S.I.) values of both upper (1.06) and lower (1.03) arches were around 1.0mm with no individual value greater than 2.0mm.

Subsequently, positive casts were produced from flat wax bite marks and compared with dental casts. In this second comparison, there was a reduction in the mean S.I. of the upper (0.88), whereas for the lowers it was unchanged at 1.02. No individual value was greater than 2.0. While giving lower arch values that were similar, the use of a positive gave improved match values for the upper arch (0.88 vs 1.06). This indicates that whenever possible, a cast of the bite mark should be prepared to give a second confirmatory assessment of the comparison.

In the third comparison, the wax bites were matched with the reference points marked on the casts and points traced on overlays. The upper arch revealed a mean S.I. (1.05) similar to the results above, but the lower arch gave a slightly higher mean S.I. (1.69) with a maximum value well over 2 (2.72).

Somewhat better results (upper = 1.02; lower = 1.04) were noted in the fourth comparison, where reference points were marked on the positive and compared with points marked on overlays placed on the photographs of the dental casts. Maximum values were around 2 for the upper but exceeded 2 for the lower arch.

In the fifth comparison, reference points marked on overlay placed on photographs of the positives of wax bites, were compared with dental casts which had points marked, photographs taken and points traced on overlays. In this matching, excellent results were achieved for the upper (mean S.I. = 0.79) and lower arches (mean S.I. = 1.09). Again, however, the lower arch yielded a maximum over 2.

The final comparison was between the positives of wax bite impressions and the dental casts of the subjects. In both cases, points were marked, photographs taken and points traced on overlays for comparison. Here too, the results of the upper (0.98) and lower (1.12) arches were excellent. Maxima here exceeded 2 for both arches.

Interestingly, when a dental cast, which had been photographed and points marked on the photograph, was compared with the same cast when points had been marked directly on the cast, photographed and points traced on an overlay, it was found that the results were not significantly better than with any of the above matching of bite marks. The mean upper arch S.I. value for this cast to cast comparison was 0.75mm, while the lower was 0.90.

Table 3: Summary of results of comparisons of a subject's flat wax bite with dental casts of the upper (U) or lower (L) jaw of that subject ("self") and with 10 other subjects ("non-self"). Photographs of the cast and of the wax bite were taken and points marked on overlays placed on the photographs. Note that the Similarity Index (S.I.) is given only for the "non-self" comparison yielding the lowest and that yielding the highest S.I. from the 10 comparisons. These S.I. values are compared with those arising from the "self" comparisons.

Subject code	Cast of upper (U) or lower (L) jaw.	S.I. values from 10 'non-self' comparisons in each row.		S.I. value from comparison with 'self' i.e. wax bite with dental cast.	Number of 'non-self' S.I. values which were less than the 'self' value.
		Highest	Lowest		
B-S	U L	5.946 4.164	2.537 1.854	1.140 0.814	0 0
J-Y	U L	7.941 6.085	1.745 1.665	0.816 0.689	0 0
K-U	U L	5.867 4.698	1.396 1.983	1.048 0.728	0 0
L-K	U L	6.647 7.225	1.543 2.434	0.975 1.966	0 0
H-S	U L	5.326 5.431	1.584 1.246	1.048 1.104	0 0
C-N	U L	5.709 5.891	1.682 1.512	1.669 0.818	0 0
W-U	U L	5.196 5.875	2.021 1.640	1.133 0.861	0 0
Z-L	U L	5.201 5.486	1.927 1.292	0.875 0.761	0 0
S-K	U L	4.815 3.863	2.194 1.354	1.372 0.876	0 0
R-I	U L	6.537 5.437	2.118 1.988	0.696 1.123	0 0
A-D	U L	4.990 3.739	1.402 1.575	0.880 1.243	0 0
Overall:	U L	7.941* 7.225*	1.396† 1.246†	1.669¥ 1.966¥	0 0

* These are the highest S.I. values obtained from a total of 110 'non-self' comparisons.
† These are the lowest S.I. values obtained from a total of 110 'non-self' comparisons.
¥ These are the highest S.I. values obtained from 10 'self' comparisons.

Overall, the data from 84 "self" comparisons ranged from 0.39 to 2.72 with a mean of 1.09±0.03 (SEM). There was a trend for the lower jaw comparisons to yield slightly higher S.I. values. These data are summarised in Fig.3 which shows that the data are normally distributed over a usefully narrow range.

These data indicate that all of the various comparison methods used produced excellent results and that the best "fits" were those which gave values of approximately 1.0mm or lower. It is also clear that matches from photographs were as good as those when reference points were marked directly on the casts and the former is the recommended procedure.

It must, however, be emphasised here that the bite marks on the Moyco Dental Wax were very clear and registered accurate margins around each indentation. This ideal situation cannot be expected to pertain in "real life" situations such as bites in foodstuffs or skin.

A photograph of the flat wax bite mark for an individual was compared with photographs of dental casts from each of the other 10 subjects, giving a series of "non-self" comparisons. These were repeated for each of the 11 subjects giving a total of 100 "non-self" comparisons, each with S.I. data for upper and lower jaws. Figure 3 summarises in graphical form the results of these comparisons together with a summary of the results of 42 "self" comparisons. All data from this series of comparisons is not given but Table 3 provides selections, showing only the highest and lowest S.I. values obtained from the "non-self" comparisons of each subject with the others. These are compared with the S.I. value from the appropriate "self" comparison, i.e. the subject's wax bite mark compared with their own dental cast.

In contrast to the "self" comparisons noted above, there appeared to be a trend in the "non-self" comparisons, for the S.I. values derived from lower jaw comparisons to be somewhat less than those from the upper jaw, but this trend was not statistically significant.

The "non-self" S.I. values from wax bites compared with dental casts ranged from 1.25 to 7.94, whereas the corresponding "self" S.I. values ranged from 0.69 to 1.97. There was, in fact, no actual overlap in these data because in no subject did any of the "non-self" comparisons yield an S.I. value that was lower than the "self" value for that subject.

Combining the "non-self" S.I. values from all the comparisons (upper and lower jaws) performed in this study (n = 220) and outlined in Table 3, we obtained "non-self" S.I. values ranging from 1.25 to 7.94 with a mean of 3.50±0.11. This compared with overall "self"

Table 4: Overall summary of data from all "self" (n = 84) and "non-self" (n = 220) comparisons, as printed out from "SCIP". These data are presented graphically in Figure 4.

'Self' comparisons:					
Mean	Std. Dev.	Std. Error	Variance	Coeff. Var.	Count
1.09	0.2689	0.030	0.28	49.58	**84**
Minimum	Maximum	Range	Sum	Sum squared	# Missing
0.389	2.728	2.339	87.52	116.10	318
'Non-self' comparisons:					
Mean	Std. Dev.	Std. Error	Variance	Ceoff. Var.	Count
3.50	1.575	0.106	2.48	44.996	**220**
Minimum	Maximum	Range	Sum	Sum squared	# Missing
1.246	7.941	6.695	769.91	3237.40	180

S.I. values of 0.39 to 2.73 with a mean of 1.09±0.03 (n = 84). These data are presented in Table 4 and graphed in Fig.3, which shows that the "non-self" data is also normally distributed. There was a small region of overlapping S.I. values between the lowest "non-self" value of 1.25 and the highest "self" value of 2.73, with the actual cross-over point of the two curves occurring at 1.68.

DISCUSSION

When teeth come into contact with certain materials, they leave prints or impressions, and the morphology and arrangement of the teeth in the dental arch and any peculiar dental features can create identifiable marks. If such a feature is present but of low frequency in the general population, then the mark becomes more characteristic. Unusual characteristics in a dentition may be more important than the actual number of points of similarity and they can be used equally for implicating or eliminating a suspect. Unfortunately, in practice bite marks can never be taken to represent with absolute accuracy the dentition of the originator, particularly if it has no unusual characteristics. This emphasises the importance of seeking characteristic details if present and matching them to the marks produced. Furthermore, the process of biting may consist of a combination of incising, sliding, shearing and compression forces on tissues which themselves possess a variety of inherent tensions and contours, and in foodstuffs of varying fragility and resistance. All of these variables produce distortions in the bite impression. Dental characteristics that can frequently be recognised are the presence or absence of teeth, shape of tooth, pattern of arches, mesio-distal dimensions, and such unusual features as supernumerary teeth, rotation, fractured teeth, diastemata, and inter-dental distance. Furthermore positional relationships between an offender and a victim can be determined by the location of the bite mark. This becomes important circumstantial evidence which may aid in corroborating the victim's history.

A systematic sequence for digitisation of the arch shape has been developed and strictly maintained throughout this study. Reference points were selected to represent the width of individual incisor teeth and also the arch shape represented by recording of the cusps of posterior teeth. It is important to note that in most bite cases, the width of the tooth marks is produced by the distance between the relevant mesio- and disto-incisal margins of the incisors (i.e. the width of the tooth at the maximum depth of penetration) rather than the length of the incisal edge. As is frequently the case in person identification, the method developed will have a greater potential to eliminate suspects than in positive identification of a biter. However, with an increased number of reference points, a more accurate matching

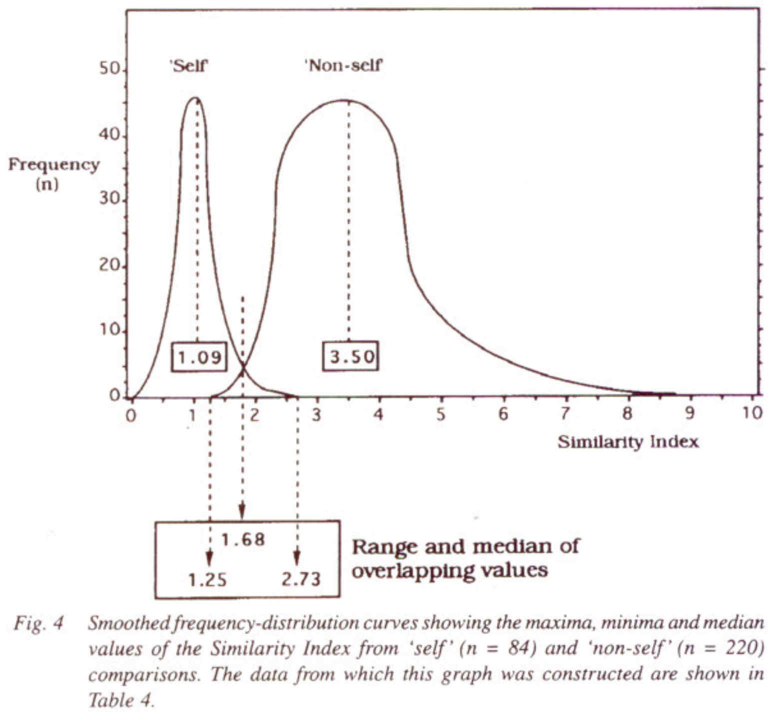

Fig. 4 Smoothed frequency-distribution curves showing the maxima, minima and median values of the Similarity Index from 'self' (n = 84) and 'non-self' (n = 220) comparisons. The data from which this graph was constructed are shown in Table 4.

of the bite mark with the teeth of the offender becomes possible.

The choice of a reference "cut-off" point for use in forensic bite mark identification can thus be made by referring to Fig.4. The best candidates would appear to be the cross-over point at 1.68 or a round figure of 2.00. The latter is preferable in the sense that only 7 of the 84 "self" values were above this value, whereas 11 "self" values were greater than 1.68.

It is our recommendation therefore that a Similarity Index of 2.00 be used to differentiate between "self" and "non-self", i.e. between the perpetrator of the bite mark, giving an S.I. of less than 2.00, and a non-perpetrator giving an S.I. above 2.00.

We have further shown that using "SCIP", a bite mark can be classed as a "good" fit with the teeth of the offender when the value of the Similarity Index is approximately 1.0mm.

CONCLUSION

A method for the forensic investigation of bite marks based on metrical characters (quantitative assessment) has been presented. A computer program ("SCIP") identifying and measuring the location and extent of relative deformation of two shapes was developed for use in this study. After initial evaluation, a mathematical procedure based on the "least squares" algorithm was chosen for our analyses in preference to the "robust" method. This produced minimal discrepancies between two determinations of coordinates and a characteristic Similarity Index (S.I.), which would assist in the identification, could be derived.

This Similarity Index provides a convenient numerical value which we hope will become recognised in courts as being based on a valid quantitative scientific test especially in cases where there is a need to eliminate some suspects involved in bite marks.

The standard bites were produced on wax specimens so that distortion-free bites and positives of them could be made. Comparison of bite marks on wax (or their reproduction as positive casts) with casts of the teeth of a "subject" were made with the object of obtaining optimum values for this index. We have shown that a S.I. value of 2.00 or less indicates the likelihood of the bite mark having been made by the person whose dental cast was used in the comparison. Conversely, S.I. values in excess of 2.00 are indicative of inappropriate matches.

A future improvement on this methodology would be the ability to make three dimensional measurements which would enhance the comprehensiveness of the identification. Only planar measurements are involved in the present study but the positioning of the coordinates for the linear measurements can, nevertheless, provide an indirect indication of the angular relationship of each tooth. The problems posed when bites are inflicted on curved surfaces will be dealt with in a subsequent paper[4].

In this study, a new quantitative method has been developed which we hope will contribute to future bite mark investigations. The simple numerical indices produced will be easier to interpret and more readily understood when presented as evidence in courts of law.

ACKNOWLEDGEMENTS

We are grateful for the help and advice of Professors T. Brown and G. Townsend, Drs L. Richards and M. Hashimoto, Ms A. Neville, Mr J. Glover and Mrs. E. Formenti. Thanks are due to the Faculty of Dentistry and The University of Adelaide for Scholarships for P.N.

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* *"SCIP" program modified from original program by T. Brown. The algorithm used is based on the method of Sneath for least squares matching.*
† *Comalco Alfoil, Leigh-Mardon Pty. Ltd., Sydney.*
¥ *Columbus Dental, St. Louis, MS, U.S.A.*
§ *Investo Dental Manufacturing Co., New South Wales.*
¶ *Volpi "Intralux 6000", Wild-Leitz, Heerbrugg, Switzerland.*
• *Moyco Industries, Philadelphia, U.S.A.*
** *"Yellowstone-Hard", Investo Dental Manufacturing, New South Wales.*
†† *Photographic Wholesalers Ltd., Adelaide, South Australia.*
¥¥ *Kodak "T-Max 400" film, Kodak, Australia.*
§§ *Calcomp Digitizer Products, Anaheim, U.S.A.*
¶¶ *Logi-Tech, South Australia.*

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QUANTITATIVE FORENSIC EVALUATION OF BITE MARKS WITH THE AID OF A SHAPE ANALYSIS COMPUTER PROGRAM : PART 2; "SCIP" AND BITE MARKS IN SKIN AND FOODSTUFFS

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ABSTRACT

In a previous paper[1], we have shown that the use of an interactive shape analysis computer program (SCIP") and the derivation of a quantitative Similarity Index[1] greatly facilitated the comparison of experimental flat wax bite marks with the dentition of various 'suspects' and the identification of the agent producing the bite. In this study, "SCIP" was employed in an attempt to quantify the comparison, in the form of the Similarity Index (S.I.), between the "offender's" teeth and the bite marks produced on foodstuffs and on human skin, under experimental conditions. The use of "SCIP" and the S.I. is recommended as a routine means of eliminating suspects in bite mark cases. If a reasonable number of reference points have been registered in the bitten material and particularly if the perpetrator has any unusual features in the anterior dentition, the matching of the bite mark with the actual offender is a possibility with this method.

Keywords: Quantitative shape analysis, "SCIP", bite marks, Similarity Index, skin, foodstuffs, person identification.

INTRODUCTION

Bite marks in skin and foodstuffs have frequently been used as a method of identification in the past[2,3,4,10] and bite mark evidence has achieved a high degree of reliability[9]. There are problems however with the accuracy of a mark made by a tooth in soft, flexible or friable materials[2,3,4,8]. Computers have been employed in the digitising and overlaying of images of bite marks[2,3] but the subsequent comparisons are still made using subjective criteria.

In the present study, the shape analysis program "SCIP" was employed to derive experimentally a quantitative comparison between a subject's teeth and the bite marks made on curved surfaces such as human skin or foodstuffs. Values of indices obtained in a variety of comparisons using this shape-fit program were then evaluated, such that statistical limits of individuals could be determined from bite marks produced under different conditions. The reliability of using this program in identifying bites on a curved wax matrix and on skin and foodstuffs in experimental situations was investigated.

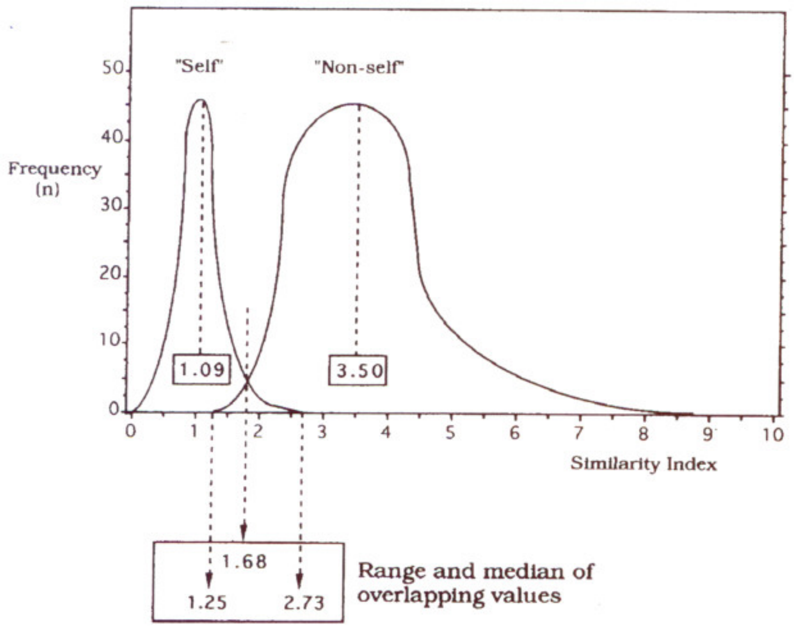

Fig. 1 Smoothed frequency-distribution curves showing the range of control values, from a flat wax bite, for the Similarity Index (S.I.) from "self" and "non-self" comparisons. The overall mean S.I. (±S.E.M.) for 84 "self" values was 1.09±0.03 with a range of 0.39-2.73. For 220 "non-self" comparisons, the mean S.I. was 3.50±0.11 with a range of 1.25-7.94. The region of overlapping S.I. values is thus 1.25-2.73 with a cross-over (median) point of 1.68.

We have shown previously[1,5] that in a comparison of the dental casts with experimental flat wax bites the actual 'perpetrators' of the bite marks achieved S.I. scores which were almost invariably less than 2.0. On the other hand 'non perpetrators' yielded S.I. values of greater than 2.0 with a mean of 3.50±0.11 (Fig.1).

METHODS AND MATERIALS

The shape comparison interactive program, 'SCIP'

This computer program[1,5] has been adapted from an original Fortran shape analysis program[6] and uses a "least squares" algorithm to match coordinates obtained from sets of analogous points selected to describe the shapes under study. The degree of matching is an expression of the similarity between two shapes. The residual value or average residual length (in mm) of the overall 'fit' is a useful single number, which describes the degree of difference between two specimens. In this study, the average residual length value, the Similarity Index (S.I.), has been used as the numerical indicator of similarity between the bite mark and a cast of the dentition of a 'suspect'.

Production of experimental bite marks

For producing wax bites on curved surfaces, a 1.5mm thick sheet of dental wax* was wrapped around a sheet of 10mm thick EVA (polyethylene vinyl acetate) foam, which encircled a piece of PVC (polyvinyl chloride) tubing (30mm diameter, 2mm wall thickness), so that the overall diameter of the biteable form was about 53mm. The EVA foam was attached to the underlying PVC tubing with strips of double-sided adhesive tape placed away from the area to be bitten, and the foam was secured with elastic bands at each end.

The EVA foam provided a soft underlay to simulate the consistency of human dermal tissue. Subjects were requested to bite slowly into the wax surface in order to make a clear indentation of the upper and lower arches.

For this study, casts of eleven subjects[1] were randomly selected (six males and five females) and the subjects themselves requested to produce "test bites" on the curved wax form from which casts were made as before[1]. Four from this group were then selected to perform "test bites" on foodstuffs which were then compared with the casts of their dentitions. Another subject (T-R) was requested to make a bite mark on the skin of a volunteer and this mark was compared with the casts of the dentition of the perpetrator and of the 11 subjects noted above.

Details of photographic procedures, selection and digitising of reference points, are contained in paper 1[1]. For each subject in a group of 11, a comparison was made between the curved wax bite impression or their positive casts and the subject's dental cast. For ease of description these comparisons were termed "self" (Table 1). In another trial, wax bite impressions were also compared with dental casts taken from other subjects (i.e. non-perpetrators). These matches were classified "non-self".

Photographing bites made on a curved wax surface

A study was undertaken to determine the ideal camera angle for taking photographs of a bite mark on a curved wax surface. The upper and lower arches of the bite marks were each photographed at different angles, i.e. 90°, 76°, 60° and 45° (Fig.2). While taking these photographs, it was decided that the point of focus would be the midpoint between a line joining the tips of both canines and the contact point of the central incisors (Fig.3). This reference focal point was also used during photography at the different angles. These angles were obtained by rotating the bite mark accordingly and with the aid of a protractor. In addition, a photograph was taken at 90° of both arches together ("U + L", Fig.2), with the point of focus being midway between the arches, i.e. in the centre of the bite mark.

Subsequently reference points for digitising of the incisal and cuspal indentations were traced on an overlay upon these photographs. Comparisons of each individual arch bite with the dental cast of different subjects were then made. Where both arches were

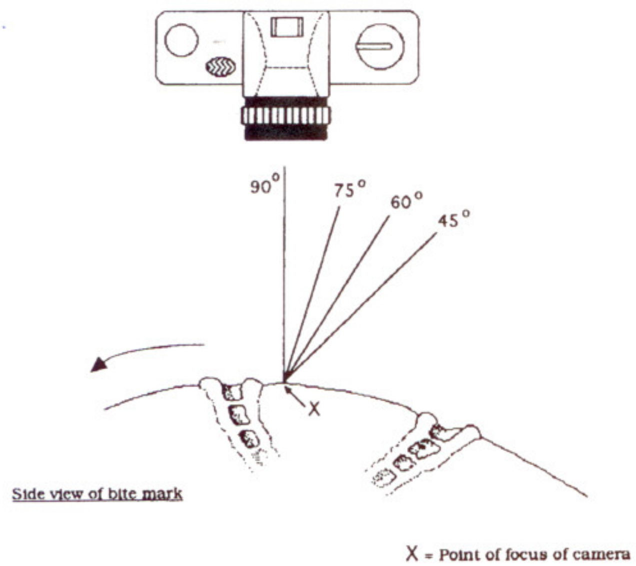

Fig. 2 Diagram showing camera angles used to photograph each arch of a bite mark on skin or curved wax surfaces.

The camera position was fixed and the object was rotated to present the four angles of incidence selected as references in this study. When both arches were photographed together, the camera was set at 90° and focussed on the mid-point between the arches (i.e. the centre of the bitemark).

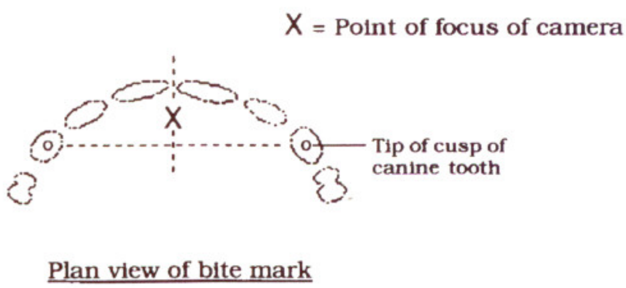

Fig. 3 Diagram of a plan view of a bite mark on skin or on a curved wax surface showing the point of camera focus used in this study.

Table 1: Similarity Indices (S.I.) resulting from curved surface comparisons, photographed at different camera angles, made between the bitemark and the cast of the subject involved (i.e. "self"-matching at different camera angles).

Angle of camera \ Subject code	B-S	J-Y	K-U	L-K	H-S	C-N	W-U	Z-L	S-K	R-I	A-D	Mean ± SEM	n
Upper: 90°	0.581	0.806	0.898	0.951	0.781	0.721	0.920	0.835	0.947	0.721	0.611	0.797 ± 0.039	11
75°	1.563	0.647	1.089	1.226	1.082	0.696	1.477	0.801	0.743	0.939	0.482	0.977 ± 0.104	11
60°	2.399	2.271	1.344	1.523	1.957	1.938	1.935	0.649	0.946	1.696	1.608	1.661 ± 0.160	11
45°	0.626	--	--	1.422	0.359	2.146	--	1.183	1.722	2.144	2.436	1.505 ± 0.265	8
Upper arch (U & L together)	2.781	1.897	4.385	1.062	2.113	2.857	1.762	1.565	1.863	1.938	2.346	2.234 ± 0.265	11
Lower: 90°	0.816	1.944	0.709	1.122	0.670	0.742	0.734	1.562	1.232	0.959	0.661	1.014 ± 0.126	11
75°	0.902	1.412	0.668	1.702	1.243	0.911	1.144	0.768	1.650	1.485	1.110	1.181 ± 0.106	11
60°	2.348	--	0.677	1.577	2.127	1.775	1.782	0.788	4.698	0.927	1.063	1.776 ± 0.372	10
45°	3.120	--	1.108	1.390	0.442	1.939	--	2.221	2.297	0.233	0.420	1.463 ± 0.334	9
Lower arch (U & L together)	1.784	0.562	3.385	0.875	1.860	2.140	1.541	1.445	1.960	0.748	2.168	1.679 ± 0.240	11

Values underlined indicate the best match or 'fit' obtained in a separate series of comparisons (data not shown) between "self" and "non-self", i.e. where the "self" match value was shown experimentally to be lower (as expected theoretically) than any value from "non-self" comparisons between that subject and any of the ten other subjects.

photographed together at 90° the upper and lower arches were distinguished and separate comparisons made with the upper and lower dental casts.

Bite marks in foodstuffs

The suitability of using the shape analysis methodology on bite marks produced on selected foodstuffs was investigated. Bites were produced on four commonly available foodstuffs:

(a) apples representing a 'shearing' bite

(b) Cheddar cheese (a 20gm block) representing a 'sliding' bite

(c) chocolate-coated confectionery bar representing the complex bite produced in a non-homogeneous food product

(d) Chewing gum representing a 'chewed' bite

Four subjects were requested to make a firm, normal bite in each item of food such that the anterior teeth marks were reproduced and a quantity of the material removed with the bite. The chewing gum was chewed until pliable and then an impression of the anterior teeth made in it.

Photographs were taken using the same procedures as with the previous flat wax bites[1], each arch shape of the bite mark being arranged parallel to the scale measurements. The processing of the film and making of the prints followed the standard procedure[1,5].

Each upper and lower bite mark was compared with the dental cast of the "perpetrator" ("self" match) and with dental casts of three other subjects ("non-self" match).

Bite marks on skin

In addition to these investigations, the usefulness of the computer program in the analysis of bite marks produced on skin was investigated.

An experimental bite was inflicted by one volunteer on the biceps muscle of another volunteer. The upper arch was photographed immediately with the reference camera angle of 90°, the film was processed and the print enlarged to life size. Reference points were then marked on an overlay placed on the photograph, digitising was performed and the data recorded in the computer.

Comparison of the bite mark with the casts of all the subjects involved in the earlier experiments, including the biter, were performed to find any suitable match.

RESULTS

1. The Similarity Index (S.I.) in control experiments

Earlier[1], we described the development of the S.I. as a useful numerical index for comparing bite marks with the dentition producing them. That study utilised 'idealised' experimental bites into flat wax forms to derive a mean S.I. and variation around it for a large series of "self" comparisons. Overall, the data from 84 such "self" comparisons ranged from 0.39 to 2.72 with a mean of 1.09±0.03 (standard error of the mean). These control data are summarised in Fig.1 which shows that the data is normally distributed over a usefully narrow range.

Table 2: Variation in success of matching a bite mark to the dental cast of the subject, as the angle at which the bite was photographed was changed.

Arch of bite mark	Camera angle	Number of matches which proved to be: Correct	Incorrect	No. of correct matches as % of total
Upper	90°	9	2	81.8
	75°	7	4	63.6
	60°	6	5	54.5
	45°	0	8	0
	U & L together	2	9	18.2
Lower	90°	7	4	63.6
	75°	4	7	36.4
	60°	3	7	30.0
	45°	1	8	11.1
	U & L together	3	8	27.3

The choice of a reference 'cut-off' point for use in actual forensic bite mark identifications can thus be made by reference to Fig.1. The best candidates would appear to be around the cross-over point of 1.68 or say at a round figure of 2.00. The latter is preferable in the sense that only seven of the 84 "self" values were above this figure.

It is our recommendation therefore that a Similarity Index of 2.0 be used as a standard to differentiate between "self" and "non-self", i.e. between the perpetrator of the bite mark giving an S.I. of less than 2.00 and a non-perpetrator giving an S.I. above 2.00.

2. The Similarity Index in curved surface comparisons

The results (Table 1) indicate that the lowest S.I. values were obtained when an individual arch of the bite mark was photographed at 90°, the means for "self" matches being 0.80 for the upper and 1.01 for the lower arch. These values are as comparatively low as those from the flat wax bites (Table 1). As the angle of incidence of the camera was reduced the S.I. values increased markedly. The success rate in matching bite marks to the perpetrator decreased as the S.I. increased so that even at 75° the success rate was only 63.6% for the upper and a mere 36.4% for the lower arch (Table 2). The photography of the upper or lower arch of the bite mark from a point of focus in the centre of the bite mark was not successful as it gave very high S.I. values and extremely low success rates (Table 4). Even with a camera angle of 90° the lower arch matching (63.6%) was noticeably less successful than the upper arch (81.8%).

It would appear that photography of a bite mark at any camera angle of less than 90° will result in high S.I. values and a significantly reduced chance of matching the bite mark to the dentition of the perpetrator.

These results are in conflict with findings that the curvature of the bitten surface does not produce significant distortion[9]. While this may indeed be true for bite marks with only the incisor teeth registering it may not be so when posterior teeth are included. In the present study the volunteers were instructed specifically to bite with a wide opening of the mouth in order to involve the posterior teeth.

The analysis of bite marks in foodstuffs (Table 3)

(a) Apples

Of the eight full bites investigated it was not possible to distinguish individual tooth marks in the lower arch by two of the subjects because the impressions of teeth were insufficiently detailed. Of the remaining six it was only possible to make a correct "self" match in two cases, one with the upper arch bite and one with the lower. Incorrect matches were obtained in the other

Table 4: Experimental bite marks made on human skin.

SUBJECT CODE	Similarity Index
	UPPER JAW
B-S	2.708
J-Y	1.483
K-U	2.202
L-K	1.933
H-S	2.119
C-N	2.945
W-U	1.790
Z-L	2.513
S-K	1.492
R-I	1.532
A-D	1.823
Mean ± SEM	**2.049 ± 0.151 (n = 11)**
Range	1.483 - 2.945
Subject T-R (self match)	**1.201**

These Similarity Indices (S.I.) were obtained when the upper arch bite produced on the skin was compared with the upper dental casts of the perpetrator (subject T-R) and of 11 other subjects. The value underlined is the lowest S.I. obtained in this series and thus indicates the best match or 'fit'.

four cases. Thus a success rate of only 33% was achieved with bite marks in apples.

(b) Cheddar cheese

With this material it was possible to observe the teeth marks for all eight full bites. A successful match was however only possible in three instances (38%), in one case for the upper arch and two cases for the lower. The remaining five cases were mismatched.

(c) Chewing gum

It was possible to distinguish and teeth marks for all eight arch bites with this material. A successful match was obtained in four cases (50%), two for the upper arch and two for the lower.

(d) Chocolate-coated confectionery bar

It was not possible to make any useful reading of the teeth marks as the bitten edges of the thin chocolate coating crumbled into the softer underlying layers.

Bite mark in skin

In this series of comparisons shown in Table 4, the S.I. value (1.20) obtained for the "self" match of the perpetrator was well within the range of "self" values obtained from flat wax bite marks. It was also lower than all the indices derived from 11 "non-self" comparisons which ranged from 1.483 to 2.945 with a mean of 2.05±0.15 (Table 4). This effectively demonstrates that bite marks in skin can be successfully matched to the perpetrator.

DISCUSSION

Comparison of bite marks in wax (and their positive transmutation) with casts of the teeth of a "subject" were made for obtaining optimum values for this index. We have shown[1] that a S.I. value of 2.00 or less indicates the likelihood of the bite mark having been made by the person whose dental cast was used in the comparison. S.I. values in excess of 2.00 are indicative of inappropriate matches.

The standard bites were produced on curved wax specimens so that distortion-free bites and positives could be made. It must be noted however that considerably more bite pressure is required to produce a recognisable bite mark on skin than in a wax sheet. The reason for this is that the skin absorbs a considerable proportion of the kinetic energy of the bite before sufficient force is generated to produce a visible injury. Human skin tends to move when bites are made, particularly when the additional sucking action of the tongue is considered[3,7].

Clearly, many as yet unquantified factors are involved in skin bite mark recognition. Despite these differences we have shown that a reliable identification of the perpetrator can be made with skin bites, provided sufficient detail is registered in the bite mark.

Table 3: Comparisons of experimental bite marks in various foodstuffs with the dental casts of the perpetrator and of three other subjects. Only the closest "non-self" match, i.e. the lowest Similarity Index (S.I.) value, of the three non-perpetrators was chosen for each foodstuff.

Foodstuff	S.I. values obtained from:		B-S	L-K	R-I	Z-L	Matches made	Matches made / total
Apple	Match with self	U	1.651	1.476	0.906	1.112	1	2 / 6
		L	--	--	0.912	1.059	1	
	Closest non-self	U	1.112	1.284	1.097	0.757	3	4 / 6
		L	--	--	0.670	1.086	1	
Cheese	Match with self	U	1.172	0.858	0.684	0.947	1	3 / 8
		L	0.585	0.670	2.699	1.2760	2	
	Closest non-self	U	0.629	0.548	1.357	0.825	3	5 / 8
		L	0.693	0.577	0.565	1.289	2	
Chewing gum	Match with self	U	0.973	1.058	1.328	1.069	2	4 / 8
		L	0.798	0.529	0.454	0.648	2	
	Closest non-self	U	0.452	0.663	2.013	1.142	2	4 / 8
		L	1.332	0.487	0.795	0.625	2	
Chocolate confectionery bar	Match with self	U	--	--	--	--	0	0 / 0
		L	--	--	--	--	0	
	Closest non-self	U	--	--	--	--	0	0 / 0
		L	--	--	--	--	0	
Totals:	n =		5	5	6	6		22
	Correct matches:		2	0	4	3		9
	Incorrect matches:		3	5	2	3		13

As is frequently the case in person identification the method developed will have a greater facility for eliminating suspects than in positively identifying the perpetrator[3,8]. With an increased number of reference points however precise matching of the bite mark with the actual offender becomes possible[3,10]. We have further shown that using "SCIP" a bite mark can be classed as a good fit with the teeth of the offender when the value of the S.I. is approximately 1.0mm.

Concerning bites in foodstuffs it has been made clear from the results of this study that the consistency of the bitten material must be sufficiently firm, yet plastic, in order to create clearly distinguishable bite marks. For example, a solid bar of milk chocolate (homogeneous) may well have yielded better results than the composite chocolate-coated confectionery bar used. The latter had been chosen as a representative of a very common type of snack which offered something of a challenge to an investigating forensic odontologist.

Chewing gum, while capable of leaving an accurate impression sufficient to compare successfully with the dentition of a suspect[4], can often record multiple or overlapping bites which can make useful comparisons impossible[2].

Unfortunately none of the foodstuffs tested yielded a degree of success in matching the bite to the perpetrator greater than the incidence of inappropriate matches. It must however be noted that these results with foodstuffs, although not favourable, were from bites produced by young adult subjects whose anterior teeth were complete and particularly well aligned. Furthermore, they were encouraged to perform only "normal" bites rather than contrive an idealised "experimental" bite. It is likely that more convincing results would have been obtained if the subjects were of different age or had mis-aligned or missing teeth. The main reason however is probably that only two to four anterior teeth marks on each arch were present for comparison thereby reducing the number of reference points available for matching. Sometimes it was only possible to discriminate indentations from two teeth.

It was not possible in this study to carry out three-dimensional measurements which would have made identification more complete. Only linear measurements were involved but the positioning of the co-ordinates for the linear measurements provided an indirect indication of the angular relationship of each tooth.

This study has led to the development of a new quantitative scientific method which we hope will play a significant role in future investigations of bite marks in skin and foodstuffs.

CONCLUSION

Bite mark evidence is becoming increasingly useful in the criminal justice system. Bite marks left on foodstuffs or skin have led to incrimination of an offender(5), and it is hoped that the law will become fully aware of the significance of this type of evidence. Specially trained examiners are in a better position to recognise, record and interpret this evidence and then present it to the court.

A method for the forensic investigation of bite marks based on metrical characters (quantitative assessment) has been presented and a computer program ("SCIP") identifying and measuring the location and extent of relative deformation of two shapes has been developed for use in this study. The Similarity Index which resulted provides a convenient numerical value which we hope will become recognised in courts and used to ensure justice is done.

ACKNOWLEDGEMENTS

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A BITEMARK AND A FRACTURE?

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ABSTRACT

The kidnap and brutal murder of the eleven year-old daughter of a fire brigade officer in the town of Wassenaar in the Netherlands on September 29, 1980, resulted in the first ever appearance of a forensic odontologist as an expert witness in the history of Dutch law.

This previously unpublished case is now reviewed for its historic significance, and also because it presents an interesting problem of interpretation of odontological evidence relevant to the identification of the offender, and raises issues concerning proper procedures for the utilisation of expertise in forensic odontology.

Key words: bite marks, expert witness, forensic odontology, murder

CASE REPORT

On Monday September 29th, 1980 in the Huijbrechtse School in Wassenaar, a town near the Netherlands city of The Hague, during a needlework class, Edith Post, the eleven year-old daughter of a fire brigade officer was given permission by her teacher to collect some materials from a cupboard in the school kitchen. When she did not return to the classroom within a reasonable time the teacher began searching for her, and when she could not be found Edith was reported missing.

Three days later, on Thursday, October 2nd, the partly unclothed body of a young girl was found almost submerged in a reservoir in the dunes near Wassenaar. The head, face and body of the girl bore bloodstains and she was soon identified as Edith Post. An autopsy performed by the chief pathologist of the laboratory for forensic pathology of the Ministry of Justice established the cause of death to be severe skull damage caused by heavy blows to the head with a blunt object. Unfortunately, since no swabs were taken of the blood stains, no examination of blood samples was carried out. This oversight was to have significance later on.

The following day, October 3rd, after a wild chase in the city of The Hague a 31 year-old man, KH, well known to the police, was arrested. In the course of the investigation that followed it was revealed that KH had been seen in Wassenaar in the company of a girl, possibly Edith Post, on September 29th. In custody in Wassenaar police station KH remained silent during interrogation.

Meanwhile, the Dutch police had been investigating two other unsolved murders. The second of these had been committed in May 1979 and on the 15th of that month the body of Thialda Visser, aged 12, was recovered from the Laakharbour in The Hague. The cause of death was found to be strangulation. About six weeks before, on April 5th, the bullet riddled body of Emy deBoer, 18 years-of-age had been found in the woods near Nistelrode in the Dutch province of Noord-Brabant.

Investigations in the home of KH revealed the presence of a well equipped "torture room" which had been soundproofed, as well as numerous hard pornographic video-tapes and pornographic magazines. Moreover, traces of the presence of both Thialda Visser and Emy deBoer in the so-called "torture room" were found.

Further evidence that might have associated KH with the body of Edith Post emerged on October 7th, 1980, through an anonymous telephone call received by the Wassenaar police who were strongly urged "to take a good look" at his left hand. In response to this information the chief pathologist who had carried out the autopsy on the body of Edith Post was asked to examine KH's left hand and discovered on the left little finger a laceration which had not been noticed since his arrest on October 3rd (Figs. 1 and 2). It was the pathologist's strong impression that this laceration might be a bitemark and he at once sought the advice and opinion of an expert in forensic odontology who visited the suspect and took impressions and photographs of the finger and hand.

The suspect's explanation for the lesion was that he had been bitten by a dog in the Kinderenstraat in Amsterdam and had gone to the out-patients' department of the St. Lucas hospital in Amsterdam for treatment on or around September 30, 1980.

The hospital confirmed that KH visited the waiting room in the company of two young adults, one of

Fig. 1. Left hand of KH showing injury to little finger (posterior view) (scale: 2 cms).

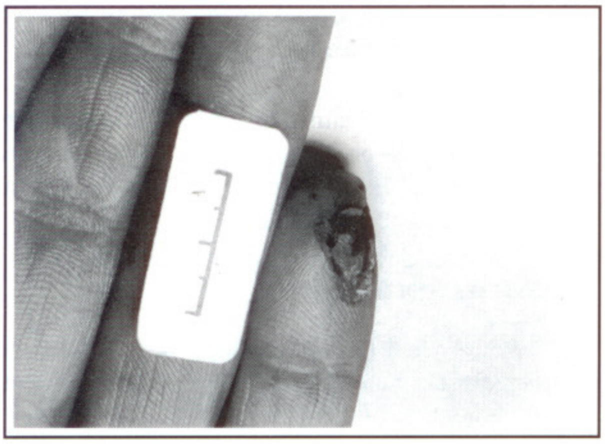

Fig. 2. Injury to little finger (anterior view) (scale: 2 cms).

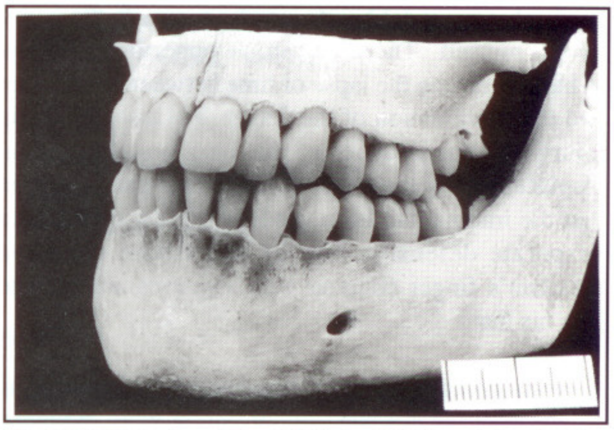

Fig. 3. Maxilla and mandible of Edith Post, left lateral view showing vertical fracture of labial plate mesial to left central incisor.

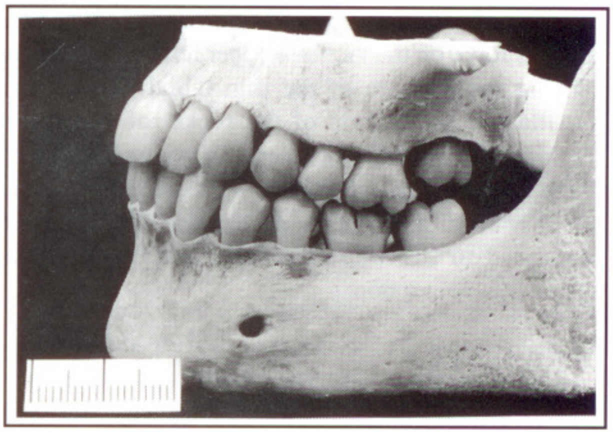

Fig. 4. Maxilla and mandible of Edith Post showing vertical fracture of labial plate distal to left central incisor.

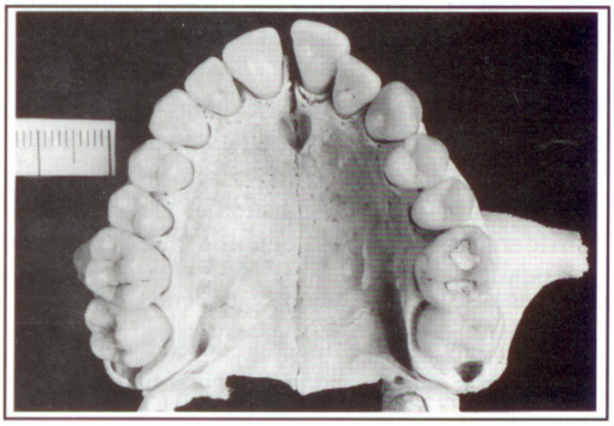

Fig. 5. Maxilla of Edith Post, palatal view, showing anterior displacement of left central incisor, and fracture of palatal margin of tooth socket.

whom had been treated for a dog bite said to have been inflicted in the Kinderenstraat. The medical staff declined to make further comment about treatment provided.

Following the examination of the suspect the forensic odontologist sought permission to examine the jaws of the victim. This proved more difficult than expected since the body had already been released to the family for burial. However, upon the insistance of the forensic odontologist the jaws were removed shortly before the burial and after maceration of the soft tissues an examination of the maxilla revealed a small vertical fracture of the labial plate on each side of the upper left central incisor (Figs. 3 and 4) with a noticeable anterior displacement of this tooth and a small crescent shaped fracture of the palatal margin of the tooth socket (Fig.5).

In consideration of the pattern of injury on the finger of KH the odontologist concluded that it had been produced originally by human teeth but there may have been subsequent deliberate interference with the injury by KH himself. There was ample opportunity for this to happen during the lapse of time between the murder and the examination of the finger. He associated this injury with the fractures of the maxilla and the labial displacement of the tooth of Edith Post and proposed that the trauma had been produced in the course of a desperate defensive bite by the victim upon the assailant's finger coupled with vigorous attempts to free his hand.

KH was charged with the murders of the three girls. At the trial the forensic odontologist gave evidence and expressed his opinion that the victim had bitten very hard on the little finger of the left hand of the offender whose attempts to free his hand produced the forward force on the victim's upper left central incisor causing the fracture of the thin labial plate of the maxilla and the margin of the socket of this tooth, forcing its forward displacement. In stating his opinion to the court he was careful to emphasise that he could not offer absolute proof for it. KH was convicted and sentenced to life imprisonment, losing an appeal against his conviction.

DISCUSSION

The association of the injuries on the finger of KH with the damage to the dentition of Edith Post in the manner described by the forensic odontologist directly linked the murderer with the victim and posed a powerful argument against him.

In proving this association, the timing of the injuries to KH and Edith Post was crucial - a task made more difficult by a delay of up to 8 days from the commission of the offence to the examination of the wounds. In consideration of this association three important questions emerge:

1.Was the injury to the finger produced by the teeth of a dog or of a human, and in particular by the teeth of Edith Post?

2. Was the injury to the dentition produced before or after death? Could it have occurred accidentally in gaining access to the mouth during the resection of the jaws?

3. Were the forces generated by the interaction of the bite and the attempt to withdraw the finger from the mouth sufficient to cause the displacement of the tooth and fracture the associated bone?

In retrospect these issues may be debated at length and some may question the validity of the opinion of the forensic odontologist and whether his evidence may have contributed to a miscarriage of justice in the conviction of KH. It is important however that his evidence should not be taken in isolation. It is not known what weight was placed on it by the court and what body of other evidence was available. It is always easier to make judgements in hindsight, but in this case what is significant is that the forensic odontologist was in the best position to form an opinion in the circumstances because he examined the material at first hand. However, his task would have been easier had he been given the opportunity to view the damaged dentition of Edith Post at the time of the autopsy, and had a full medical examination of KH revealed the damage to his finger immediately following his arrest - a routine procedure which is followed in some countries.

This case was a landmark one in Holland. Not only did it open the doors of the courts of law in that country to the expertise of forensic odontology but it also highlighted the potential role of an experienced forensic odontologist working together with the pathologist and police as an investigating team. It emphasised the need for close cooperation, communication and mutual understanding between each member of that team.

Finally, how many dentists or forensic odontologists reading this today, on noticing the slight irregularity of the left central incisor in the mouth of Edith Post, would have attached a sinister significance to it?

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SCANNING ELECTRON MICROSCOPY, A USEFUL TOOL IN FORENSIC DENTAL WORK

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Paper read at the 13th Meeting of I.A.F.S., Düsseldorf, Germany, 1993

ABSTRACT

In selected cases there is a need for microscopic information found on the surface of tooth specimens. Scanning electron microscopy is the method of choice. Based on the knowledge of the structural organization of the mineralized dental tissues differential diagnoses of physical and chemical changes can be made. It is suggested that the forensic dental profession cooperates in establishing a collection of reference material illustrating different traumas to enamel and dentin, deposits on teeth and the structure of restorative dental materials as they will appear after some years in position on a tooth. Four different cases are presented.

Keywords: Surface structures, deposits on enamel, surface of restorative materials

INTRODUCTION

The mineralized nature of teeth, their resistance to degredation and individuality including details of their structures, dental restorations or deposits on the tooth surfaces can be of great value in a forensic dental context.

Radiography, close-up photography and microscopy of ground sections are commonly used, but judging from the forensic dental literature electron microscopic scanning of surface structures is not very often included in the documentation of specimens. There are, however, reports of bite mark analysis, evaluation of fractured teeth, and also deposits on teeth[1-4].

The authors of this article do not advocate the immediate purchase of electron microscopes for forensic departments, or that scanning should be carried out in all cases, but only that specialists in this field be involved when necessary[5,6]. In this report some cases where scanning has added to the investigation are demonstrated.

In the first instant it is important to be aware of the normal ultra-structure of teeth and in Fig.1 a review of the enamel surface structure of human teeth is demonstrated. The specimens represent intact cleaned enamel from an unerupted tooth and the magnifications used are 600, 2000, 20000 and 60000 times respectively. The sequence of pictures at the same time demonstrates that the human body's hardest and most resistant mineralized tissue contains only 3% organic material[7]. In most forensic dental cases, however, only low magnifications from 100 to a few thousand times are needed.

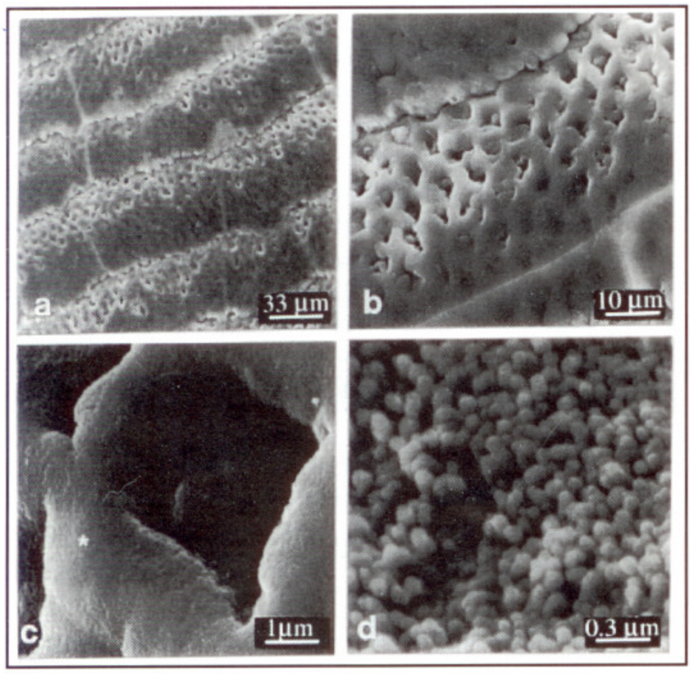
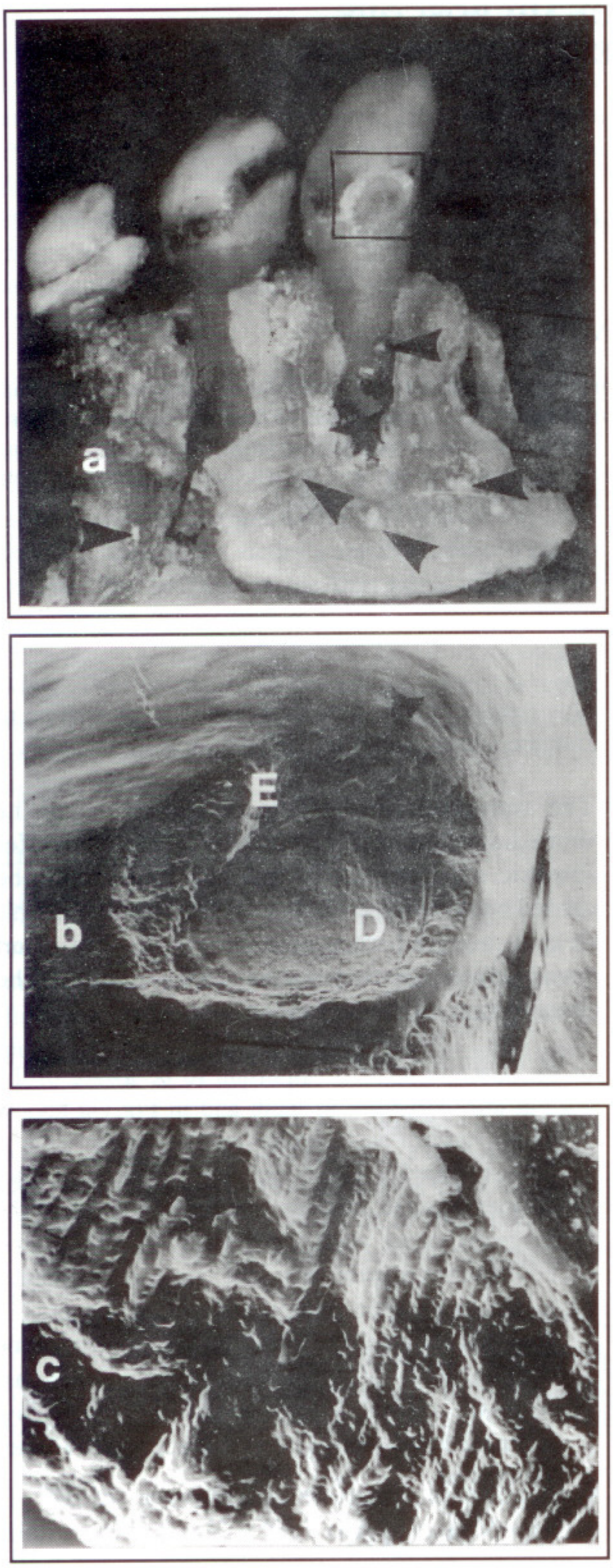


*Fig. 1. Micrographs showing the enamel surface from an unerupted tooth at different magnifications a = x 600, b = x 2000, c = x 20000, d = x 60000. Note the appearance of the enamel rods on the surface before the enamel had been exposed to attrition. * marks position of detail (d).*

CASE REPORTS

Case 1

The first case is an example of physical stress to the enamel surface leading to fractures of the enamel rods. Figs. 2a-d show the marks left on the teeth after a dog had chewed the facial bones of its dead owner. The fracture site on the crown is only located in areas of former demineralization from superficial dental caries and a characteristic pattern of the fractured enamel rods appears on the scanning pictures. The detailed structure of the



mark has an overall step-like appearance, but surprisingly it is also slightly rounded in form, a condition which is similar to that produced by extraction forceps. This is shown in Figs. 3a-d where the physical stress also produced a step-like appearance but with much sharper and better defined steps. The almost identical macroscopic marks in these teeth demonstrated different microscopic details.

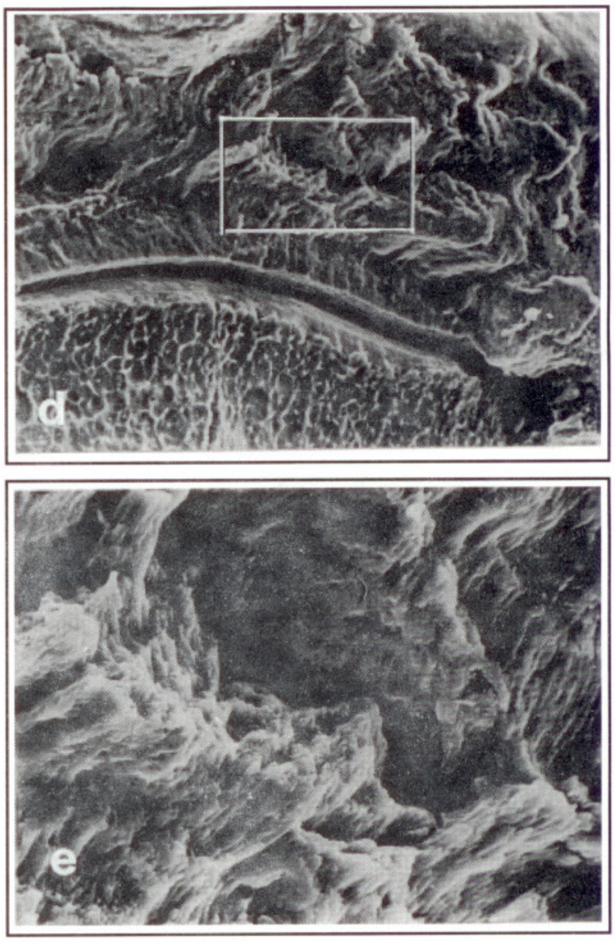


Fig. 2, a - e.

a) Tooth 43 with a cervical defect from a dog's bite. Additional marks are seen on the surface of the bone and the roots (arrows).

b) Scanning of the mark in the enamel of the canine (x 10). E enamel, D dentin and the arrow marks, detail (c).

c) The edge of the mark showing the surface and the fractured rods (x 500).

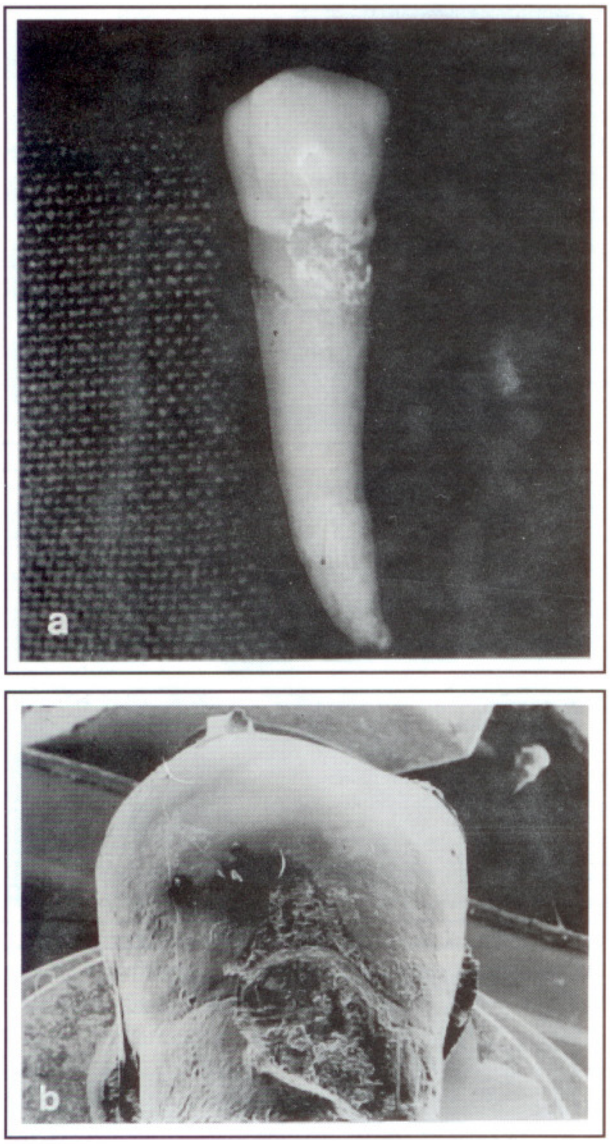
d) At the bottom of the mark the steplike fracture site is seen (x 100).

e) Rounded "steps", detail from (d) (x 300).

Cases 2 & 3

In a second and third case deposits on the tooth surface were used to approximate the "time of death". The first was from a human cranium found in May 1993 near the northern coast of Denmark. There was no evidence of dental treatment, but the teeth appeared pink from internal red discolouration. The phenomenon of pink teeth is well known[8] and indicated a recent death, but as there is no documentation regarding the duration of the discolouration, estimation of the "time of death" is difficult. It is known, however, that the colour fades rather quickly when the specimen is allowed to dry out[8].

The finding of barnacles was of some help (Fig.4). The marine biologists consulted estimated the type to be Balanus crenatus and that the oldest of the organisms was not more than 6 weeks old making it probable



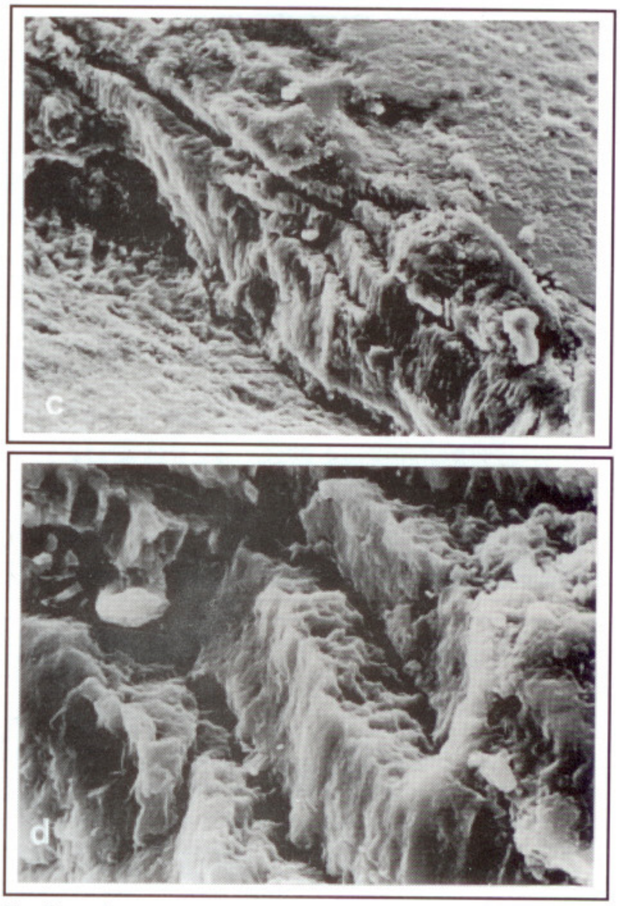


Fig. 3, a - d.
a) Lower premolar with a cervical mark made by extraction forceps.
b) Scanning picture showing the mark partly in the enamel and partly on the root surface (x 8).
c) The enamel edge of the fracture site (x 150).
d) The sharp "steps" in contrast to figure 2 (e) (x 750).

that the growth of the barnacles had started after the past winter and that the person probably died during the late autumn last year or during the winter. The SEM investigation also revealed some diatomes Coconeis scutellum (Fig.5), but this could not add to the estimation of how long the skeleton had been in the sea. Earlier reports have shown that barnacles can be used in identification cases to determine the time of death[(4)].

Fig. 4.
"Young" barnacles on the occlusal surface of a molar from the cranium found close to the coast of Denmark (x 40).

Anthropological measurements of the skull and the facial bones had shown a possible similarity to a Russian sub-population[(9)], and the individual was probably a sailor from a passing ship in Danish territorial waters. The case remains unsolved as there has been no report of a missing person who could be matched to the remains.

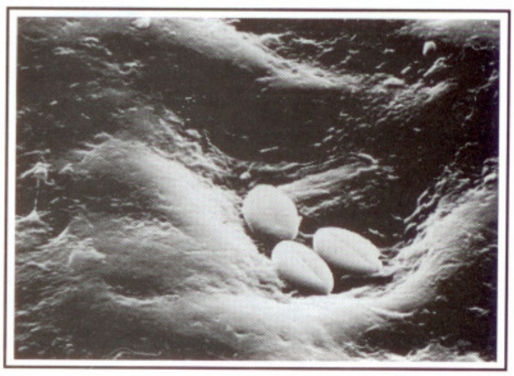
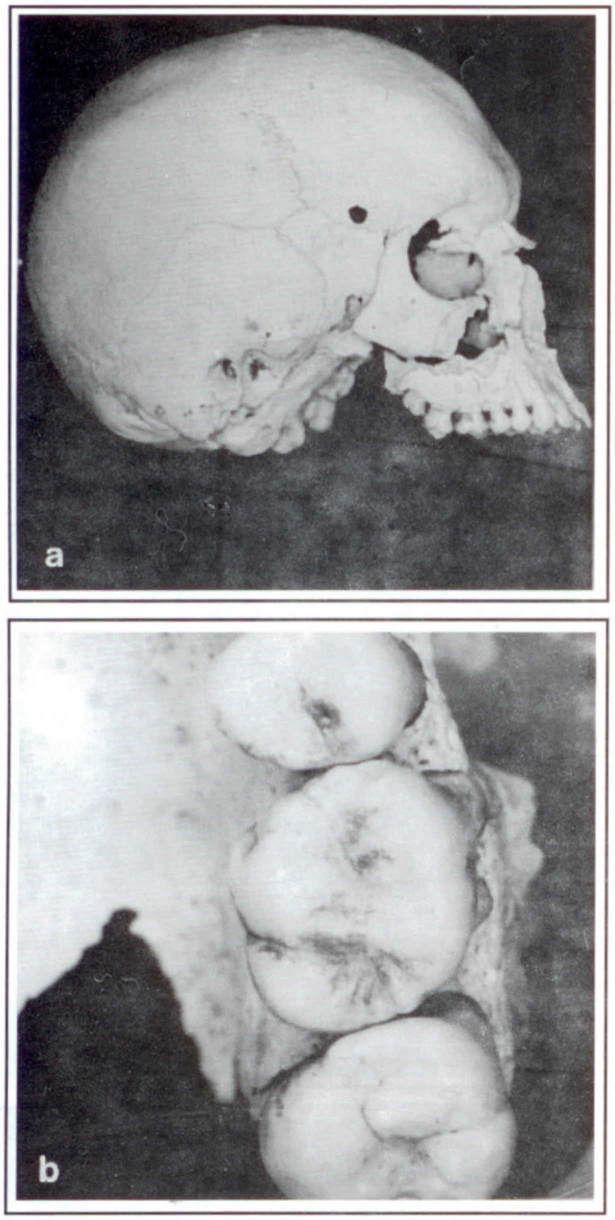


Fig. 5.
Diatomes (Coconais scutellum) found on the same tooth as in figure 4 (x 90).

The third case is also an example of microscopy of deposits on teeth. The SEM investigation turned out to be most illuminating and concerned a cranium found in the sea late in 1992 close to the western coastline of Sweden by a Danish fisherman. At first sight the



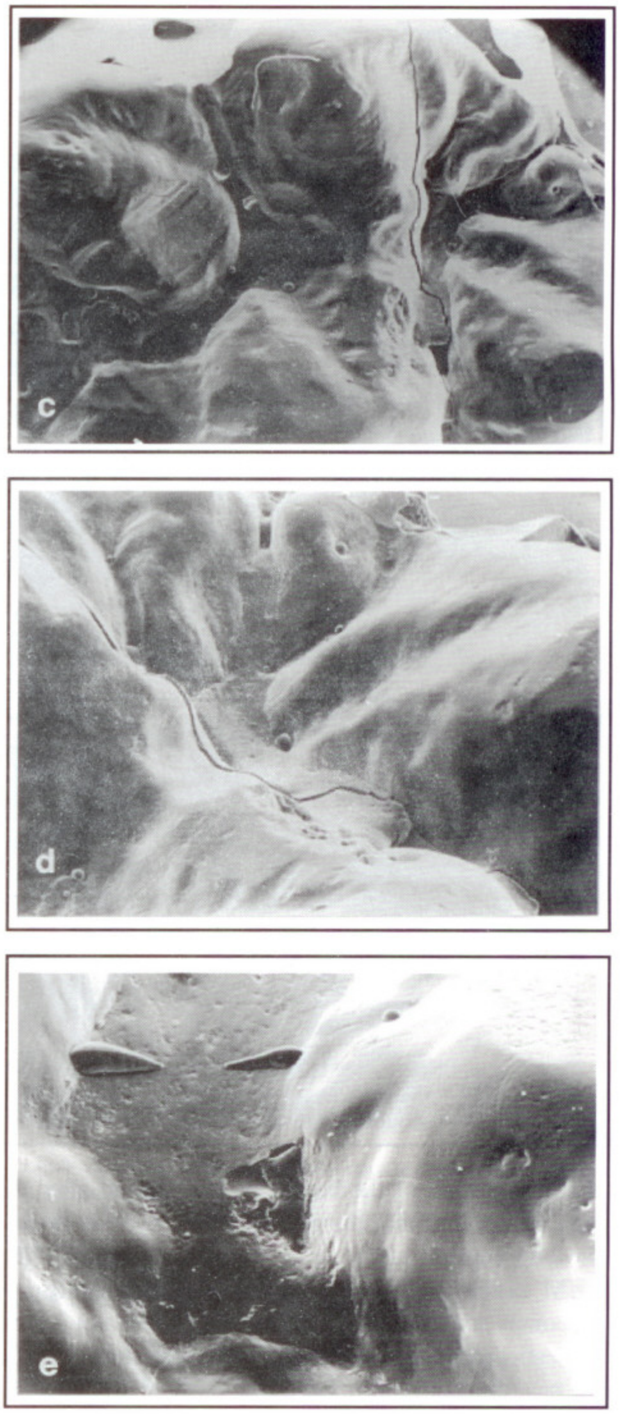


Fig. 6, a - e.

- *a) A cranium from a young Scandinavian male found in the sea near the Swedish coast.*
- *b) The close-up of the first molar reveals a shallow fissure system.*
- *c-d-e) Scanning of impressions from the occlusal surface demonstrates the plastic fissure sealants.*

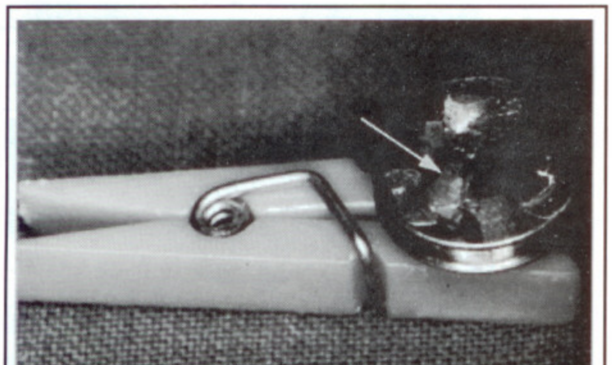


Fig. 7. A foreign object (arrowed) together with two pieces of enamel ready for scanning microscopy.

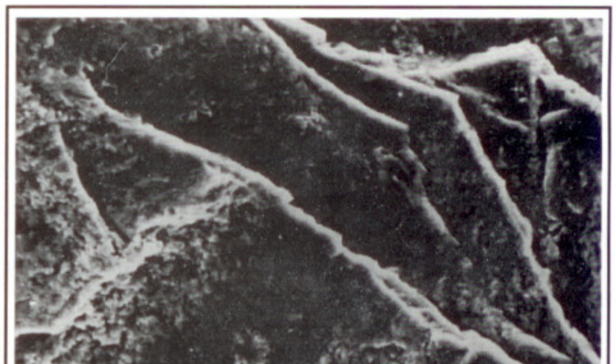


Fig. 8. The object from figure 7 shows no resemblance to dental tissues.

specimen looked like an archeological specimen; the bone was totally dried out and bleached, but a closer look showed fissure sealing of the occlusal grooves on the first permanent molars (Figs.6a-d). The plastic sealants used as a preventive measure were introduced around 1970 and their presence could bring the determination of time of death from prehistoric/historic time to at least a year after 1970. Observations on the development of the roots of one third molar pointed to an age of 20-25 years, and the anthropological finding indicated a male of Scandinavian extraction. After an inquiry to missing persons in Scandinavia a young male of 19 years was reported to have been missing from a ferry-boat since the summer of 1990, and based on ante- and post-mortem radiographs the cranium was identified as belonging to this particular person. It appeared from the dental records of the missing person, that the fissure sealants were placed in 1979 and the SEM picture showed a perfect fit after 13 years, including two and a half years on the sea bed.

Case 4

The last case is an example of SEM of a small tooth-like object which was allegedly part of a broken tooth. It had the colour and hardness of dental enamel, and Fig.7 shows the specimen coated and prepared for scanning microscopy. (The object is located in the middle together with two pieces of dental enamel). The case arose from a consumer complaint with a demand for compensation for the broken tooth claimed formerly to have been intact and untreated. The scanning microscopy showed a laminated surface with no resemblance to dental tissues and indicating rather some kind of ceramic material. The complaint was therefore questioned (Fig.8).

CONCLUSION

There are many forensic dental applications possible for scanning electron microscopy, and it is the authors' experience that scanning specialists are willing to put current work aside in order to help with forensic cases. It is therefore recommended that more widespread use of the technology be made leading over the years to a substantial collection of reference material to the benefit of forensic dental profession.

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FORENSIC ASPECTS OF AESTHETIC DENTISTRY

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ABSTRACT

Treatment for aesthetics is playing an increasingly important role in dentistry. However as this treatment is elective litigation from patients may increase in future because of its costly nature, the subjective outcomes and the reluctance of health insurance to cover the costs. It is the dentist's duty therefore to ensure that treatments are fully explained, the costs are fully quoted, the patient given sufficient time to consider and accept the treatment, that the highest standards of treatment are adhered to and complete records kept.

Keywords: Aesthetic dentistry, litigation, informed consent, Germany.

Treatment for aesthetics is playing an increasingly important role in dentistry. On the one hand, expectations and demands of patients have increased while the dental profession discovers new treatment modalities under the concept of "aesthetic dentistry". The dental measures carried out under this aspect are, of course, no less subject to legal implications and safeguards than any other medical and dental treatments.

Aesthetic and forensic aspects seem almost diametrically opposed: the one strongly marked by subjectivity, preference and taste, the other normative and subsumable, strictly committed to objective rules and regulations. Although no general principles are capable of bridging this apparent gap, these disparate phenomena must be brought to a common denominator in a case of legal contention.

The dentist is acting within the law as a matter of principle if the treatment is justified, if it is undertaken with the informed consent of the patient and is in accordance with the best treatment principles. This forensic axion covers the three interlinked and fundamental preconditions which have to be satisfied in any treatment if it is to stand a legal challenge.

Seen in its strictest terms where treatment should be aimed at curing disease and alleviating pain, sepsis and suffering an intervention for the sake of aesthetics alone may not be justifiable. However, aesthetic impairment may be a source of mental suffering in its own right, (e.g. a child whose prominent teeth expose him to ridicule by his fellow pupils) and is indeed an indication for corrective dental treatment. In addition, the concept of treating aesthetics has diversified, not only because of the opportunities available in treatment modalities but also because of increasing variety in life styles and the striving by individuals towards so-called self-fulfilment. Ambiguous new requirements, typical among them that for "quality of life", seek to endow dental treatment with additional facets. These endeavours to expand the frontiers of treatment are particularly found in the field of cosmetic dentistry.

Legislators appear to be reticent to include rules governing aesthetic treatment, although there is no mistaking the fact that legal standards become more stringent as a treatment intervention is less indicated. If such a case is then brought to litigation, officiating judges are found to exercise hesitancy in assessing a cosmetic result, relying entirely on the testimony of the experts, who for their part display remarkable reserve in committing themselves on an aesthetic result. The fact is rather that appointed experts are geared more than ever to whether the workmanship was *lege artis,* and whether the selected method was the correct one or at least reasonable. No appointed expert will venture voluntarily onto the thin ice of subjective appraisal *(de gustibus non est disputandum)* unless he has to assess an exceptionally fine or a grotesquely poor result, one not open to discussion. He will otherwise keep to whether or not the treatment was in line with the state of the art. The appointed expert having expressed his opinion on this matter, the judges immediately feel confident once again to turn to their legal reasoning with respect to the duty to provide adequate information. It is precisely here rather than in the actual aesthetic result that the crux of liability legislation in cosmetic dentistry is highlighted. Court rulings are unanimous in classifying the cosmetic treatment contract also as a service contract, one giving no guarantee of success but implying a commitment to take the greatest possible care[4]. Treatment planning and detailed consultation or instruction of the patient must take special account of the following questions:

- Is the objective actually attainable?
- Are the patients' concepts realistic or exaggerated?
- What methods are available?
- What opportunities and limitations, advantages and risks are inherent in the selected method?
- Observance of the dentist's categorical imperative: *primum nil nocere*, i.e. is the damage-benefit ratio acceptable?

- What do the risks of the treatment, should they materialise, imply for the individual patient's quality of life?

The problem in Germany is illustrated by the brief extract quoted below from a relevant verdict pronounced by the German Federal Court of Justice in 1990[2]:

"The fact that the Court of Appeal has refuted a treatment error is not open to question. What can be questioned is whether the consent given by the patient to the cosmetic surgery was legally valid on the grounds of adequate information on consequences and risks. For the less a treatment is necessary on medical grounds, the more the patients, to whom this intervention is recommended, or which they themselves request, must be informed of its prospects of success or of potential consequences. This applies in particular to cosmetic surgery not serving, at least not primarily, the healing of a physical condition but rather a psychological and aesthetic need. The patients must be informed in these cases of what improvements they can expect in the most favourable circumstances, and potential risks must be made absolutely clear to them, so that they can give serious consideration to whether they are prepared to accept any failure of the already uncomfortable intervention and moreover any permanent disfigurements or impairments to their health, even if these are only remotely a consequence of the intervention. It is inherent in the special responsibility of the surgeon performing cosmetic surgery to impress upon the patient the pros and cons and all consequences. For this reason the judicial system also places very stringent demands on instruction of the patient prior to cosmetic surgery".

Another factor to be borne in mind is that the doctor and dentist would be well advised to comply also with their duty to provide adequate economic information, especially with respect to cosmetic intervention. Prior to surgery taking place, the surgeon should state unequivocally that the health insurance agency might not foot the bill for the operation. This regulation exists because in the absence of a clearly defined medical/dental condition problems with health insurance payments may arise and the patients must be forewarned. In the event of the health insurance agency refusing to cover costs and of the surgeon not having drawn the patient's attention to this possibility, the fee may be forfeited even if the operation was successful[3].

Finally, it must be pointed out that the instruction must be given in due time, i.e. sufficiently long before the surgery to give the patient real decision-making freedom. Cosmetic surgery is by its very nature not urgent, so that instruction given within an insufficient period has to be classified legally as too late and the resulting consent by the patient as legally invalid[1].

CONCLUSION

Legislation can be said to give the patient's right to self-determination a very high rating. It leaves cosmetic surgery as a valid treatment and does not brand intervention on sound non-diseased structures as unethical; it does also ensure that the patient is provided by the surgeon with all information needed to make a considered and responsible decision for or against the intervention. The implication for the professions with respect to cosmetic treatments is that they need to be more than ever on guard concerning their commitments, the duty to take due care, and in particular the duty to provide adequate information and to keep records.

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