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Contents

A QUANTITATIVE ANALYSIS OF SUBTRACTION IMAGES BASED ON BITE-WING RADIOGRAPHS FOR SIMULATED VICTIM IDENTIFICATION IN FORENSIC DENTISTRY

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ABSTRACT

The comparison between ante- and post-mortem radiographs constitutes an important basis for victim identification in forensic dentistry. Due to the decline in dental caries among children that has occurred in Western countries over the last 20 years, the number of restorations in future populations will be limited. It is likely that this will impede successful victim identification in the future. It was the aim of this study to evaluate a new radiographic technique, subtraction radiography based on bitewing radiographs and determine whether it could provide an objective quantitative measure for victim identification. Bitewings randomly sampled from a large population of adolescents (13-19 yrs) were video-camera-recorded and digitized. Subtraction images were performed of pairs of bitewings originating from the same individual (identical images) and from different individuals (non-identical images). The images were separated into two groups, one without fillings (12 identical and 48 non-identical) and one with simple amalgam fillings (15 identical and 60 non-identical). The distribution of grey shades in the subtraction image was used as the parameter for evaluation of homogeneity in the images. Subtraction images derived from identical radiographs were significantly more homogeneous than those derived from non-identical radiographs ($p<0.001$) in both the group with and without fillings. Although the difference was statistically highly significant, the distribution of grey shades in the two groups overlapped. Thus, the grey shades in the subtraction image cannot *per se* unequivocally establish the identity of a victim, but may add to the subjective comparison of two radiographs in victim identification. **(J Forensic Odontostomatol 1994; 12: 1-5)**

Key words: Radiography, computer-assisted; diagnosis; forensic dentistry.

INTRODUCTION

In forensic dentistry, the comparison between ante- and post-mortem radiographs constitutes an important basis for victim identification. Bitewing radiographs of the teeth have played a particularly significant role as this is one of the most commonly performed radiographic examinations.[1]

A recently described digital technique, subtraction radiography, is based on superimposition of two radiographs achieving an overlap of identical anatomic structures in the images, thereafter the homologous information in the one image is subtracted from that in the other. The subtraction technique is a means of evaluating differences in two radiographs taken with a time interval, but will at the same time provide a measure of homogeneity in the images. Digital subtraction radiography was introduced a decade ago as an aid in dental diagnosis and has been used for a variety of diagnostic purposes where small tissue changes, not readily visible to the naked eye, may be detected.[2] The technique has not, however, been used as a tool for evaluating similarities in the two images. In radiograph-based victim identification, emphasis is put on characteristics of tooth and bone morphology and pathology as well as individual dental treatment such as endodontic and tooth crown restorations.[3] Due to the decline in dental caries amongst children which has occurred in Western countries over the last twenty years,[4] the number of restorations in future populations will be limited. Further, the change in choice of filling materials from amalgam to composites or glass ionomers will result in a different radiographic appearance as some of these new materials are either not visible on radiographs or possess a radiopacity close to that of enamel or dentine.[5] It is likely that such changes will impede victim identification in forensic dentistry.

A recent study has demonstrated that 43% of observers presented incorrect answers in 10% of cases in which no dental therapy existed, when pairing samples of bitewing radiographs. Whilst all of the observers were able to establish identity for all cases in bitewings with dental treatment.[6] This observation seems to support the above opinion and increases the need for further diagnostic tools to identify positively by dental means victims with little or no dental therapy.

While the value of subjective observer assessment in identifying subjects, based on recognition of identical structures on radiographs, is indisputable, an objective, quantitative measure of image homogeneity may provide additional help in determining whether two radiographs originate in the same individual. It was the aim of this study to evaluate whether subtraction images based on bitewing radiographs, could provide an objective, quantitative measure for victim identification.

MATERIALS AND METHODS

The material consisted of 50 bitewing radiographs from 24 individuals, randomly selected from a large sample of bitewings of 13-19 year-old adolescents. The bitewings included the pre-molars, the first permanent molar, and in the majority of cases also the second permanent molar in the right side of the jaws. Two groups of individuals were identified:

1) 12 individuals, each represented by two radiographs, had dentitions
2) 12 individuals, each represented by two - though in two cases by three - radiographs, had dentitions with one to four amalgam fillings in the molars, but no other treatment (Fig. 1a, b, c).

The time period between the two-three bitewing examinations of the same individual was 2-3 years. The radiographs had all been taken in the Community Dental Health Care for children's clinics as part of routine diagnosis and treatment planning. No radiographs were taken for the purposes of the present study.

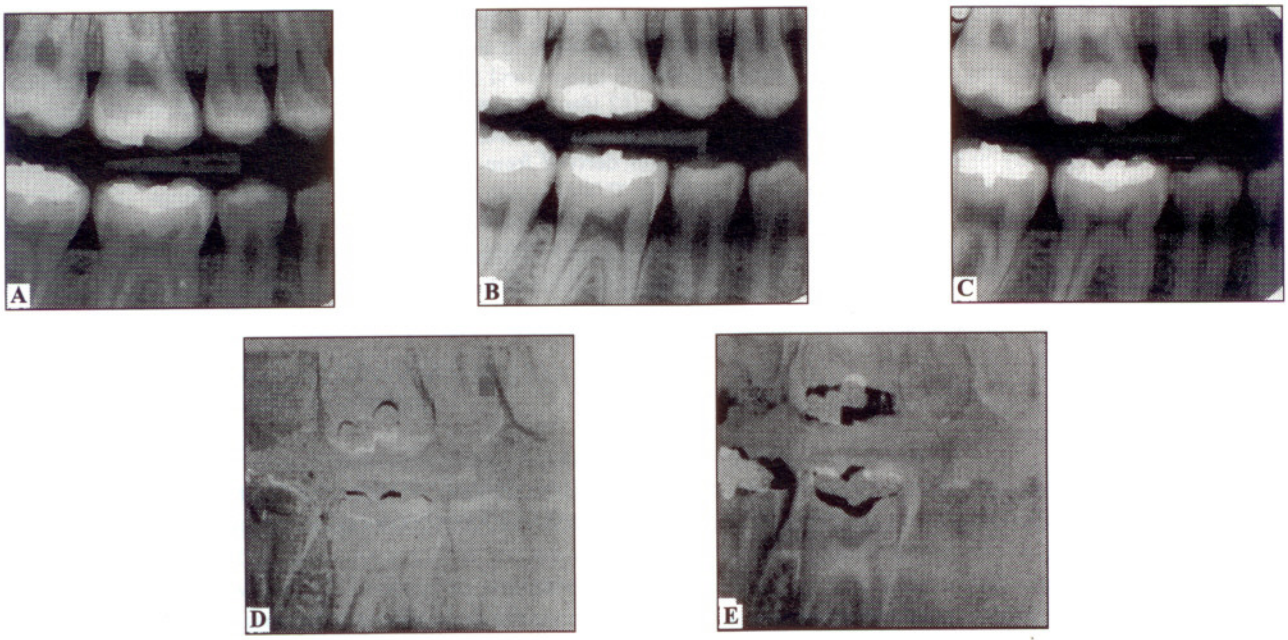

Fig 1: Radiographs from the same (a+c) and two different (b+c) individuals with fillings and the resulting subtraction images [d(ac) and e(bc)].

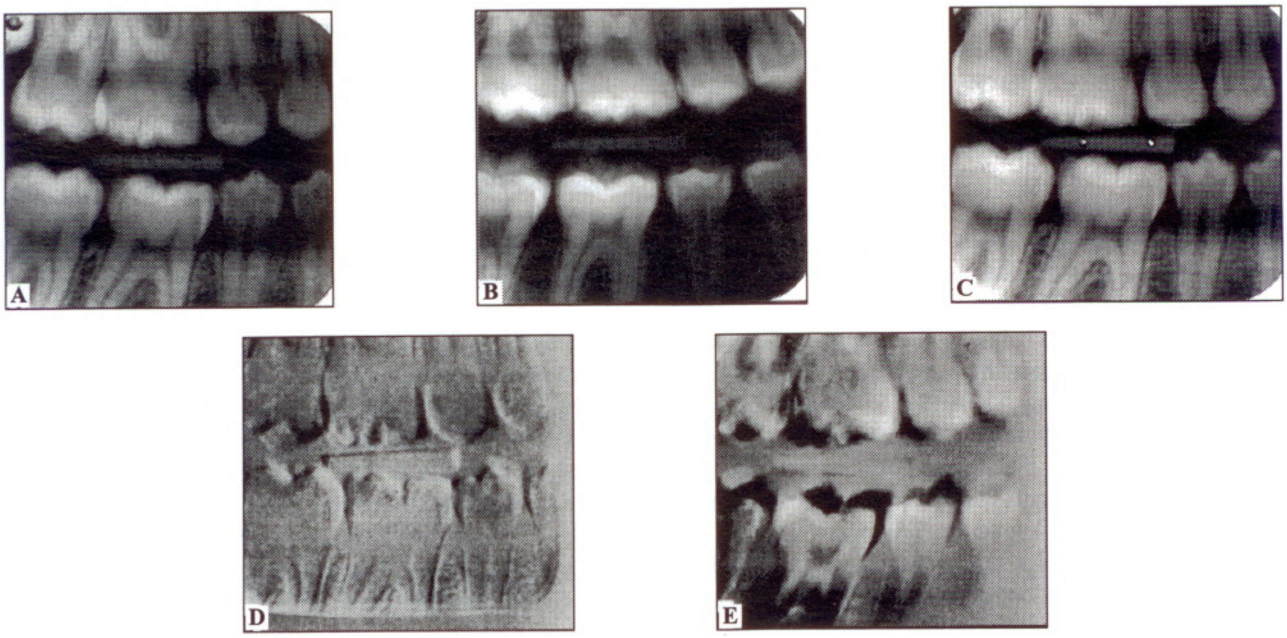

Fig 2: Radiographs from the same (a+c) and two different (b+c) individuals without fillings and the resulting subtraction images [d(ac) and e(bc)].

The radiographs were recorded by a black and white CCD-video camera (512 scan lines). A personal computer hosted a digitization card*, and the images were displayed on a quality video monitor. During digitization of a radiograph, the information in the image is decomposed into bits (binary digits), and positioned in rows and columns called a matrix. Each unit in this matrix is termed a pixel (picture element) which assumes a digital value corresponding to a shade of grey.

Thus, the information contained in any digital image may be described by the number of pixels and the number of shades of grey available in the system.[2] The present digitizing system operates with 512x512 pixels and 256 shades of grey.

The subtraction program in use has been developed in collaboration with programmers,[7,8] and is based on positioning reference points as landmarks for superimposition of the two images to be subtracted.[9] Ten reference points were positioned in each image before subtraction coinciding with the edges of amalgam fillings (in images with fillings) and at cemento-enamel junctions.

Subtractions were performed between the images originating in the same individual, hereafter named "identical" images, and between images originating in different individuals, hereafter named "non-identical" images. Figs. 1(d,e) and 2 illustrate subtraction images representative for identical and non-identical images with and without fillings respectively. The number of images in each group can be seen in Table 1.

Identical

	N	$\bar{x}$	min.	max.	sd
+ Filling	15	12.3	8.1	15.3	2.1
- Filling	12	16.6	9.2	23.4	3.7

Non-identical

	N	$\bar{x}$	min.	max.	sd
+ Filling	60	18.3	14.3	36.1	4.5
- Filling	48	24.2	19.0	33.7	3.4

Table 1: Mean ($\bar{x}$), minimum, and maximum values and standard deviation (SD) for the parameter expressing image homogeneity in identical and non-identical subtraction images with and without fillings

In digital image subtraction, the numeric values of two superimposed pixels are subtracted. When two digital images are numerically identical, the resulting subtraction image consists of a totally homogeneous image surface where all pixels have the same value or grey shade. When images are not totally identical, superimposed pixels with different values are subtracted, resulting in various shades of grey in the subtraction image. The more variation that exists in two radiographs before subtraction the larger the number of grey shades presenting in the subtraction image.[9] The homogeneity of the subtraction image may thus be evaluated by calculating the number and the distribution of grey shades in the image. The grey shade distribution can be illustrated as an image histogram (Fig. 3).

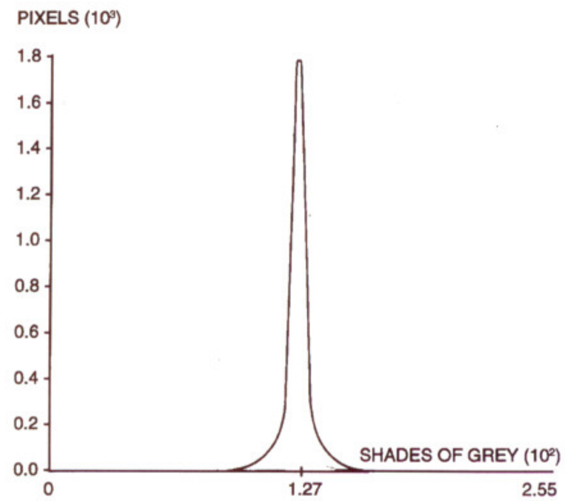

Fig 3: Histogram of the distribution of the shades of grey in a subtraction image. The standard deviation (SD) of this histogram may be used as a parameter for measuring image homogeneity (in this situation the SD is not a statistic).

The standard deviation (SD) of this image histogram may be used as a parameter when evaluating image homogeneity.[10] Thus, the SD in this situation is not a statistic, but a quantitative measure for the homogeneity in the subtraction image. The Student's t-test was used to test differences in image homogeneity (using the SD as the test parameter) between the two groups with and without fillings and between identical and non-identical images in either of the groups with and without fillings.

PC Vision, Imaging Technology Inc., Woburn, Mass., USA

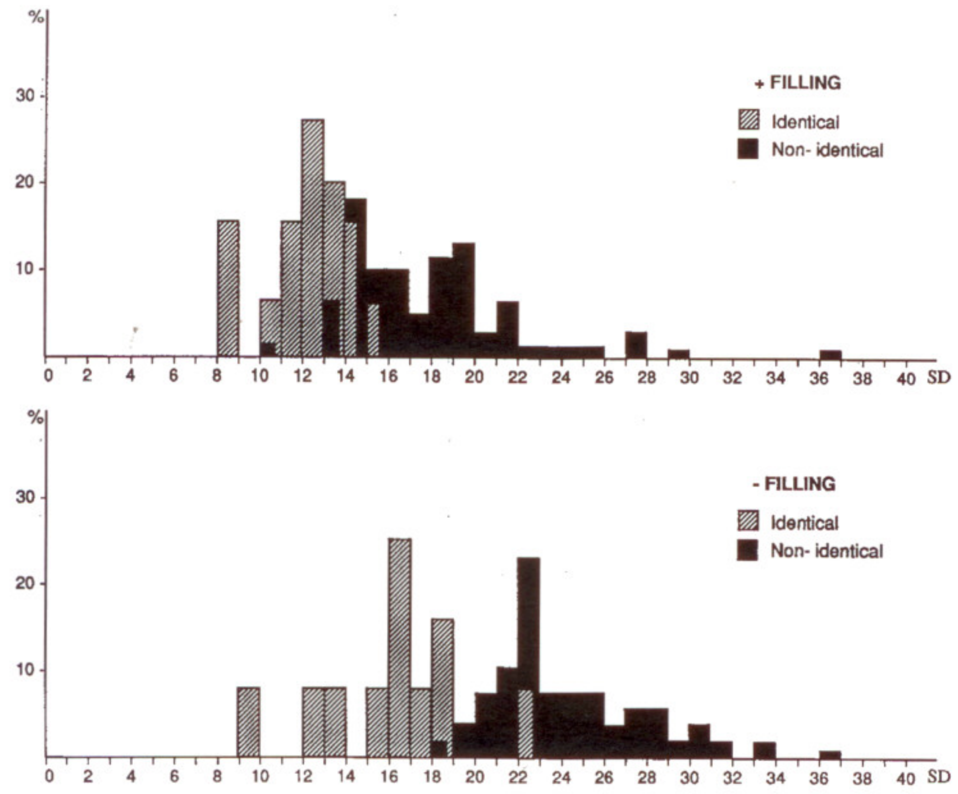

Fig 4: Distribution of the SD of the subtraction image histogram in the groups of identical and non-identical images with and without fillings.

RESULTS

In the total group with fillings (identical + non-identical radiographs), the mean SD of the distribution of grey shades in the subtraction image was 17.1. In the total group without fillings, the mean SD of the histogram was 22.7. Thus, lower SDs were seen in the group with fillings than in the group without fillings. This difference was statistically significant as well in the group of identical ($p<0.002$) as non-identical images ($p<0.001$).

In Table 1, mean, minimum, maximum values and standard deviations for the SD of the subtraction image histogram are presented for identical and non-identical images in the groups with and without fillings. The overall distribution of the SD in these samples is demonstrated in Fig. 4.

Subtraction images derived from identical radiographs were more homogeneous (lower SDs) than those derived from non-identical radiographs in both the samples with and without fillings. The differences between the identical and non-identical groups were highly statistically significant ($p<0.001$) whether or not fillings were present.

DISCUSSION

When detecting tissue changes, a pre-requisite for digital subtraction radiography is that projection geometry is accurately reproduced so that all unchanged background structures will be eliminated in the image. The more severe the misalignments during recording, the more "noise" or non-homogeneities there will be in the subtraction image. The present study set out to evaluate whether bitewing radiographs of the same individual, conventionally taken in the Community Dental Health Care for children, were reproducibly recorded to such an extent that the number of grey shades ("noise") present in subtraction images made between these radiographs was less than when made between radiographs from two individuals. The two bitewings simulated ante- and post-mortem radiographs. It was evident from the results that intra-individual variability was significantly less than inter-individual variability as the subtraction images in the identical-image group were more homogeneous than in the non-identical-image group.

Highly statistically significant differences were observed between the identical and non-identical images irrespective of whether or not fillings were present. The SDs of the image histograms in the identical image group with fillings were however, much larger ($\bar{x}$SD=12.3) than in a previous study in a similar age and treatment group ($\bar{x}$SD=4.1) where a standardized radiographic recording set-up was used and with a three month period between recordings.[10] This large difference in SD between similar groups can be ascribed to the non-reproducibility of radiographs taken in the Community Dental Health Care Clinic. In a post-mortem radiographic recording of a victim with all teeth present, it may be possible to standardize the recording geometry to resemble closely the ante-mortem image as recently illustrated in a case of drowning.[11] In other forensic situations like fire cases, the value of the technique may, however, be more limited.

In the group without fillings, the difference between the mean values of identical and non-identical images was much larger than in the group with fillings. This may be explained by the fact that some of the children who had fillings had an additional filling made in the period between the two bitewing radiographs. The presence of a new amalgam filling in the second radiograph will give rise to large amounts of "noise" in the subtraction image, and thus increase the number of grey shades in the image. Similarly, fillings imaged on radiographs from different individuals, will not superimpose properly and will leave the subtraction image with black and white borders where the fillings do not match (Fig. 1e). The average SDs of the image histograms were smaller in images with than without fillings. This observation is in accordance with a previous study in animals of the effect of the presence of amalgam fillings on the quality of the subtraction image.[12]

Although the differences between the mean SDs of the image histograms in the groups of identical and non-identical images were highly statistically significant, an overlap existed between the distribution of the SDs in the two groups as visualized in Fig. 4. This means that the objectively measured SD of the subtraction image histogram cannot *per se* unequivocally establish the identity of a victim as interpreted from the present study of simulated ante- and post-mortem radiographs. The homogeneity of a subtraction image may, though, be a measure that adds to the subjective comparison of individual tooth and bone characteristics on radiographs. A forthcoming report will evaluate the accuracy of the subtraction technique based on observer performance in identifying whether or not images derived from subtractions between radiographs are from the same or two different individuals.

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A NON-DESTRUCTIVE DENTAL METHOD FOR AGE ESTIMATION

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ABSTRACT

Dental radiographs have rarely been used in dental age estimation methods for adults and the aim of this investigation was to derive formulae for age calculation based on measurements of teeth and their radiographs. Age-related changes were studied in 452 extracted, unsectioned incisors, canines and premolars. The length of the apical translucent zone and extent of the periodontal retraction were measured on the teeth while the pulp length and width as well as root length and width were measured on the radiographs and the ratios between the root and pulp measurements calculated. For all types of teeth significant, negative Pearson's correlation coefficients were found between age and the ratios between the pulp and the root width. In this study also, the correlation between age and the length of the apical translucent zone was weaker than expected. The periodontal retraction was significantly correlated with age in maxillary premolars alone. Multiple regression analyses showed inclusion of the ratio between the measurements of the pulp and the root on the radiographs for all teeth; the length of the apical translucency in five types; and periodontal retraction in only three types of teeth. The correlation coefficients ranged from r=0.48 to r=0.90 between the chronological and the calculated age using the formulae from this multiple regression study. The strongest coefficients were for premolars. These formulae may be recommended for use in odontological age estimations in forensic and archaeological cases where teeth are loose or can be extracted and where it is important that the teeth are not sectioned. **(J Forensic Odontostomatol 1994; 12: 6-11)**

Key words: Teeth, age estimation, dental radiographs

Running title: Non-destructive dental age estimation

INTRODUCTION

Estimation of an individual's age based on teeth may be used in studies of archaeological material for identification of an unknown dead body and occasionally in dealing with living individuals. Methods for age estimation employed in forensic cases usually require grinding of the tooth either according to the half-tooth technique[1] or by the preparation of thin sections.[2,3] These methods require that one or more teeth are destroyed which may be undesirable for cultural reasons or conservation requirements.

Of the six age-related changes in teeth first enumerated by Gustafson[2] in his pioneering work, the degree of attrition, periodontal retraction, root resorption and apical translucency can be assessed on unsectioned teeth. Apical translucency has been advocated for use as the only age-related change[4-6] or in combination with periodontal recession.[7]

Dental attrition continues throughout the functional life of the tooth. It is commonly used as an age indicator in archaeological studies of skeletal remains. However, great cultural and individual variations in attrition make this factor rather unreliable. Only a weak correlation with age has been found in a contemporary study,[8] and it has been claimed that prediction of an individual's age by scoring dental attrition is so imprecise that it is of little practical value.[9] Root resorption is considered to make little if any contribution to age estimation formulae, and other changes such as those in tooth colour are often too strongly influenced by external factors to be reliable.[10]

Secondary dentine deposition is a slow continuous process which gradually reduces the size of the pulp cavity,[11] and measurements of the width and length of this cavity may be taken as an indirect measurement of secondary dentine deposition.[12] These measurements may be made on dental radiographs which give information about the pulp cavity. It has been shown that the scoring system advocated by Gustafson[2] may be adapted for use on the radiographs to estimate age; the apical translucency has, however, then to be omitted.[13]

The purpose of the present study was to employ multiple regression analysis to find a method for dental age calculation by the use of measurements from macroscopic and radiographic examination of extracted, unsectioned teeth.

MATERIALS AND METHODS

A total of 452 extracted incisors, canines and premolars from a Caucasian population were chosen for this study, and measurements were made both on the teeth and on their radiographs. Since previous studies [5,12,14] have shown that there are no significant differences in age-related parameters between contralateral teeth of the same type, left and right teeth were pooled, but only one tooth from each individual was included in the analysis. Teeth which had been root-filled or had a crown restoration were not included, nor were teeth with root fractures, root resorption or class V fillings which overshadowed the coronal extension of the pulp on the radiographs, so that neither the width at the cemento-enamel (CE) junction nor the length of the pulp could be measured. The number of teeth of the various types is shown in Table 1. Most teeth were extracted in general dental practices, and for each tooth the reason for extraction was given by the practitioner. A few teeth were removed from corpses in forensic cases and after extraction the teeth were stored in 4% buffered formaldehyde solution. During examination a radiograph was taken with the mesio-distal plane and the long axis of tooth parallel to the film and the x-ray beam perpendicular to it. An Eggen holder[15] was fastened to the long cone of the x-ray unit and used to facilitate standardization. A Philips Oralix 50* X-ray machine was used, the film-focus distance being 22 cm and the exposure time 0.32 sec. Kodak Ultraspeed (DF-58)** film was employed and was developed according to the manufacturer's recommendations.

With a pair of vernier callipers the total root length from the CE junction to the apex on the mesial surface was measured on each tooth. The length of the translucent zone from the root apex was also measured, as described by Bang and Ramm.[4] The shortest distance from the CE junction to the attachment of the periodontal fibres was measured on the mesial surface of the root of each tooth. On the dental radiographs the length of the root on the mesial surface and the length of pulp were measured. The root and the pulp width on the radiographs were measured in a stereomicroscope with a measuring eyepiece, both at the CE junction and midroot half-way between the apex and the CE junction.

STATISTICAL ANALYSES

The measurements were entered into an IBM PS/2 portable computer together with information on the gender, the age of the patient when the tooth was extracted, and the reason for extraction. The statistical analyses were performed using the SPSS/PC+ statistical package.[16] The statistical program was employed to calculate the following ratios from the measurements on radiographs:

*FL = PL/RL
*FWCE = PWC/RWC
*FWMR = PWMR/RWMR

(*For abbreviations see list below*)

For each type of tooth an analysis of the mean values and ranges, using the Descriptives subprogram, was run. The Regression subprogram was applied to calculate the correlations between age and the other variables. The same program was employed in the multiple regression analysis, with age as the dependent variable. A stepwise procedure was used, with inclusion level at $p<0.05$ and exclusion level at $p>0.055$.

Tooth type	No	Mean age (yrs)	Age range (yrs)	Mean T (mm)	Mean P (mm)	Mean FWC	Mean FWM	Mean FL
Max 1	60	53.8	27-89	6.1	4.7	0.04	0.11	0.87
Max 2	38	50.3	12-81	5.8	5.5	0.08	0.12	0.92
Max 3	34	56.3	27-86	6.7	5.0	0.10	0.13	1.02
Max 4	53	40.3	13-90	5.6	2.9	0.07	0.06	1.02
Max 5	25	41.4	15-72	5.2	5.0	0.10	0.10	1.00
Mand 1	53	61.2	28-95	4.4	6.4	0.06	0.06	0.98
Mand 2	54	61.8	28-98	7.3	6.4	0.06	0.06	0.94
Mand 3	52	64.3	28-99	7.3	5.3	0.07	0.12	0.99
Mand 4	47	51.0	14-99	6.7	4.2	0.11	0.10	1.05
Mand 5	36	45.0	13-94	5.6	3.3	0.11	0.13	1.02

For abbreviations see list below

TABLE 1. Number of teeth, mean age, age range and the mean of the measurements for apical translucency (T), periodontal retraction (P) and of the ratios between the pulp and root on radiographs (FWC, FWM, FL).

*Phillips Medical Systems Inc. Rontgenstrasse, Hamburg, Germany.
**Kodak-Pathe. Zone Industrielle, 71102 Charlon-sur-saone, Cedex, France

LIST OF ABBREVIATIONS

T = apical translucency (mm)
P = periodontal retraction (mm)
FL= PL/RL
FWC = PWC/RWC
FWM = PWM/RWM
PL = pulp length on radiographs
RL = root length on radiographs measured on mesial surface
PWC = pulp width at CE junction on radiographs
RWC = root width at CE junction on radiographs
PMW = pulp width at midroot on radiographs
RWM = root width at midroot on radiographs

RESULTS

Descriptive statistics are shown in Table 1 and Pearson's correlation coefficients between age and the different measurements in Table 2. The ratio between the width of the pulp and the root on radiographs showed the strongest correlation with age. It was negative, implying an inverse relationship, but significant at the p<0.01 level for all types of teeth at the CE junction and for all except three types of teeth measured at midroot. The correlation between age and the ratios between the pulp and the root length was also negative, which produced significant correlations for all but three types of teeth, but for maxillary canines alone this correlation was stronger than that for the width ratios.

Periodontal retraction was significantly correlated with age for only two types of teeth, and apical translucency was significantly correlated with age for all except three types (Table 2).

Tooth type	T	P	FWC	FWM	FL
Max 1	0.27	0.01	-0.37*	-0.41**	-0.14
Max 2	0.20	0.25	-0.66*	-0.66**	-0.32
Max 3	0.26	0.30	-0.46*	-0.33	-0.48*
Max 4	0.62**	0.60**	-0.65**	-0.36*	-0.64**
Max 5	0.55*	0.76**	-0.71**	-0.65**	-0.57*
Mand 1	0.34*	0.02	-0.54**	-0.50**	-0.27
Mand 2	0.33*	0.12	-0.71**	-0.24	-0.51**
Mand 3	0.61**	0.07	-0.65**	-0.15	-0.50**
Mand 4	0.65**	0.29	-0.69**	-0.62**	-0.54**
Mand 5	0.66**	0.37	-0.64**	-0.71**	-0.40*

1-tailed Significance: *=p<0.01 **=p<0.001
For abbreviations see list.

TABLE 2. Pearson's correlation coefficients between age and apical translucency (T), periodontal retraction (P) and size of the pulp cavity (FWC, FWM, FL)

Tooth type	Formula	r	SEE
Max 1	Age=71.2-133.7FWM-56.OFWC	0.50	14.51
Max 2	Age=69.3-14.5FWM-63.OFWC	0.72	11.93
Max 3	Age=120.2-62.5FL	0.48	13.54
Max 4	Age=82.0-95.9FWC+2.OT+1.7P-50.6FL	0.83	10.15
	Age=112.6-85.OFWC+2.4P-116.3FWM-64.8FL	0.80	11.22
Max 5	Age=30.8+2.5P-96.OFWC+3.7T	0.90	8.48
	Age=36.9+2.9P-102.9FWC	0.86	9.70
Mand 1	Age=40.3-122.4FWC+4.4T	0.65	11.37
	Age=68.5-124.4FWC	0.55	12.54
Mand 2	Age=72.1-173.6FWC	0.71	12.54
Mand 3	Age=43.8-139.6FWC+3.8T	0.78	10.51
	Age=75.9-174.7FWC	0.65	12.73
Mand 4	Age=75.5-185.9FWC-105.4FWM+1.4P	0.78	13.71
Mand 5	Age=54.0-107.OFWM-97.OFWC+2.4T	0.82	13.14
	Age=80.0-192.7FWM-96.6FWC	0.77	14.35

For abbreviations see list.

TABLE 3. Formula for age calculation based on multiple regression analysis of the size of the pulp chamber on dental radiographs, the periodontal retraction and apical translucency. Where applicable, a separate equation is given exlcuding apical translucency. (SEE = standard error of the estimate).

The formulae derived from the multiple regression analyses with age as the dependent variable are shown in Table 3. Where applicable, separate equations are presented excluding apical translucency in cases where teeth cannot be extracted. The ratio between the width of the pulp and that of the root was included in the regression formula for all types of teeth except maxillary canines, where the ratio between the length of the pulp and that of the root was included. Periodontal retraction was included for three types of teeth and apical translucency for five. The strongest correlation between age calculated according to the formula and chronological age was found for maxillary second premolars when apical translucency was included, while the weakest was for maxillary canines.

DISCUSSION

The teeth examined in this investigation came from a variety of sources which may represent the state of the dentition in a normal population more closely than if only teeth free from signs of diseases had been selected. It may more strongly reflect the dental conditions found in forensic cases and possibly also those found in archaeological population studies.

The non-destructive method here presented may be applied in dry skeletal material, where single-rooted teeth are often loose in the jaw or can be removed with ease and repositioned. In corpses where the decomposition is not so advanced the teeth can be extracted, examined and then replaced in the socket.

Dental radiographs such as are processed daily in dental practices have so far found little use in age estimations. Their application for the measurements described above requires unsectioned teeth and is a simple means to obtain information about the size and form of both the root and the pulp cavity. A stereo-microscope at low magnification was employed in the present study to obtain more accurate measurements, but the results were obtained in a fairly short time compared to that required by methods where the teeth have to be sectioned.

The root and its pulp cavity are considered to be only slightly influenced by pathological processes affecting the crown and may remain for examination after trauma and fires. In the present study only the ratio between the length and width of the pulp and the root on radiographic film was used, in order to reduce the effect of a possible variation in the magnification and angulation. The mesio-distal plane of the tooth parallel to that of the film was chosen, so that periapical dental radiographs could be used in this method of age estimation. Experience has however shown that if the film is at an angle to the mesio-distal plane of the tooth, the ratio between the pulp and the root will be influenced, and the formulae for age calculations arrived at in this study are then inapplicable.

Dentine continues to be formed on the entire pulpal wall throughout the life of the tooth. After the eruption of the tooth the deposition of secondary dentine is slow, but gradually the size of the pulp cavity decreases.[11] The pulp width may be employed as an indirect expression of an increased amount of secondary dentine.[12] In the present study the correlation coefficients between age and the ratio between pulp and root measurements on radiographs were negative, confirming the inverse relationship, and for many types of teeth this relationship was somewhat strong. The results concur with those of another study where several methods and ways of measuring the size of the pulp cavity on half-sectioned teeth were examined.[12] A positive relationship with age would have been obtained if the ratio between the measurement of the root and that of the pulp had been calculated, but this would not have affected the interpretation of the results nor the applicability of the method.

In this study the width ratio showed a stronger correlation with age than the length ratio for all types of teeth except maxillary canines; this may indicate that the rate of deposition of dentine on the mesial and distal walls is more closely related to age than that on the roof of the pulp cavity. The same observation has been made in other studies of molars where the thickness of the dentine in the roof did not increase with age at the same rate as on the pulpal floor and on the walls.[17,18]

Apical translucency can be measured on non-sectioned roots which have been removed from their sockets. Of the six age-related changes described by Gustafson,[2] apical translucency has been considered to be the single factor most closely related to age.[3,19] In the present study the measurement of apical translucency on its own gave a surprisingly weak and, for three types of teeth, insignificant correlation with age. The correlation figures obtained in other studies were stronger and made a significant contribution to the regression.[3-5, 19-21] Low correlation coefficients have also been found in investigations of anterior teeth,[6,22] but stronger correlation has been obtained for premolars[6,23] and these concur with the results in this study. The teeth were stored in formaldehyde for a variable length of time - up to several years - before examination. The possible effect this storage might have on the extent of the translucent zone has not been examined in this or (to our knowledge) in any other study, but it may have influenced the results.

Periodontal retraction in the present investigation was found to be significantly related to age for maxillary premolars only. In a previous study[14] where the measurements were, as in this case, made on the mesial surface of the roots, the correlation coefficients were significant only for premolars from both jaws and for the mandibular premolars the figures were almost equal to those found here. Because of the lower number of teeth in the present study, however, the finding was not rated significant. The above mentioned investigation[14] tested several methods of measuring periodontal retraction and disclosed weak, but for some teeth significant, correlations. Its results may suggest that, if four sides of the root had been measured instead of only one, a slightly stronger correlation with age might have been obtained. Other studies using scoring systems have obtained correlation coefficients ranging from 0.49 to 0.72 for all types of teeth.[3,24] The fact that more than one tooth was taken from the same individual and that the mean age was lower for most types of teeth than in the present study might explain the stronger coefficients.

Two or more age-related factors have been used in many methods of age estimation.[2,3,7,20,21,25,26] The present study employed measurements from both the intact root and the radiographs. The regression formula obtained included the width and/or the length of the pulp cavity for all types of teeth, but the apical translucency was included for only five types. Most other studies include the apical translucency in the regression formula, whether the inclusion is tested for its significance or not.[2,3,7,20,21,25,26] Apical translucency and secondary dentine have previously been shown to make the most significant contributions to the regression formulae.[20,21] Periodontal retraction was included for maxillary premolars and mandibular first premolars. Periodontal retraction on its own was not found to be significant at the $p<0.01$ level for the latter type of tooth, but the inclusion may be explained by a less restrictive inclusion level in the regression and in addition by the fact that, as the regression proceeded, the partial correlation between age and the various remaining factors changed. In another study where multiple regression analyses were employed, periodontal retraction was included for maxillary second and mandibular first premolars alone;[21] this inclusion fits in with the results obtained in the present study.

The method of age estimation here described should be tested on an independant collection of extracted teeth from individuals of known age. Since the present radiographs were taken with the mesio-distal plane of the tooth parallel to the film and only relative measurements were used, the formulae presented in this study must only be employed on periapical radiographs taken with the same parallel technique. If age estimations of living individuals should be required, the formulae which exclude apical translucency may be employed and the periodontal recession could be measured on the radiographs, making an allowance for the inaccuracies included. Further studies should be carried out to assess the accuracy of age estimation from radiographs of living individuals.

In summary, this study demonstrates that radiographs may be utilized in dental age estimation, and also that apical translucency may not be such a reliable factor in age estimation as was previously found. The method may be employed when preservation of the material is requested, as in archeological studies and in forensic investigations in which the permanent removal of teeth from the jaw is undesirable. The correlation coefficients between the chronological age and the age calculated by the formulae were strongest for premolars and this may be an advantage, because these teeth are less prone to damage by trauma or fire and also more often retained in skeletal material.

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ACCURACY OF DENTAL REGISTRATIONS IN FORENSIC ODONTOLOGY AMONG DENTISTS AND DENTAL STUDENTS

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ABSTRACT

In forensic odontology, registration of dental characteristics is crucial in the identification procedure. It has been found that the most common errors made are incorrect registration of restorations and confusion about premolars and molars in both jaws. In an earlier study, dental students were observers and the charting was made without radiographs. However, in practical forensic work dentists make the registrations and radiographs are usually available. In this investigation eight dental students and eight dentists made registrations on ten excised macerated jaws with the aid of radiographs. The mean number of errors for each jaw for the students and the dentists was 4 and 3 respectively. The most common error among the dentists was incorrect registration of restorations, while errors on registrations of missing teeth were most common among the students. Even though the material in this study was limited, the results indicate the importance of re-examining the postmortem findings before the comparison with the antemortem data is done. Additionally, the forensic work should be performed by specialists. **(J Forensic Odontostomatol 1994; 12: 12-14)**

Keywords: Forensic odontology, dental registrations, dental students, dentists

Running title: Dental registrations in forensic odontology.

INTRODUCTION

In forensic odontology, registration of dental characteristics is a crucial step in the identification procedure. Earlier studies[1,2] have shown that when dental surgeons chart they may overlook structures or restorations. further, notes on paper about dental characteristics are not as reliable as radiographs because they rely on words or a diagram rather than the complete, graphic representation. The radiographs are thus very important because they provide an accurate, permanent and detailed record of findings in bone and teeth.[3,4]

In an earlier study of dental students' ability to register postmortem findings,[5] it was found that the most common errors were incorrect descriptions of restorations and confusion about premolars and molars in both jaws. In that study, no radiographs were available and only dental students were used as observers. However, forensic casework is done by dentists with the aid of radiographs and the aim of this study was to evaluate and compare the registrations of dental characteristics by students and by dentists with the aid of intraoral radiographs.

MATERIAL AND METHODS

Eight dental students from the fourth year of undergraduate dental education made registrations during a practical seminar as part of the course in forensic odontology. The other team comprised eight dentists working on the same excised, macerated jaws from the mortuary of the Department of Forensic Medicine, Goteborg. Three were forensic odontologists, one was an oral radiologist, one was a temporomandibular joint specialist and three were general practitioners. Five maxillae and five mandibles from deceased persons were used in the study.

The observers were asked to register missing teeth (ante- or post-mortem), positions of teeth, type and number of restorations and findings from radiographs, for example root fillings. The number of dental characteristics for each jaw varied between 16 and 20. The observers were provided with intraoral periapical radiographs of areas that contained teeth with restorations. Each tooth had more than one characteristic (range 1-4).

The observers were allowed to formulate their own criteria for the different parameters and there was a time limit of 2 hours for the procedure. The observers' registrations were compared with those made by two of the authors (HB & LR). If the observers did not register, made an incorrect registration or registered too many characteristics, it was judged as an error.

RESULTS

The number of dental characteristics that should have been registered on the five maxillae and the five mandibles was 187, i.e. some of the teeth had more than one characteristic. The mean number of errors for the dentists was 28 (range 16-35), the mean number of errors for the students was 40 (range 20-66) and the forensic odontology with the longest experience (27 years) made the least errors. The other two forensic odontologists made 19 and 29 errors respectively (the latter had only very limited experience). The general practitioners made 22, 24 and 33 errors whereas the TMJ specialist and radiologist made 34 and 35 errors respectively.

The most common errors among the dentists were incorrect definition of the extent of the restoration (66), confusion between molars and premolars (60) and no registration of restoration (40). The most common errors among the dental students were no registration of ante- and post-mortem lost teeth (83), no registration of restorations (63) and confusion of teeth (55).

DISCUSSION

The outcome of forensic work depends to a large extent on the quality of the postmortem material. Further, the reliability of the registrations depends on several factors including the examination methods available and the thoroughness and the experience of the observers. In an earlier study by Rasmusson and Borrman,[5] dental postmortem registrations were made by dental students without the aid of radiographs. As the practical forensic work is handled by dentists with special training in forensic odontology, it was of interest also to study the performances of dentists with and without a background in forensic odontology. The results from this study show that the overall performances of the dentists were superior to those of the dental students. It was, however, a small and selected group that was investigated.

In spite of the fact that radiographs were available, all the dentists made more errors on the tooth numbering (premolars and molars) than the students did. Nortje and Harris[6] stated that radiographs are especially valuable for the analysis of endodontically treated teeth, retained root tips and impacted teeth. since there were only two teeth which were endodontically treated in our material there were not many "hidden details" to be registered with the aid of radiographs. Also, incorrect definition of the extent of the restorations was more common among the dentists. This might be explained by different opinions about the anatomical borders of the teeth. The extension of a restoration can, for example, be recorded as a MOD instead of a MODB or *vice versa*.[7] In practical forensic work where definitions of restorations are difficult to detect, radiographs taken at different angles might be useful to help define their extent.

Three of the dentists in this study had special training in forensic odontology. Their results were, not surprisingly, the best among the dentists and their errors were mostly incorrect definition of the restorations. The results emphasize the importance of recording distinct definitions of restorations on dental charts and as stated by Clark[8], dentist members of mass disaster teams must receive detailed instructions concerning the completion of charts. Furthermore, it is not surprising that the inter-observer variability was significantly higher among the students, probably due to less clinical training.

"No registration" of ante- and post-mortem lost teeth was the most common error among the students. However, it has to be remembered that the dental students might not be familiar with words such as "ante- and post-mortem". Further, students have only very limited or no experience in evaluation of healing after ante-mortem extraction or post-mortem loss of single teeth, as was seen on the macerated jaws.

The most common error in dental chartings among dental students found in the earlier study by Rasmusson and Borrman[5] was incorrect registration of restorations and confusion about premolars and molars. In the present investigation this type of error was only the third most common. Furthermore, fewer errors concerning tooth migration might be explained by the fact that radiographs were available in this study and not in the previously mentioned investigation.

In this study the accuracy of dental registrations among the dentists and the dental students was not very good. However, the interobserver variability was significantly higher among the students, perhaps because of difficulties in following the instructions or understanding terminology. Additionally, the students are not used to working within strict time limits as the dentists are in their clinical work. The dentists who made the most errors were two specialists in other fields, i.e. oral radiology and stomatognathic-physiology. their high number of errors could be explained by the fact that they do not perform general dentistry, which includes charting on a daily basis.

In conclusion, the results from this study show that special training in forensic odontology is crucial for the reliability of the identification procedure. Although this investigation did not show that the performances of the observers were improved by using radiographs the legal implications of using radiographs cannot be disputed.

It is also advantageous if the forensic odontologists work in pairs when doing the dental chartings as is recommended and practised in mass-disaster identifications.[8,9] The odontologists can then check each others' performances before the signed statement of an identity of an individual is made.

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THE HELDERBERG AIR DISASTER - FORENSIC ODONTOLOGICAL INVESTIGATIONS

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ABSTRACT

A Boeing 747-224B Combi of the South African Airways, the "Helderberg", crashed into the sea near Mauritius on 28 November 1987. All 159 people on board died and dental tissues were present in only eight of the 15 lots of human remains recovered. Ante-mortem dental records were collected by a team in Johannesburg while the post-mortem examinations were conducted in Mauritius.

The special circumstances surrounding an accident at sea resulted in the low number of bodies available for identification procedures. Of the eight remains which included dental tissues, five were identified by means of simple dental restorations, advanced dentistry, anatomical features of teeth and stages of development of teeth. One of the victims was identified by a process of exclusion and radiographic evidence played a decisive role in the identification process. **(J Forensic Odontostomatol 1994; 12: 15-18)**

The variety of record-keeping styles and abbreviations used in different countries posed a major problem during the process and it is concluded that international standardization in record-keeping requires urgent attention.

Keywords: Mass disaster, dental identification, dental records, forensic odontology

Running title: Mass disaster victim identification

INTRODUCTION

The identification of victims of aircraft accidents poses many problems, but a variety of procedures, methods and techniques has been established to address them.[1-3] The important role played by dental means in identifying victims of these accidents is indisputable, but perhaps not so widely appreciated. The number of cases in which dental identification is playing a significant role in disaster victim identification is growing, but varies from only a few[4] to the majority of identified persons,[5-6] depending on circumstances such as time, degree of mutilation and fragmentation, burning, decomposition and the extent, type and location of the accident. The purpose of this report is to present the special circumstances and experiences surrounding the Helderberg crash. This was only the second major disaster in the history of the South African Airways, the first being the Windhoek aircrash in 1968[7] in which 123 people were lost and dental records contributed to the identification of 25% of the victims.

THE HELDERBERG AIR DISASTER

A Boeing 747-244B Combi of South African Airways, the "Helderberg", flight SA 295, departed from Taipei's Chiang Kai Shek airport on 27 November 1987 for Plaisance airport, Mauritius. At about 00h07 on 28 November 1987 the aircraft crashed into the Indian ocean, some 134 nautical miles north-east of Plaisance airport[8] killing all 159 people on board. The identification team was activated within 12 hours and the medico-legal investigations commenced on 29 November 1987.

IDENTIFICATION PROCEDURES

A. Retrieval of Bodies

A total of 15 lots of human remains was recovered and presented for post-mortem examination[8] and identification procedures. All the material was recovered within the first seven days after the accident and transferred to the well-equipped mortuary at the SSRN Hospital in Mauritius.

B. Ante-Mortem Records

A team of dentists and auxiliaries operating from an office at Jan Smuts Airport, Johannesburg, South Africa, was responsible for the collection of the dental records of the victims. All were transferred to standardized charts, from which facsimile copies were made and sent to the post-mortem team in Mauritius where a total of 135 ante-mortem records was compiled. Records of the remaining 24 victims could not be traced. Updating of records took place as additional information was received.

C. Post-Mortem Identification Procedures

Following the general post-mortem of the bodies, dental examinations were performed. The low number of bodies retrieved allowed two teams of two dentists each to chart and radiograph all the oral tissues. The post-mortem findings were then compared to the ante-mortem records and whenever possible radiographic evidence was used as the final basis for identification.

Apart from the dental records received from the ante-mortem team, a considerable amount of dental information was provided to the post-mortem team by victims' families. Although some of this information was useful, it was mostly disjointed and sometimes difficult to interpret (Fig. 1).

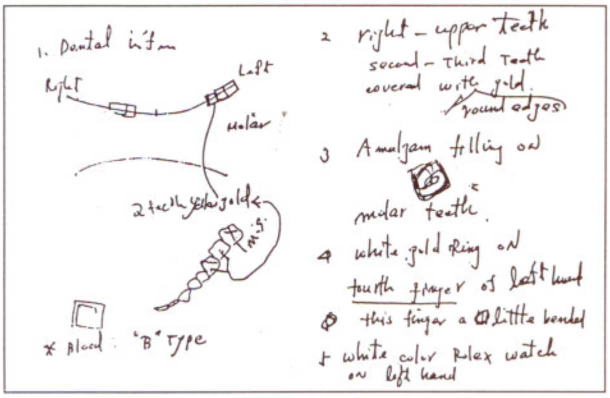

Fig. 1. Handwritten dental and other information of one of the victims as provided by his family.

While the dental team was waiting for bodies to be brought into the mortuary, the ante-mortem records were grouped according to gender, age, complete denture wearers, partial denture wearers, extent of dental treatment, country of origin, etc. Standardized charts were used both for the ante- and post-mortem records, but colour coding distinguished the one from the other.

D. Results of Identification Procedures

The impact of the crash resulted in severe mutilation of bodies and in some instances only fragments of the jaws were available for examination. As a result of the special circumstances (an accident at sea) only 15 (9.4%) bodies (or parts thereof) were recovered. Of the 8 bodies examined and containing oral structures, 5(62.5%) were identified. Dental evidence was the sole means of identification with the exception of one, where distinctive jewellery made a minor contribution. Of the three that were not identified, one had no dental restorations, one had only a single restoration, while the third had had extensive dental treatment. However, the ante-mortem information in the latter case was inconclusive.

The following is a selection of the more noteworthy identifications:

Body No. 1

Both the maxilla and mandible showed fractures but all tooth bearing parts of the jaws were available for examination. A total of 29 dental procedures were demonstrable, including root canal treatments, veneer crowns, post-crowns, pin-reinforced restorations and a partial denture. Dental records of Ms A consisted of only 6 radiographs that were taken of the distal parts on one side of the jaws. No records were available of the rest of the teeth, or of a partial denture. Comparison of the ante- and post-mortem records showed four outstanding corresponding features, including two post-crowns, a pin-reinforced restoration and a dental composite restoration (DO) on a premolar, as well as eight ordinary features. Despite the sparse ante-mortem records that were available, positive identification was possible.

Body No. 2

The available post-mortem material demonstrated only one dental restoration and two cavities where amalgam restorations had probably been present. A primary canine tooth, first and second primary molars and first permanent molar were present on the one side of the mandible and a second primary molar and first permanent molar on the other. Several partially developed teeth in different stages of development could be demonstrated on radiographs (Fig.2).

Fig. 2. Radiographs of the lower jaw of Body No.2. Note the fully-erupted first permanent molars and other permanent teeth in different stages of development.

On the basis of the stages of development of the teeth present the age of the victim was estimated to be 6-8 years. According to the passenger list and information provided by the airline, there were only two children on the flight. The one was a baby of 15 weeks and the other, a girl of six years and three months. By a process of elimination (exclusion), Ms E was positively identified.

Body No. 3

A total of 23 dental restorations and procedures could be seen at post-mortem examination. Extensive crown and bridge work was present, as well as root canal treatments with root canal fillings on mandibular central and lateral incisors. Comparison of the dental records of one of the passengers showed nine corresponding features with the post-mortem findings, including five white metal crowns. Dental treatment which could not be demonstrated on the post-mortem material (Fig.3) had been carried out on five teeth belonging to Mr F, e.g.

Mr F
Post-mortem - Body No.3

18* extracted	18 present and crowned
14 metal crown	14 occlusal amalgam restoration
11 Dental composite restoration	11 anatomically sound (unfilled)
21 Dental composite restoration	21 anatomically sound (unfilled)
34 MO Amalgam restoration	34 anatomically sound (unfilled)

*Teeth are numbered according to the FDI two digit numbering system.

On grounds of available dental records, it was thus not possible to identify body No.3.

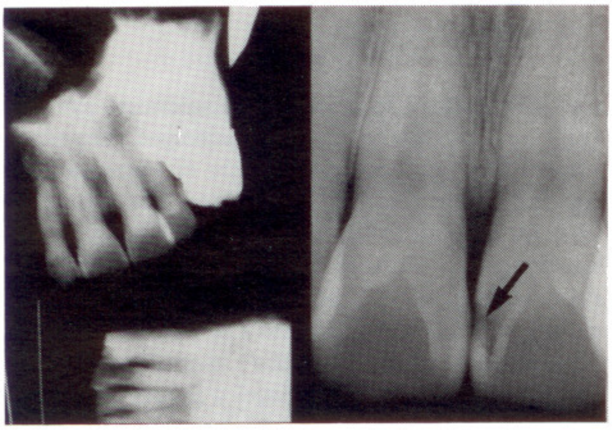

Fig. 3. Comparison of the anterior maxillary teeth of Mr. F. (right) and Body No. 3 (left). Note the cavities on the teeth of Mr. F. (arrow) and the anatomically sound corresponding teeth of Body no.3.

DISCUSSION

The special circumstances surrounding an aircrash at sea[9] became obvious soon after the investigation commenced. Submersion of the aircraft and its contents resulted in the low number of available victims for identification and although decomposition was not advanced, mutilation of the bodies was extensive.

All five identifications achieved were by means of dental characteristics and the importance of dental restorations in the identification of mass disaster victims was clearly demonstrated.[10,11] Simple dental restorations as well as advanced dentistry played an important role in the procedures, as did anatomical and developmental features of the teeth. In four of the five cases identified radiographs played a decisive role and their value should never be under-estimated. The ante-mortem records were generally of reasonable quality and in some cases excellent but the sketchy information provided by families of victims, while in some cases useful, was sometimes frustrating because it was incomplete.

International major disasters, where people from different countries are involved (10 countries in this case), present enormous problems regarding dental records. A vast number of different styles of record keeping, tooth numbering systems and abbreviations resulted in hours spent on interpretation and standardization of records. The experience gained from this investigation emphasizes the need for international standardization in dental charting and record keeping. The International System (Federation Dentaire International), where each tooth is identified by a two digit number,[12] was the system used in most instances and we unreservedly support it as the system of choice for international standardization.

The post-mortem medico-legal team was well organized and the dental team was an established part of the investigation from the start. The communication systems were also of high standard and despite the problems experienced with facsimile transmission of information,[13] the identification process was completed without any problems. In all cases where positive identification was considered probable, the original records were viewed by the post-mortem team for authentication.

CONCLUSIONS

1. The special circumstances surrounding an accident at sea resulted in the low number of bodies available for identification.

2. Dental identification played a decisive role in all the identification procedures.

3. Simple and advanced dentistry, as well as anatomical and developmental features of teeth, formed the basis of the identification process.

4. Radiographic evidence played a major role in the identification process.

5. International standardization in record keeping requires urgent attention.

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THE DUTY OF THE DENTIST TO KEEP RECORDS - SIGNIFICANCE AND RELEVANCE ACCORDING TO GERMAN LAW

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ABSTRACT

A dentist is duty-bound to keep dental records. The keeping of accurate records is in fact a legal obligation and an integral part of the medical or dental contract which can be used as evidence in court and a patient has the right to inspect and to take possession of the objective information contained in the records. Incomplete or inadequate records lead to a reversal of the burden of proof in German jurisdiction. **(J Forensic Odontostomatol 1994; 12: 19-20)**

Key words: Dentistry, medical law, dental records.

Records describing the treatment of a patient date back to the early beginnings of medicine and dentistry. They are necessary in making the diagnosis and therapy coherent and complete. Fundamental changes, however, have taken place in recent times in the legal classification, function and character of dental and medical records.[11] In the begining they were considered merely as a memory aid for the clinician but in 1978 the German Federal Court of Justice passed a judgement setting a legal precedent that changed this point of view completely.[2] The Federal Court judged that the records should not only be considered as the personal notes of the clinician, but should also cover objectively the observations found during the examination or treatment of the patient. The necessary standard of care, laid down in § 276 of the German Civil Code (BGB)[9], was thus extended to the record keeping of the clinician. The standard for dental and medical records is therefore now a full and objective description of the treatment and examination of the patient, instead of simply a memory aid.[10]

The prevalent opinion today is that the duty to keep records is a contractual commitment.[12] The legal importance of this duty to keep records becomes obvious in dental and medical law suits. In cases of negligence or malpractice, the burden of providing proof is laid on the shoulders of the patient, which is often very difficult.

In German civil law each party has to prove that the preconditions of the claim are fulfilled. The party that sets a claim for damages has to prove that there has been a fault, damage and a causal connection between fault and damage. When the facts of the case cannot be proved by the party that has the burden of proof (plaintiff), a judgement of '*non liquet*' is passed (i.e. unsolvable) and the party that has the onus of proof loses the case.

A claim that a clinician acted negligently, causing injury during treatment may be very difficult to prove because of a lack of expertise. If the records can be consulted the facts can be clarified and the case becomes simpler. It would be unfair to the patient if the rules of the onus of proof were invoked when these records are missing or incomplete.

For these reasons, the principle of burden of proof has been simplified by legislation. In cases in which one litigant intentionally impedes or prevents access to the evidence by the other party, the burden of proof can be completely reversed.[7,13] This applies in particular when a clinician neglects to keep current records (incomplete, inconsistent or behind schedule). Each clinician involved in a law suit with a patient is duty-bound to submit their records to the court and if they fail to do so or if the records are incomplete or inconsistent, a judgement of 'non liquet' is passed and they will lose the case. The practitioner has now to prove that they acted as a reasonable practitioner, even if complete records of a particular treatment were not kept.

The Federal Court of Justice further simplified the responsibility of the patient in 1982 when it granted the right to inspect and take possession of his/her dental and medical records and radiographs, within or beyond the scope of a law suit.[1,3,4] A clinician may not challenge this right to access the objective findings contained in the clinical record. The Court based its opinion, referring to the German Constitution, on the fundamental right of self-determination of the patient and their right of personal dignity.[6]

All clinicians have a clear and contractual duty to keep correct and complete records of their patients.[14] This means: a complete anamnesis including special features issuing from it, such as allergies, predisposition to specific illnesses, medical risks as a result of previous illnesses or accidents, clinical findings, radiographs, results of laboratory tests, diagnosis, therapeutic measures taken, advice and recommendations to the patient, especially the explanation of the nature and the gravity of intended measures for the therapy and the patient's informed consent. All this has to be done in a methodical and chronological order.

The treatment can then easily be reconstructed from the medical record, avoiding complications and confusion. The less routine and more complicated the treatment the more detailed the documentation has to be. Whereas keywords may be sufficient for ordinary treatment, detailed recording may be essential in risky or complex cases.[5] The need for accurately kept records can no longer be questioned. The legal aspects of the patient-dentist relationship are becoming more and more important and patients do not hesitate any longer to take legal proceedings against their clinicians. Accurate dental records will then protect the lcinician against unjustified claims for damages by dissatisfied patients. Given that, ideally, the clinical records should be of the highest standards the Court gives credit and is satisfied by adequate ones. Well kept records are a strong source of evidence and, in the Courts' view, will not readily be contradicted by a patient.

The keeping of dental records is not a tedious choice, but an indispensable part of patient care. It is not only a form of quality assurance but also a very important weapon in the event of a law suit. May the legal relevance of good record keeping always remain a purely hypothetical matter!

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