ISSN 2219-6749

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The Journal of Forensic Odonto-Stomatology

Volume 25, n. 1 - Jun 2007

OFFICIAL PUBLICATION OF THE
INTERNATIONAL ORGANIZATION FOR
FORENSIC ODONTO-STOMATOLOGY

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THICKNESS OF THE DENTAL (RADICULAR) CEMENTUM: A PARAMETER FOR ESTIMATING AGE

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ABSTRACT

The present study used 127 extracted teeth from people aged 16 to 90 years old. The aim of this research was to verify the reliability of the method using a single dental parameter based on the correlation of the radicular cementum thickness and the chronological age of the subject. The thickness was measured both on the lingual side and on the vestibular side of the tooth, at two different levels: apex and one third of the root length from the apex. The data were reported through a Cartesian graph with the X-axis showing the cementum thickness and the Y-axis showing the subject's age. The correlation between age and the increase of the cementum thickness is more statistically evident when the measurement is taken at the apex (R^2=0.67), in comparison with the measurement taken at approximately one third of the root length from the apex (R^2=0.56).
(J Forensic Odontostomatol 2007;25:1-6)

Key words: dental, cementum thickness, age estimation, identification

INTRODUCTION

The importance of using dental methods to identify unknown cadavers is well known, so the role of histological modifications of the teeth is relevant in ageing. Many different methods have been studied and proposed for ageing unknown deceased people.[1-23] The cementum increase represents the most relevant way of exhibiting histological modification that occurs to the teeth during the subject's life.[24,25]

Many authors have described the contribution and importance of the cementum in studies that use one or multiple dental parameters.[26-28] The aim of this research was to verify the reliability of the method using a single parameter based on the correlation of the radicular cementum thickness and the chronological age of the subject.[29,30]

MATERIALS AND METHODS

The present study used 127 teeth, extracted from different individuals involving both sexes (67 females and 60 males) and various ages (range from 16 to 90 years old). The dental samples were collected in a general dental surgery, subsequent to clinical dental treatment planning for various conditions (mostly periodontal pathologies or orthodontic therapy).[31] None of the samples presented fillings or endodontic treatments. After the teeth were extracted, they were washed using only running water. Detergents and disinfectants were not used since they may alter the histological characteristics. A diamond cutter was used to mark the vestibular side of the tooth. The teeth were stored in rigid containers filled with a decalcification solution for an average of 15 days (minimum 10 maximum 25). The decalcification time depends on the size of the teeth: about 10 days for the smaller teeth including incisors and about 15 days for the molars. After decalcification, the samples were removed from the liquid and placed in paraffin wax. Using a microtome, sections were cut longitudinally at a thickness of 5 micron, in lingual-vestibular direction, passing through the radicular apex. Since some multi-radicular samples present difficulties in cutting due to the natural curve of the roots, a section of each root was prepared; the section was chosen based on the best visualization of the apex. Sections were then coloured with a hematoxylin-eosin stain and observed through an optical microscope equipped with an eyepiece micrometer magnification X4.*

The thickness was measured both on the lingual side and on the vestibular side, at two different levels at the apex and at the one third of the root length from

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the apex. Using methods described by Solheim,[8] these measurements were labelled as follows:

- C1: lingual side, at one third of the root length from the apex;
- C2: vestibular side, at one third of the root length from the apex;
- C3: lingual side, at the apex;
- C4: vestibular side, at the apex.

Data were reported through a Cartesian graph with the X-axis showing the cementum's thickness and the Y-axis showing the subject's age. Using standard descriptive statistical methods of linear regression, the data were inserted into the regression formula to obtain the predicted age.[32] The regression model (3rd degree polynimial) seemed to give approximate reliable data to describe a plausible mathematical correlation between the cementum thickness and age. The model provided a two-fold analysis: descriptive-explanatory and predictive. The descriptive-explanatory analysis examined the correlation between Y (age) and X (thickness). The predictive analysis targeted predicting the chronological age of the subject, when the cementum thickness is known. Since there is a difference in the mean thickness value at the two levels (the cementum thickness at the apex is usually the thickest) the analysis was conducted by separating the measurements at the C1-C2 level and those at the C3-C4 level.

RESULTS

To obtain a regression equation[33,34] using all of the collected samples, we first calculated the average value of cementum thickness at the C3-C4 level

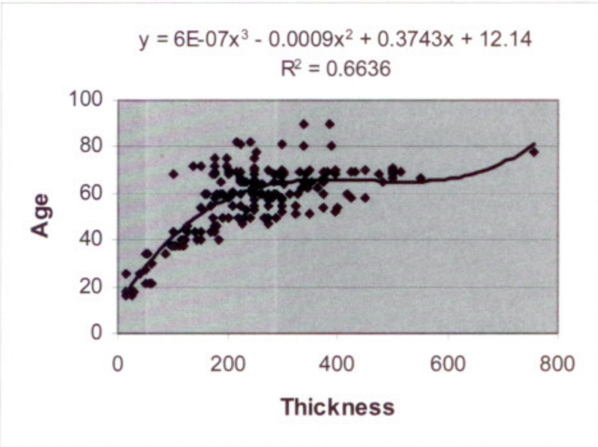

Fig.1: Relationship of chronological age and cementum's thickness at the apex

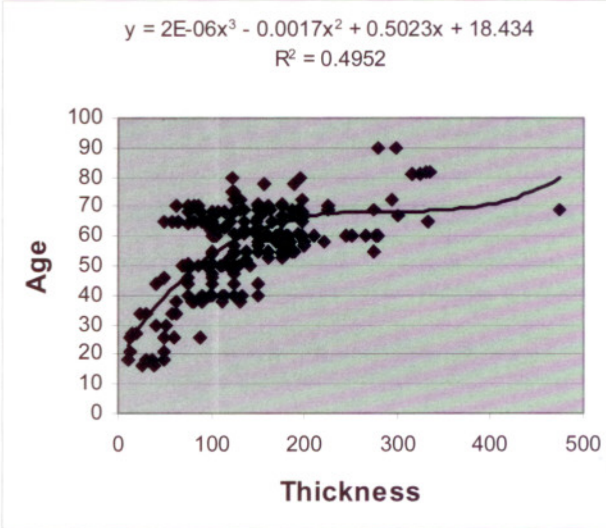

Fig.2: Relationship of chronological age and cemetum's thickness at the C1-C2

($\bar{x}$ = 243.7) and the mean age of subjects ($\bar{y}$ = 57.2), then we mathematically minimized the distance of data points from the 3rd degree equation, obtaining the following equation:

$$y = 6 \cdot 10^{-7} \cdot x^3 - 0.0009 \cdot x^2 + 0.3743 \cdot x + 12.14$$

with R^2=0.66 while the correlation coefficient of Bravais-Pearson (r) was 0.68.

The estimated age for the average thickness value ($x=\bar{x}$) resulted equal to 58.6 years ± 1.49 years with the range of the reliability at 95%. Fig.1 shows data from the entire sample at the apical position (C3,C4). The variation of the confidence interval depending on the average deviation is shown in Table 1.

Similar analytical procedures were applied to the values obtained at one third of the root length from the apex. From the 254 measurements at this level, the following regression equation was obtained:

$$y = 2 \cdot 10^{-6} \cdot x^3 - 0.0017 \cdot x^2 + 0.5023 \cdot x + 18.434$$

with R^2=0.49.

Figure 2 shows data from the entire sample at one third of the root length from the apex (C1,C2). In Table 2 the values of the confidence intervals are reported in relationship to the average deviation ($\bar{x}$ = 134.6) obtaining a determination coefficient of the Bravais-Pearson formula equal to 0.61. Similarly,

***Table 1:** The confidential interval and limits of reliability at the C2-C4*

Average disparity	Estimated Age	Range of reliability interval	Range of age
0	58.6	1.49	57.1-60.1
100	58.8	1.71	57.1-60.5
-100	49.1	1.71	47.4-50.8
200	53.4	2.24	51.2-55.7
-200	26.8	2.24	24.6-29.1

***Table 2:** The interval of reliability and limits of reliability at C1-C2*

Average disparity	Estimated Age	Range of reliability interval	Range of age
0	47.7	1.62	54.1-57.3
100	45.3	2.40	42.9-47.7
-100	33.8	2.40	31.4-36.2
134.6	34.4	2.89	31.5-37.2
-134.6	18.4	2.89	15.5-21.3

the same procedure was individually applied to each type of the dental samples (see Table 3).

Incisors

Forty two incisors were analysed (168 measurements), 16 mandibular incisors and 26 maxillar incisors. The correlation values are rather satisfactory for the C1-C2 incisors measurements of both arches and for the C3-C4 values in the upper incisors. On the contrary the correlation index is meaningless in reference to measurements of the lower incisors at the apex (C3-C4).

Canines

Thirty two canines were analysed (128 measurements), 14 lower canines and 18 upper canines. Both the upper canines' measurements and lower canines' apical measurements demonstrated to be reliable enough for showing a correlation. The measurements of the lower canines at C1-C2 level did not show a strong correlation with age.

Premolars

Fifteen premolars were analysed (60 measurements), 6 lower and 9 upper in total. The upper premolars at the two different root levels and lower premolars at C1-C2, showed a good correlation between the cementum thickness and age factor.

***Table 3:** 3rd degree equation, correlation coefficient (R), determination coefficient (R^2) for each kind of tooth*

			Equation	*r*	R^2
Incisor	*up*	*ap*	$y = -9E-07x^3 + 0.0005x^2 + + 0.0424x + 36.583$	0.53	0.43
		mid	$y = -5E-07x^3 + 0.0002x^2 + + 0.1224x + 40.89$	0.60	0.36
	low	*ap*	$y = 3E-06x^3 - 0.0027x^2 + +0.8542x - 20.582$	0.09	0.07
		mid	$y = -3E-07x^3 + 0.0006x^2 + -0.1554x + 71.473$	0.47	0.45
Canine	*up*	*ap*	$y = 2E-06x^3 - 0.0017x^2 + +0.5735x - 0.7459$	0.58	0.59
		mid	$y = 2E-05x^3 - 0.0107x^2 + +1.6687x - 27.237$	0.58	0.49
	low	*ap*	$y = 9E-07x^3 - 0.0011x^2 + +0.4679x + 3.2203$	0.65	0.64
		mid	$y = -1E-05x^3 + 0.0065x^2 + -0.8259x + 91.051$	0.18	0.16
Premolar	*up*	*ap*	$y = 1E-07x^3 - 0.0006x^2 + +0.3641x + 8.3435$	0.85	0.88
		mid	$y = -6E-07x^3 - 0.002x^2 + +0.759x - 4.2603$	0.84	0.76
	low	*ap*	$y = -2E-05x^3 + 0.0204x^2 + -6.1736x + 659.47$	0.47	0.42
		mid	$y = -6E-05x^3 + 0.0338x^2 + -6.6545x + 483.32$	0.84	0.76
Molar	*up*	*ap*	$y = 3E-06x^3 - 0.0024x^2 + +0.6656x + 2.265$	0.53	0.47
		mid	$y = 3E-07x^3 - 0.0006x^2 + +0.2764x + 31.659$	0.61	0.51
	low	*ap*	$y = -3E-06x^3 + 0.0025x^2 + -0.4955x + 72.982$	0.70	0.69
		mid	$y = 9E-06x^3 - 0.0035x^2 + +0.433x + 37.401$	0.26	0.12
Third Molar	*up*	*ap*	$y = -7E-07x^3 + 0.0003x^2 + + 0.0664x + 25.076$	0.98	0.99
		mid	$y = -5E-05x^3 + 0.011x^2 + -0.4821x + 30.786$	0.95	0.98
	low	*ap*	$y = -0.0008x^3 + 0.0906x^2 + -2.8602x + 45.677$	0.33	0.22
		mid	$y = 0.0003x^3 - 0.0465x^2 + +1.897x + 5.1987$	0.05	0.32

Molars

Sixteen molars were analysed (64 measurements), 6 mandibular and 10 maxillary samples. The prediction of the molars demonstrated fairly satisfactory results for the maxillary samples and the lower at C3-C4. It was determined to be less reliable for the lower at the C1-C2.

Table 4: *Average values of the statistical parameters: R, R^2*

	r_{av}	R^2_{av}
Upper at C3-C4	0.69	0.67
Upper at C1-C2	0.72	0.62
Lower at C3-C4	0.57	0.56
Lower at C1-C2	0.36	0.36

Table 5: *Prediction efficiency of the method considered for the entire sample*

	Prediction Affidability		
	< 5 years	**< 8 years**	**< 10 years**
C1-C2	28%	51%	64%
C3-C4	37%	58%	71%

Third molars

Twelve third molars were analysed (48 measurements), 7 lower and 5 upper molars. The results from both measurements of the upper third molar demonstrate a determination coefficient at almost 1.0. Despite this excellent result we must note the scarcity of the third molar samples. Whereas, the measurements at both levels of the lower third molar show a very low correlation between cementum thickness and age.

DISCUSSION

The statistical analysis conducted on the variation of the radicular cementum thickness and the age increase suggested an interesting relationship between the two variables. Table 4 shows the average values of the statistic parameters (*r*, R^2) referring to the different points of measurements. Generally, the correlation between age and the increase of the cementum thickness seems to be more statistically evident when the measurement is taken at the apex (R^2=0.67 for the upper at the C3-C4 level and R^2=0.56 for the lower at the C3-C4 level), rather than at the one third of the root length from the apex (R^2=0.62 for upper at the C1-C2 level and R^2=0.36 for lower at the C1-C2). In particular, the different types of teeth samples do not provide the same capacity in predicting age.

The incisors show interesting values of the determination coefficient even if not quite significant, although the measurements taken at the superior level of the upper root and at the lower one third of the root from the apex appear more predictive (R^2=0.43 and R^2=0.45 respectively) than the other measurements. The canines seem to be slightly better than the incisors in the predictive ability at both levels especially referring to the measurements taken of the upper and lower canines at C3-C4, while the lower canines at the C1-C2 level appear to be not significant for predictive ability (R^2=0.16). The upper premolars cementum thickness (at both levels) and the lower premolars at one third of the root from the apex shows a very good correlation with age augmentation (R^2=0.88, R^2=0.76 and R^2=0.76 respectively). We may suppose that such a high determination index is due to the fact that all ages (16 to 70 years) are homogeneously represented in the sample of this kind of tooth. It could be deduced for other teeth samples (i.e. mandibular incisors) the lower value of the determination coefficient is due to the small range of subjects' age in our sample. The molars, like the canines, show a better predictability at the C3-C4 level in the jaw (R^2=0.69 at the apex). The relationship between age and cementum thickness for uppers molars appears to be suggestive (R^2=0.47 for upper molars at the apex and R^2=0.51 for the upper molars at the one third of the root from the apex) but not completely significant. The upper third molars appear to be the most significant tooth in age predicting (R^2H=1). This interesting result

Table 6: *Prediction efficiency for the most significant teeth*

	C1-C2		
	<5 years	**<8 years**	**<10 years**
Lower incisors	63%	91%	97%
Upper molars	33%	56%	72%
Upper premolars	44%	69%	81%
Upper third molars	60%	90%	100%

	C3-C4		
	<5 years	**<8 years**	**<10 years**
Upper incisors	37%	53%	63%
Lower molars	50%	71%	71%
Upper premolars	87%	87%	87%
Upper third molars	100%	100%	100%

should be confirmed on a larger population, since our sample size involving this type of tooth was distributed on a small age range; furthermore, the results for the lower third molar are not significant.

An additional consideration emerged from all of the dental samples used (see Table 4): the upper teeth were found to be significantly more reliable than lower teeth. The statistic model that we used (3^{rd} degree polynomial) proved a good correspondence between the experimental and the theoretical data. Thus, the findings conclude a good estimate of the subject's age can be determined by cementum's thickness measurements, even if the subject is less than 25 years old since these finding are slightly overestimated.[35]

Finally, the observation pointed out from Table 5 is very interesting and indicative of the efficiency of the method we used. This table shows the probability of having a good estimate of the age through measuring the tooth (upper and lower level) at the apex and at the one third of the root length from the apex (C1-C2-C3-C4). These proportions are better if the tooth used is the upper molar and/or the upper third molar. In Table 6 the prediction efficiency is shown only for the most significant teeth.

We must note that this kind of approach needs further study by increasing the sample population size and the age range diversity to be considered reliable.

CONCLUSION

The histological method and the statistical tools presented in the study respect all scientific methods including objectivity, repeatability, verification, elaboration, and interpretation of data. Furthermore, the used method was especially simple due to standard laboratory instruments, which reduced work hours in comparison with methods that do not use non-calcified dental samples. It is important to consider the gains in using standard forensic practices on a daily basis to conduct histological procedures and statistical foresight of age in a low cost way such as in this study. The results are seemingly satisfactory and reliable and can be utilized as a helpful age estimation tool.

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IDENTIFICATION OF SEX USING CRANIAL BASE MEASUREMENTS

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ABSTRACT

It is well known that the skull provides elements for sex identification. Twenty-two bones form the cephalic cranium and they are divided into *neurocranium* and *splancnocranium*. This research aimed to study different characteristics between skulls from both sexes by evaluating the following measurements: mastoid notch to incisive foramen (right and left side); mastoid notch to mastoid notch; and incisive foramen to basion. In order to do so, two hundred skulls were selected (100 males and 100 females), with information about the age of the subjects (20-55 years old), sex and ethnic group known according to records at the *Imaculada Conceicao Cemetery*, located in the city of Campinas, Sao Paulo State, Brazil. Measurements were taken using a digital calliper. The results were subjected to a statistical analysis (logistic regression and discriminate function) and showed dimorphic characteristics within the measurements. A formula with 79.9% accuracy was established for sex identification (*logito* = 25.2772 – 0.1601 x incisive foramen to basion – 0.0934 x mastoid notch – mastoid notch). The authors have concluded that the method is efficient and suitable for anthropology and forensic purposes. The research also showed that the analysis may be carried out using a practical computer program.

(J Forensic Odontostomatol 2007;25:7-11)

Key words: cranial base, skull measurements, sex characteristics, forensic dentistry

INTRODUCTION

Skulls of children and teenagers show only slightly pronounced qualitative characteristics which provide little information for sex identification.[1-3] After puberty, hormones, environment and muscle activity contribute to human skeleton development. Different characteristics between sexes may be noticed such as prominences, bone crests, apophysis and other structures showing sexual dimorphism. Such aspects are more noticeable in males, with the females showing more delicate and less pronounced details.[4-9]

Arbenz[10] stated that the human growth process normally ends between 22 and 25 years of age, and it may be influenced by nutrition, ethnic origin and socio-economic status. However, the accuracy of sex identification depends on the number and nature of the bones examined. According to Simonin[11] examination of a single bone aspect may lead to a result that can be different in the same bone. Therefore as much information as possible must be collected from the bone to increase the accuracy of the findings.

Comas[4] and Coma[1] also found that cultural activities must be considered when evaluating characteristics, especially those concerning work distribution and activities amongst the social group in question. They concluded that it is rare when identification of sex cannot be established. This is in accordance with the findings of Correa-Ramirez[12], who concluded that it is possible to achieve a level of 75 to 80% accuracy by cranium examination alone.

There are different anthropometric characteristics among ethnic groups which must be known in order to identify sex.[1] Due to a 500-year history of miscegenation, pure races in Brazil have become almost extinct. Nowadays different anthropological characteristics are less distinct than during the colonization period. The use of the *skin colour* rather than *ethnic group* in population surveys demonstrates this fact.[10, 13]

Research about sex identification is very important since it may eliminate approximately fifty percent of the subjects in human identification processes. Qualitative studies of skulls may establish the sex of the subject. However, the skulls sometimes lack important parts such as *neurocranium* and *splancnocranium* due to circumstances associated with the condition of the remains, such as victims of crime or disaster. This may represent a problem for sex prediction.

Considering that the cranial base is preserved in most cases, and anthropometric studies of this specific portion do not exist, this study aimed to investigate the different characteristics between sexes using the base of the skull.

MATERIALS AND METHODS

Sample selection consisted of 200 skulls of both sexes. Height, skin colour and age (20 to 55 years) were previously known and all data were collected, with permission, from the *Imaculada Conceicao Cemetery*, in the city of Campinas, State of Sao Paulo, Brazil. The research was approved by the Ethical Committee of the Dentistry School of State University of Campinas, which follows international guidelines for human research.

The skulls were selected according to location and the criteria of age and integrity. Skulls showing severe growth anomalies (eg: plagiocephaly) were excluded.

Distance measurements were taken using a digital calliper*, as follows:

- Distance between the anterior root of the mastoid notch and the incisor foramen on both sides,
- Distance between the left anterior root of the mastoid notch and the right anterior root of the mastoid notch,
- Distance between the Basion point (median point located in the anterior region of the magnum foramen) and the oral point (located in the palate, in the line tangent to the lingual borders of the upper central incisor alveolar process) (Fig.1).

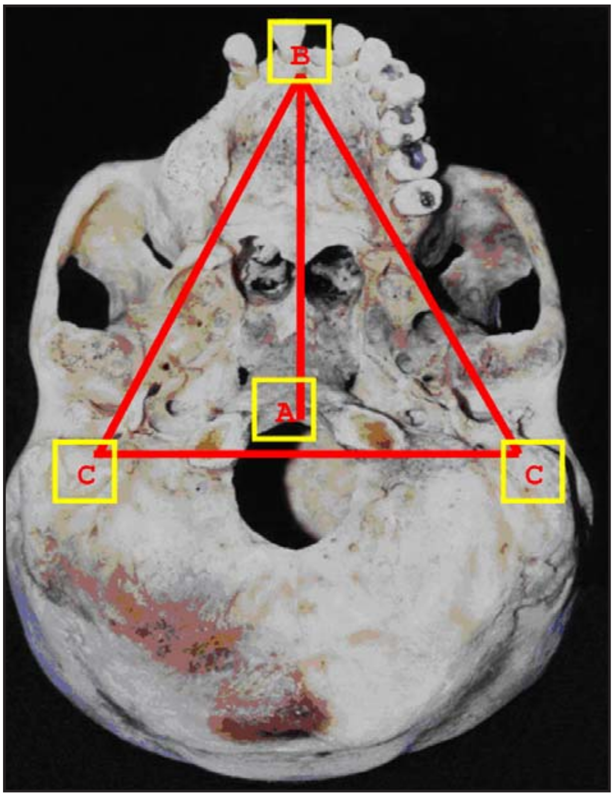
The measurements were repeated three times, after which all bones were sent to the ossuary or crematorium. Data was analysed using statistical software.** A Student t-test was performed to detect differences amongst groups relating to sex. A logistic regression was used to estimate the sex of the subject after being adjusted to a binary linear model using the variables “sex” and “distances”.

RESULTS

Data were collated for 4 measurements: right mastoid notch to incisive foramen (Table 1), left mastoid notch to incisive foramen (Table 2), right mastoid notch to left mastoid notch (Table 3) and Basion to incisive foramen (Table 4). In all cases the average distance was smaller for females than males. Moreover, for each measurement the confidence limits do not overlap between males and females, making these measurements good variables for sex prediction. The t-test confirmed the results presented in Tables 1 to 4. In addition, the standard deviation values were similar for both groups, indicating that errors during measurement were also of a similar nature.

A logistic regression model was constructed to include measured variables from the Stepwise method.[14-17] The variables “mastoid–mastoid notch” and “incisor foramen–basion point” achieved the minimal significance level. The other variables were at some point included in the model but excluded due to their low significance. The following function was determined:

Power Value = 25.2772 – 0.1601 x incisor foramen–basion point – 0.0934 x mastoid–mastoid notch



Measurements:
A – Basion (median point seen with the cranium at basal position, located in the anterior region of the magnum foramen);
B – Incisor point (central point located in the palate, in the line tangent to the lingual borders of the alveolar processes of the upper central incisors);
C – Mastoidal notch.

***Fig.1:** Cranial base measurements taken in order to predict sex*

* Mitutoyo Sul America Ltd., São Paulo, Brazil.
**SAS Institute Inc., Cary, NC, USA, Release 8/2/2001

Table 1: *Descriptive Statistic from mastoid notch to incisive foramen (mm) – right side*

Sex	Max	Min	Mean	SD	Superior limit	Inferior limit	*p*value
F	112.0	85.0	102.04	5.48	103.60	100.48	0.0001
M	123.0	93.0	106.89	5.65	108.06	105.74	

Table 2: *Descriptive Statistic from mastoid notch to incisive foramen (mm) – left side*

Sex	Max	Min	Mean	SD	Superior limit	Inferior limit	*p*value
F	114.0	85.0	102.10	5.92	103.80	100.40	0.0001
M	123.0	93.0	106.82	5.66	107.97	105.67	

Table 3: *Descriptive Statistic from right to left mastoid notch (mm)*

Sex	Max	Min	Mean	SD	Superior limit	Inferior limit	*p*value
F	106.0	79.0	96.15	7.12	98.14	94.17	0.0001
M	118.0	87.0	102.44	7.23	103.9	100.97	

Table 4: *Descriptive Statistic from incisive foramen to basion (mm)*

Sex	Max	Min	Mean	SD	Superior limit	Inferior limit	*p*value
F	98.0	46.0	83.80	7.98	86.05	81.56	0.0006
M	106.0	76.0	88.35	5.81	89.55	87.14	

(incisor foramen–basion point is the distance between incisor foramen and basion point, mastoid–mastoid notch is the distance between right and left mastoid notches)

Using the *power* value the probability was estimated by calculating the variables for females, using the following formula:

$$P = \frac{e^{power}}{(1+ e^{power})}$$

Changing the *power* in the formula for female cranium probability, an accuracy of 79.9% was established in those measured.

DISCUSSION

A number of methods have been described for sex determination including clinical examination, anthropometrical measurements, tooth growth and eruption, radiographic analysis of medullar bone, microscopic bone examination and sexual chromatin analysis (Barr corpuscles).[18-23]

However, most of these methods are unknown and/or ignored by the majority of Forensic Institutes in Brazil, or are performed with no standardized method. In order to regulate the situation it is necessary for a responsible board to investigate, as well as to standardize, the identification processes.[12]

Brazilian anthropological studies focussed on determination of sex have only just started to be performed. According to Brazilian Law, as well as Dentistry Ethical Code, it is one of the Clinicians' responsibilities to estimate sex as part of identification processes. However, few dentistry schools prepare students for this type of professional activity. Moreover, authorities frequently prevent scientific research in cemeteries throughout the country.[24] Without knowing national skull measurements, scientific investigators are forced to use international tables, which may lead to uncertain results.[24, 25]

Anthropological measurements offer a simple and cost-effective method for determination of sex. However, anthropology can only be used in subjects free of growing pathologies.[26,27] It is better applied to subjects aged between 20 and 55 years old, since teenagers and elderly people can produce atypical bone characteristics.[28,1,25] Another limitation presented by anthropological methods is that hermaphrodites or pseudo – hermaphrodites can lead to incorrect results in sex identification. It must also be recognized that biological sex is not necessarily equated with life-style gender.

Advances in biological science have highlighted the use of DNA as a means of determining not only sex, but identity if comparative material is available. It is, however, not always possible to harvest DNA and the cost of such an examination must be taken into account.

The results of this study are supported by those of other such studies.[29,12,30,26,24] Kahanoha[24] and Carvalho *et al.*[29] obtained similar results but in those studies, qualitative exams were used without specific quantitative measurements which would give more reliability and reproducibility.

A qualitative examination is possible as long as the study always deals with the same population[31] and it must be noted that in a sample of 100 subjects, 10% could be hyper-males, 10% hyper-females and 10-15% uncertain.[1, 25]

One should only provide an identification certificate after detailed and rigorous microscopic, anthropological and DNA exams. Such certificates must be detailed with results based upon reliable scientific studies and national sampling. Despite their complexity, such certificates allow us to accurately identify the subject and avoid manipulation of results.

CONCLUSION

According to the methodology used in this study, the following conclusions have been drawn:

1. Sexual dimorphism exists for the evaluated anthropometric measurements.
2. A mathematical formula has been created with a reliability of 79.9%, which can be used in Anthropological and Forensic institutes in Brazil.

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DENTAL DIAGNOSTIC RADIOLOGY IN THE FORENSIC SCIENCES: TWO CASE PRESENTATIONS

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ABSTRACT

Dentomaxillofacial radiology is a useful tool in forensic science to reveal characteristics of the structures of the dentomaxillofacial region. Postmortem radiographs are valuable to the forensic odontologist for comparison with antemortem radiographs, which are the most consistent part of the antemortem records that can be transmitted during forensic examination procedures. By using dentomaxillofacial radiology we can, therefore, give answers to problems dealing with identification cases, mass disasters and dental age estimation. We present the contribution of dentomaxillofacial radiology to the forensic sciences through two cases of deceased persons, where identification was based on information provided by radiographs. The right performance, interpretation and reportage of dentomaxillofacial radiological examination and procedures can be extremely valuable in solving forensic problems.

(J Forensic Odontostomatol 2007;25:12-6)

Key words: forensic odontology, forensic science, radiology, identification

iNTRODUCTION

Forensic radiology comprises the performance, interpretation and reporting of diagnostic radiological procedures that pertain to the courts and the law.[1-4] The use of radiology in forensic sciences is not new and it has now been over a century since a radiograph was first introduced as evidence in a court of law.

Postmortem radiographs are a valuable tool for the forensic odontologist because they, and antemortem radiographs, provide a source of robust and detailed information for comparative purposes. Even if antemortem radiographs are not available, it is very helpful to take postmortem radiographs.[3,5] It is important that the forensic odontologist takes intraoral radiographs of all of the usual tooth bearing sites, including edentulous areas, in order to screen for the possibility of unerupted teeth and retained roots and to view the anatomic structures.[3] The contribution of dentomaxillofacial radiology is very important in:

a. identification cases
b. mass disasters (radiographic comparison has increased the number of positive identifications [6,7])
c. age estimation cases

The aim of this report is to illustrate the contribution of dentomaxillofacial radiology to the forensic sciences, using two cases, where identification has been based on the information provided by radiographs.

CASE 1

The first case concerns the identification of a young woman. Human bones were found on a beach on the island of Santorini, Greece (Fig.1). There was some circumstantial evidence to indicate that they belonged to a young, female, American citizen who had disappeared on this island almost two years previously. It was impossible to base the identification procedure on visual examination or analysis of the fingerprints – in other words, on classical methods - since only bone remains were found. Moreover, DNA analysis could not be performed since the young woman in question was a native Asian who had been adopted in the USA. The possibility of identification had to be based on data provided by antemortem dental records.

Interpol located the missing girl's dentist who was able to supply her antemortem dental records. The only available data from these were a panoramic

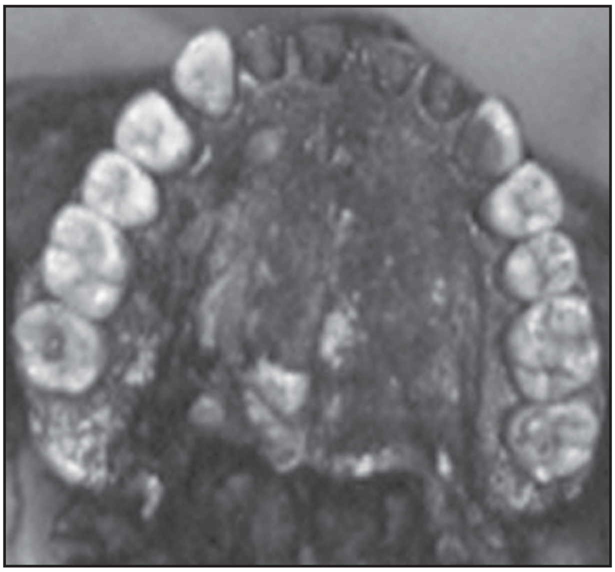

Fig.1: *Case 1 - Postmortem maxillae*

Fig.2: *Case 1 - Antemortem panoramic radiograph taken almost 10 years earlier*

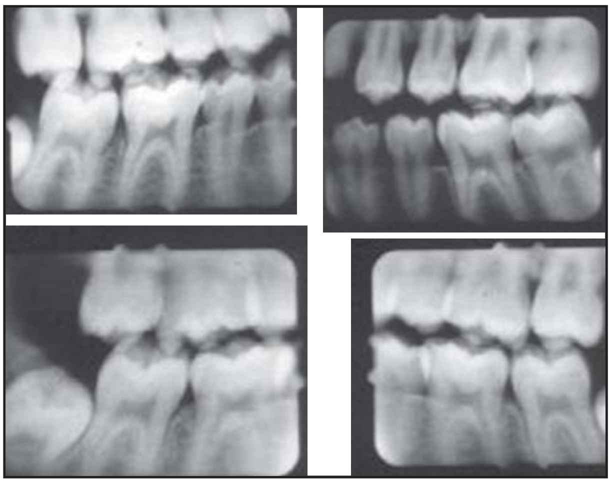

Fig.3: *Case 1 - Antemortem bitewing radiographs*

radiograph (Fig.2) and four bitewing radiographs (Fig.3). These had been taken almost ten years before the remains were found.

The jaws were examined and three periapical radiographs were taken of the mandibular molar area bilaterally and the right maxillary molar area (Fig.4). A comparison of antemortem (panoramic and bitewing) and postmortem (periapical) radiographs was carried out. Specifically, the root morphology of the molars, the morphology of the pulp cavities, the morphology of the right maxillary sinus and its relationship to the roots of the upper right molars and the bone morphology of the mandible were evaluated.

It was found that the morphology of the roots and the pulp cavities of both the molars of the right maxillary region and the molars of the mandible were consistent in antemortem and postmortem views. However, the third molars in both jaws were present in the antemortem radiographs but not in the postmortem radiographs. This was not unusual since the antemortem radiographs had been taken ten years previously and it was reasonable to assume that the third molars had been removed during this intervening period. The existing fillings in the teeth were evaluated and also found to be consistent. Careful study of the antemortem panoramic radiograph and the postmortem periapical radiograph of the right maxillary molar area revealed that the size of the second molar filling was smaller in the postmortem radiograph. The remains of the cranium were reexamined and it was found that a portion of the filling in the upper right second molar had broken away and the cavity was partly empty, thus explaining why the filling appeared smaller in the postmortem radiograph. Reassessment of the radiographs then revealed that the distal part of the filling, as shown in the antemortem panoramic radiograph, was identical in shape to that presented in the postmortem radiograph.

The conclusion drawn was that the skeleton belonged to the young, female, American citizen who had disappeared.

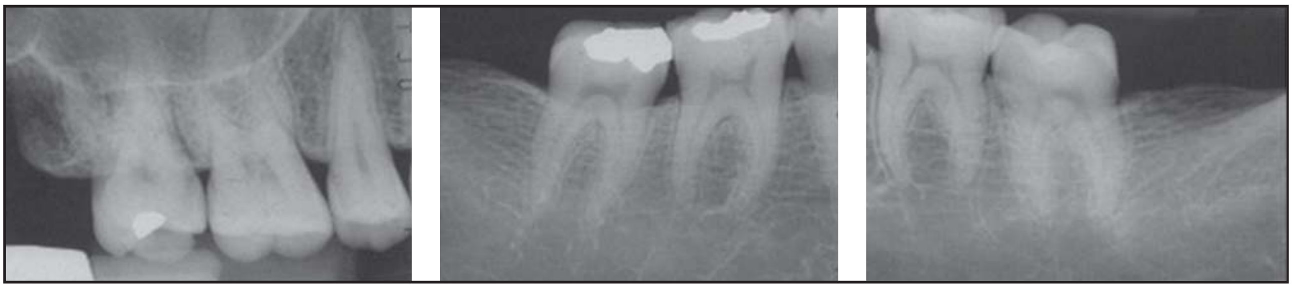

Fig.4: *Case 1 - Postmortem periapical radiographs*

CASE 2

A tourist discovered a skeleton on the island of Karpathos, Greece. This coincided with a police search for a Swedish citizen who had disappeared two years previously from the location. Clinical and radiographic examinations of the remains were undertaken (Fig.5). The Swedish embassy was asked to locate dental records for the missing person. An Interpol "Victim Identification Form", a floppy disk containing three digitized radiographs (two bitewings and one periapical) and an intraoral photo were provided.

The morphology, size, midline deviation, occlusion and shade of the teeth were evaluated on antemortem and postmortem photographs (Fig.6). The morphology of the fillings, the type of prosthetic restorations (crowns, bridges and inlays), the root canal treatments and root fillings and the intraradicular posts were all evaluated from the radiographs (Fig.7).

Twenty-eight concordant findings allowed a positive identification of the missing Swede to be made.

DISCUSSION

Forensic dentistry for identification purposes is based on the comparison of antemortem and postmortem findings with resultant matching or exclusion.[5,8-11] The identification procedures are related to the availability, quality and type of antemortem records. The most accurate data obtained during the forensic dentistry identification procedures are those that are derived from postmortem and antemortem radiographs. These are useful even in cases concerning young individuals with little or no dental treatment edentulous individuals. Radiographs are advantageous in an international context since they overcome the disadvantages of different languages and different classification systems and are accepted in courts of law as legal evidence. Dentists sometimes register only the treatment that they have performed, but radiographs reveal all previous restorations that are present within a particular field of view. It is imperative that radiographs are labeled and mounted correctly. Although therapy performed in the time span between antemortem and postmortem radiographs may change the characteristics of even unique restorations, an

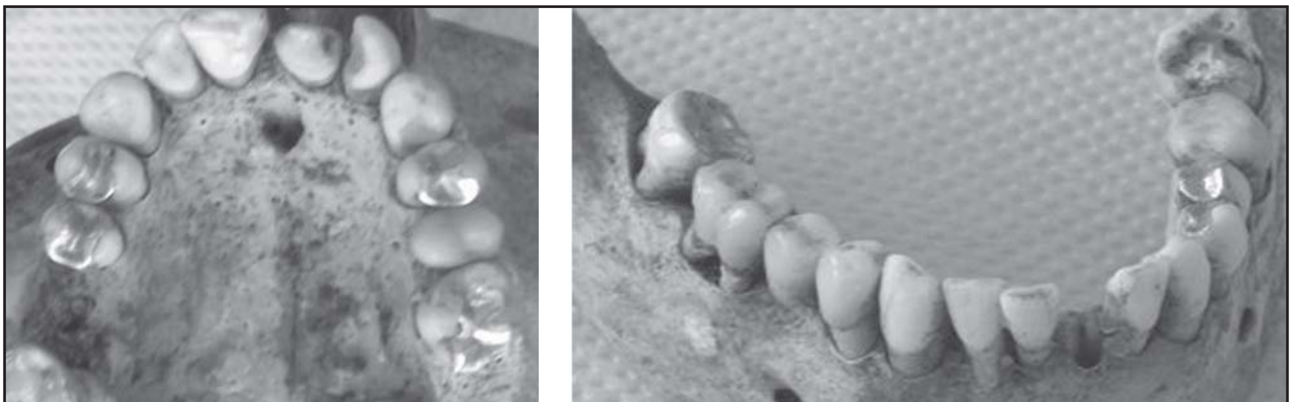

Fig.5: *Case 2 - Postmortem remains*

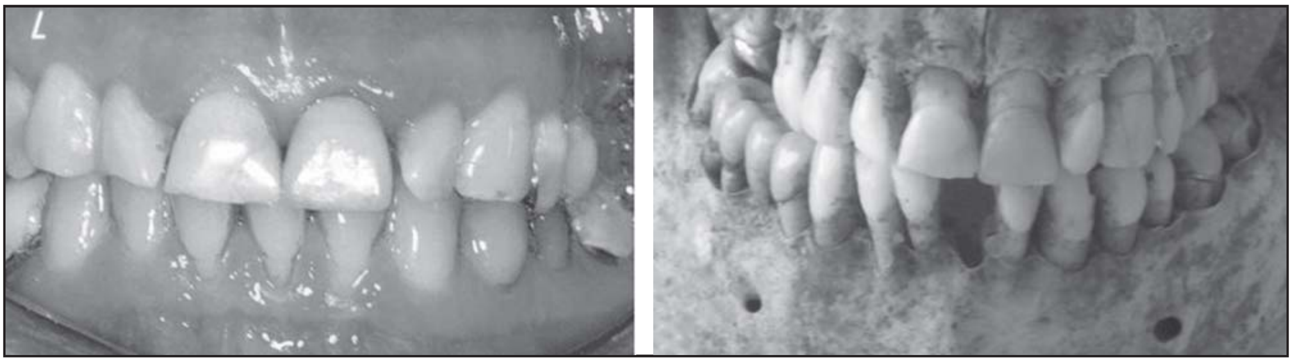

Fig.6: *Case 2 - Photographic comparison of morphology, size and shade of teeth, occlusion and midline deviation*

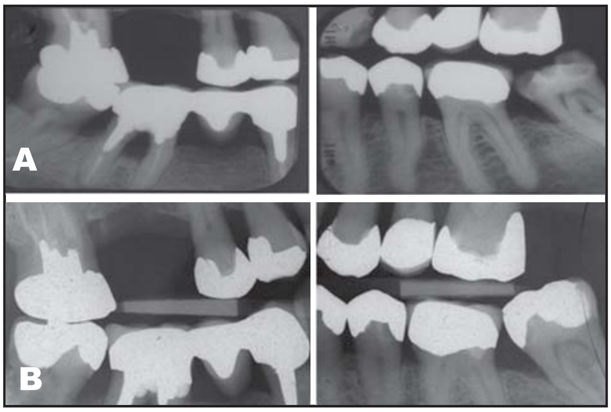

Fig.7: *Case 2 - Radiographic comparison of restorative endodontic treatment morphology in (A) postmortem and (B) antemortem*

explainable difference that would not preclude identification can be recorded.[6,7,10-14]

By studying the radiographs it is possible to evaluate details that otherwise could have been overlooked. The radiographs could reveal information concerning the anatomical structures (such as sinuses), the bone patterns (nutrient canals, incisive canal, median suture), bone pathology (sclerosis, radiolucencies), teeth and pulp morphology, root number and form, retained roots, impacted teeth, the type, extent and position of fillings, the type of prosthetic restorations, endodontic treatments, the placement of retention pins and posts, the placement and type of implants and the placement of osteosynthesis plates.[5,6,8,9,12-14]

Due to the fact that at the start of an investigation we are usually unaware of the status of antemortem radiographs, multiple postmortem images should be obtained.[4] Technically, with postmortem changes, film positioning may be more difficult, particularly in cases where it is necessary to dissect jaws in order to take radiographs.[3,5,8,9] In some cases only fragments or portions of the jaws or teeth are available for examination and should be radiographed in several orientations. In forensic radiography we should also keep in mind that exposure adjustments may be necessary during the radiographic procedures. Postmortem changes in soft tissues, which may involve complete loss of tissue, mean that the normal exposure settings for a patient may not apply.[3,4,8]

Nowadays, dental records are often electronic, including digital or digitized radiographs and intraoral photographs. The use of electronic dental records lead to improvement in the accuracy and quality of antemortem dental information.[9-11] Digital radiographs and intraoral pictures have the main advantage that they can be easily transferred and evaluated. Moreover, they can be computer processed and enhanced to generate more useful information for the identification procedures. There are documented cases that would have been unresolved without the use of digital enhancement techniques.[9,10,15-16] Forensic odontologists should also be aware of the limitations of electronic dental records. The transfer of such information, including radiographs or intraoral photographs, may raise ethical issues concerning the patient's privacy. Moreover, the probity of the data included in electronic dental records has yet to be evaluated.[9,10,14,15]

In conclusion, radiographs are a paramount tool in forensic dentistry because they reveal unique information about anatomy and previous dental treatment.[6,7,16] The cases discussed in this report are examples of the essential role of both antemortem and postmortem dental images in identification.

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DATA TRANSMISSION IN DENTAL IDENTIFICATION OF MASS DISASTER VICTIMS

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ABSTRACT

Dental evidence, especially from radiographs, has been found to be an effective method in personal identification. Previously, it has been shown that wireless personal digital assistants (PDA) can be used to transfer digitized radiographs. The purpose of this study was to set up a secure and reliable mobile connection for transferring dental digital images for disaster victim identification, and to test this new way of working in Phuket, Thailand, following the December 2004 Asian Tsunami disaster. Material and methods: Digital dental radiographs and clinical images were transferred in two separate sets using secured data transmission from a server in Finland to PDA terminals in Thailand. The mean size of the images in test 1 and test 2 were 90.7 kB and 88.1 kB, respectively. Results: The mean speed of the transmission was 3.7 kB/s with the Nokia 9500 and 3.4 kB/ s with the Qtek 2020i. The quality of all the pictures was found to be good enough for dental identification purposes. Conclusions: Wireless personal digital assistants (PDA) together with data secure transmission of digital clinical information could be used in order to assist in disaster victim identification in areas where GSM cellular networks are available.

(J Forensic Odontostomatol 2007;25:17-22)

Keywords: dental identification, data security, forensic information technology, telemedicine

INTRODUCTION

In December 2004 the Asian Tsunami disaster resulted in devastation of nature, infrastructure and people. More than 200,000 people were killed when the earthquake triggered giant waves that hit twelve countries around the Indian Ocean. In January 2005 the Thai Tsunami Victim Identification Information Management Centre (TTVI IMC) was established in Phuket, Thailand. The task of the centre was to collect the antemortem and postmortem data and carry out the comparison of those in order to identify the bodies.[1]

Dental evidence was found to be a particularly effective method of personal identification in the Thai Tsunami disaster.[2,3] Dental x-rays and clinical photos are an accurate means of positive identification. Digital images can readily be transferred via an information network. However, new information and communication tools have been used to quite a limited extent for the identification of mass disaster victims.

Previously, it has been shown that a wireless PDA, based on a GSM digital cellular phone, can be used to transfer digitized radiographs. A remote consultation link had been built with readily available technology, which was useful in radiological consultations for CT images.[4,5]

The purpose of this study was to set up a secure and reliable mobile connection for transferring dental radiographs and clinical images for disaster victim identification and to test this technology while working in the TTVI IMC in Phuket, Thailand.

MATERIALS AND METHODS

Two PDA terminal devices for image reception and viewing were used for the trial. The first was a Nokia* 9500 Communicator with Nokia mobile VPN client weighing 230 g and with dimensions of 148 x 57 x 24 mm. The device had full keyboard and two 65,536-color displays, tri-band operation for use on five continents and 80 MB built-in memory, and support for additional memory with MultiMediaCard (MMC). Nokia 9500 Communicator operated on Symbian 7.0S OS, Series 80 platform, Java MIDP 2.0 and Personal profile 1.0. In addition it had high-speed data connectivity with EGPRS (EDGE) and Wireless LAN access (WiFi, IEEE 802.11b, 2.4 GHz). The device was equipped with mobile e-mail with attachments and HTML 4.01 / XHTML browser. Security solutions were as follows: Device Lock, MMC Password Lock, OMA DRM 1.0 Forward Lock,

* Nokia Ltd., Helsinki, Finland

Fig.1: *Example of a typical radiograph used for dental identification*

SSL 3.0/TLS 1.0, Ipsec, 802.11 WPA 1.0/WEP, Operator WLAN/EAP SIM for Wireless LAN security, Java MidP 2.0 Full Security Domain, Cisco CCX Compliance and Nokia mobile VPN client. The device also had integrated VGA camera, video recorder and multimedia messaging (MMS).

The second PDA device trialed was Qtek 2020i**. It weighed 190 g and its dimensions were 60.9 x 130 x 18.2 mm. The device operated on Microsoft Windows Mobile system, Pocket PC 2003 2nd edition. It had Intel® Bulverde 520Mhz processor and memory capacity was standard 128MB ROM and standard 128MB SDRAM. The liquid crystal display was a sensitive touch screen of 3.5" transflective TFT-LCD with Back Light LEDs, 64K colours, and with the resolution of 240 x 320 pixels. In addition the device had CMOS camera of 1.3 mega pixels and colour resolution VGA (480 x 640). Qtek 2020i was equipped with Celesta file transfer software.§ The forensic dental expert was given a half hour training session in the use of the equipment.

Altogether 21 digital images of Finnish voluntary test persons were transferred in two separate sets. There were 12 radiographs, consisting of five orthopantomographs, four periapical and three bite-wing radiographs. The total number of digital clinical photos was nine. Radiographs represented typical cases used for dental identification (Fig.1). Clinical images represented cases which could assist identification of a disaster victim. The image properties of the original images are shown in Table 1.

In order to reduce the time required for transmission, the original images were compressed with a JPEG (Joint Photographers Expert Group) algorithm. The mean size of the images in test 1 and test 2 were 90.7 kB and 88.1 kB, respectively (range 26-153 kB and 28-153 kB, respectively). An experienced forensic dentist evaluated the usability of images for dental identification purposes. An experienced radiologist evaluated the quality of the radiographic images both before and after compression. The criteria used in evaluation were the quality of contrast and sharpness of the images in order to recognize tooth morphology, restorations and bone structure.

Secured data transmission to pocket terminals was tested in Phuket, Thailand. In test 1 the transmission was done with webmail over a secured connection (https) with Nokia 9500 Communicator. In test 2 images were transferred from a private Web server in Finland to Qtek 2020i terminal as simulating the situation of secured transmission of data from the server of the National Bureau of Investigation to a disaster management site. After transmission the images were saved at the mobile devices.

** HCT Corporation, M-Technology Ltd, Oulu, Finland

§ Celesta MDO Mobile Data Organiser, CCC Mobile Ltd., Oulunsalo, Finland

Table 1: *Image properties*

	Pantomographs	Intraoral radiographs	Clinical images
Original size (pixels)	2570 x 1248	1262 x 1640	768 x 576
Resolution (dpi)	72	72	72
Original colours (BitsPerPixels)	24	8	24
Number of unique colours	256	256	256
Current memory size (Mbytes)	9.18	2.03	1.30

RESULTS

The mean speed of the transmission was 3.7 kB/s in test 1 with the Nokia 9500 Communicator and 3.4 kB/s in test 2 with the Qtek 2020i (range 1.7 to 4.6 kB/s and 0.8 to 6.7 kB/s, respectively). The average total image transmission time was 30.4 sec (range 19.7 sec to 43.9 sec) in test 1, and 25.7 sec (range 23.0 sec to 37.0 sec) in test 2. There were no disconnections during the test transmissions. After transmission, the images could be successfully saved at PDA devices for possible further use.

The quality of all dental radiographs was found to be sufficient to allow dental comparison. The personal digital assistants were found to be light, easy to carry and easy to use by a forensic dentist who was familiar with using a personal computer, mobile phone, email and Windows applications.

DISCUSSION

Personal identification was the major task of forensic experts, including odontologists, in the aftermath of the Asian Tsunami. Identification of disaster victims can be done by visual identification, circumstantial evidence and physical evidence. In several disasters it has been seen that among the physical evidences, dental data are the most effective method of identification, followed by fingerprints and DNA.[6] In the Estonia ferry accident (1994) identification was established by dental means in 60% of the deceased.[7] The contribution of forensic odontology to tsunami victim identification was indisputable.[1] However, the process still could be improved with the use of modern technology.

Kieser *et al*. [8] found significant sources of error in antemortem and postmortem data. In their study, of the 78 postmortem records received from the morgue, only 68% of radiographs and 49% of photos confirmed the accompanying dental charting. This underlines the value, particularly of clinical photographs, in quality control. Of the 106 antemortem records received, 64% were either not accompanied by radiographs or had poor quality radiographs.

Dental radiographs are important data for comparison for personal identification. However, without correct notes on the original picture, it might be very difficult to distinguish left from right side from the radiographs. The first author has personally faced this problem in Thai Tsunami Disaster identification tasks, as well as in some previous identification cases.

In health care, teleradiology has been used for many years in remote consultations.[9] The greatest benefits have been shown in neurological emergencies.[10] Wireless PDA based on a GSM digital cellular phone has been used to transmit images to neuroradiologists.[5] In the studies of Reponen *et al.*[4,5] the neuroradiological diagnosis from transmitted images did not change after a later review of the original images in 97% of cases. In various studies it has been shown that a compression ratio of 1:10 to 1:15 does not affect the diagnostic quality of radiological images.[11,12] In this study the compression ratio was 1:5. Most often dental comparison for personal identification is based on dental hard tissue and dental materials such as gold or amalgam, which are easily visible in radiographs. Tooth colored dental materials are more challenging for diagnosis from radiographs. Where there is uncertainty in decision-making based on compressed pictures, the final conclusion should be made from the original radiographs.

In the Thai Tsunami Disaster Victim Identification process only Finland and Sweden delivered all the antemortem data in digital form. In Finland the collection of antemortem data and sending it to Phuket, Thailand, in digital form could be done in a few weeks.[13] The use of wireless connections and mobile equipment in the aftermath of mass disasters would offer a fast and flexible way to collect the data at the disaster site, transmit the data from home countries, and carry out the identification at the information management centre (Fig.2). The simulation of the system was carried out successfully with personal digital assistants in this study. Similar protocol could possibly be used also for the postmortem personnel.

DVI Systems International[§§] was the software used in Thai tsunami identification.[14] It operates on the PC

§§ Plass Data Software, Holback, Denmark

Windows platform, and it is one of the few internationally approved systems. It is capable of managing aspects of identification in day-to-day cases and major disasters, where it has particular advantages when victims of several nationalities are involved. The system uses Interpol forms as standard protocols for input and transfer of antemortem and postmortem information. Digital images transferred with the system tested in this study could be imported to DVI System International, and used for personal identification.

When widely available network tools are used and confidential patient data are transmitted, the privacy and data security should be high. Confidentiality of communications should be guaranteed in accordance with the international protocols relating to human rights. According to the Directive on privacy and electronic communications[15] of the European Parliament, new advanced digital technologies give rise to specific requirements concerning the protection of personal data and privacy. The successful cross-border development of the digital mobile services is partly dependent on the confidence of users that their privacy will not be at risk. Efforts have been made in the European Union[15] and other countries[16-19] to create national and international standards for the procedures and technology for protection of privacy in the electronic communications sector. Coordinated activities related to public health information architecture, standards, confidentiality, best practices, and research will be needed by all parties to improve the protection of privacy and confidentiality.[19] The privacy technology used in this study was the state of the art technology at that time.

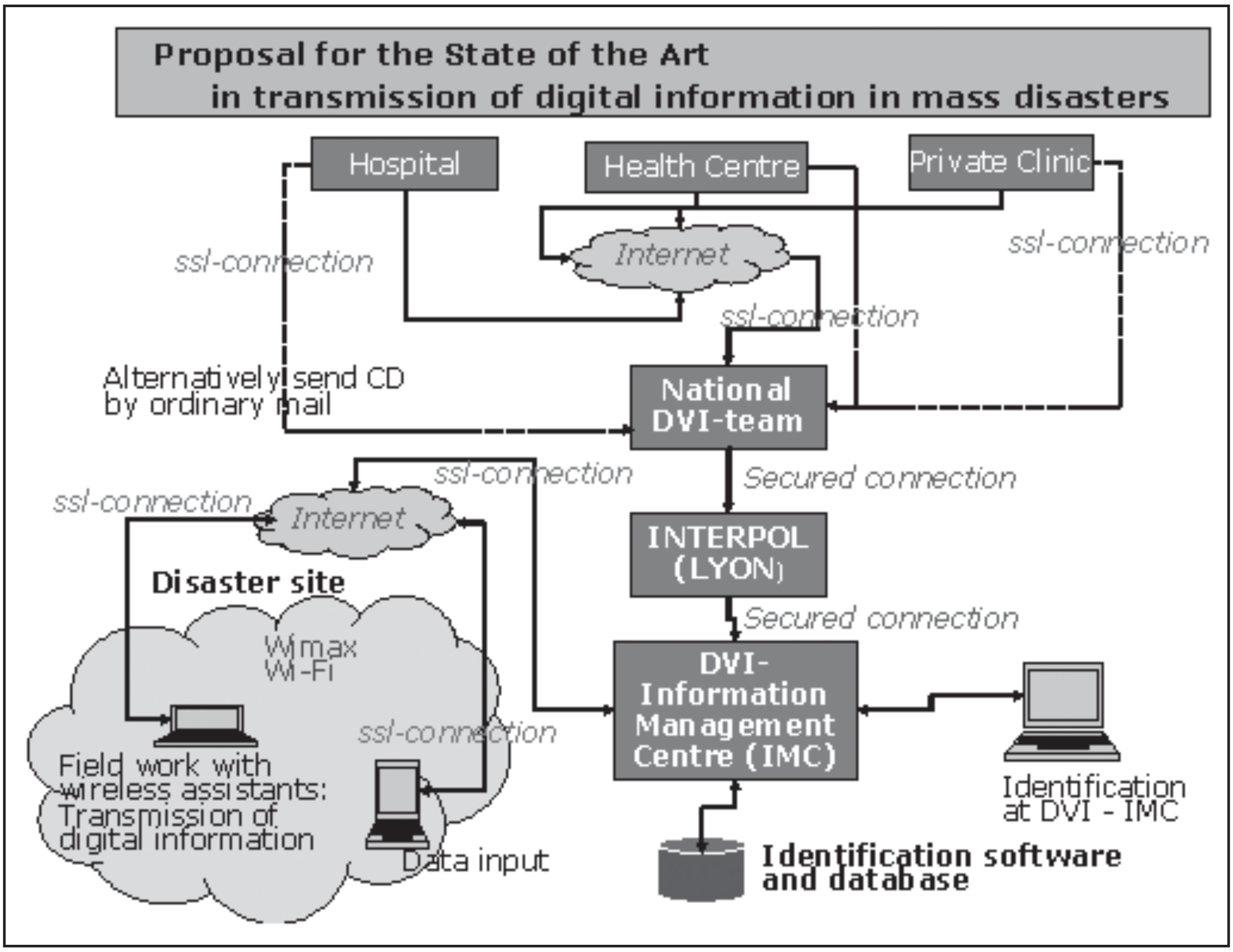

Fig.2: *Proposal for the State of the Art in transmission of digital information in mass disasters. Abbreviations: DVI, Disaster Victim Identification, SSL, Secure Sockets Layer, Wimax, Worldwide Interoperability for Microwave Access, Wi-Fi, Wireless Fidelity*

The modern portable technology is small enough to be carried at disaster sites, allowing equipment with updated databases rapid transmission of data from the morgue to the information management centre. However, there is a risk of losing portable devices, which might cause a serious risk for data privacy. Therefore, it would be important to assure that the mobile device is equipped with authorized access, user identification and password. Most often the weakest link in protection of privacy is not the technology but the human factor.

In this experiment the GSM network could be used. In some disasters, the use of GSM in the first stage might not be possible due to large devastation of the infrastructure. There exist also other global possibilities for wireless communication, such as mobile satellite services.[20] The usage of satellite communications for telemedicine was first introduced during disasters in mid 1980's.[21] However, the disadvantage compared to cellular networks is the higher price and lack of integrated PDA devices. In this study there were no interruptions during the data transmission. However, in a real scenario where there is a large volume of data to be transferred, some problems might occur.

CONCLUSION

In conclusion, wireless personal digital assistants (PDA), together with data secure transmission of digital clinical information, could be used in order to assist in dental identification of disaster victims in areas where GSM cellular networks are available. Based on experience in this study, both Nokia and Qtek systems provided good data transmission capability.

The usage of transmitted, compressed images might hasten the identification process, and help to use investigation resources more rationally. The greatest benefit would be the fast transmission of digital data to the information management centre of the disaster site, and secondly, the added value of being able to collect and/or use the data for identification at temporary morgues without fixed telecommunication lines.

ACKNOWLEDGEMENTS

The National Bureau of Investigation of Finland is acknowledged for making it possible to carry out the study in Phuket, Thailand. Nokia Ltd. and Celesta, CCC Group are acknowledged for providing the equipment and software.

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EVALUATION OF TWO DENTAL IDENTIFICATION COMPUTER SYSTEMS: DAVID and WinID3

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ABSTRACT

Human identification, by comparing dental characteristics, is considered to be one of the most reliable, accurate and rapid methods of resolving the identity of visually un-identifiable deceased persons. In recent decades computer programs have evolved to aid odontologists by suggesting records that have similar dental features. The aim of the present study was to compare two of those programs; Disaster And Victim IDentification (DAVID) and WinID3 in terms of effectiveness, accuracy and speed of data entry and to further compare them with the efficiency of the classical method of manually matching postmortem and antemortem dental records. An open disaster was simulated whereby 52 fragmented remains made of acrylic replicas and 77 provisional victims were represented on Interpol F2 postmortem and antemortem forms. The results assessed were the first seven possible matches made by each program. Manual matching of dental characteristics performed better than both programs (P<0.001) yielding 29 identifications. Eleven and six positive matches were the result of the DAVID and the WinID3 programs respectively (P=0.185). Data entry was quicker for WinID3. It was concluded that both programs are still not as accurate as the time-consuming manual matching method. The difference in performance between the DAVID and the WinID3 programs was attributed to the inclusion of more comparable dental characteristics, the inclusion of the type of dentition (deciduous or permanent) and the weighting of those characteristics by the DAVID program.

(J Forensic Odontostomatol 2007;25:23-9)

Key words: disaster, identification, forensic odontology, computer, DAVID, WinID

INTRODUCTION

Disaster is defined as a sudden occurrence that exceeds the resources available in a community to deal with, including a large number of fatalities as a result.[1] The importance of victim identification is valued worldwide. It will not only resolve serious legal and social predicaments, but also it provides a resolution to grieving families who need closure of their sadness.[2] For those reasons, disaster victim identification (DVI) was globally formalized by Interpol in 1984 with the production of the first DVI manual.[3]

Identification of the deceased is usually performed visually by the next of kin, but this approach is neither reliable nor desirable when there are multiple victims, the body has undergone postmortem decomposition or if death was a violent one (e.g. incineration, motor and aviation accidents). In such circumstances the identity must be achieved by alternative means. Medical and dental characteristics, fingerprints, and DNA comparisons are regarded internationally as scientific methods of identification.[2,3] The uniqueness of each dentition was demonstrated without the use of dental radiographs.[4] Teeth have shown a diversity that was comparable to that of mitochondrial DNA[5] even when the incidence of dental decay and restorations was declining.[6] Uniqueness of teeth together with their remarkable ability to sustain harsh circumstances make dental characteristics a reliable, and often the only identification method available.

When forensic experts are dealing with many victims, as was the case in the recent Indian Ocean tsunami when, for example, more than 5000 victims needed to be identified in Thailand alone,[7] the process becomes complex due to the large volume of postmortem and antemortem data that need to be collected and then compared. A computer program that can be employed to store, sort and match antemortem and postmortem records in a speedy and accurate manner seems highly desirable.

Forensic odontologists have attempted to simplify the diversity of dental characteristics to facilitate comparison particularly following a mass disaster.[8-11] The first reported computer-aided dental identification system: Dental Identification Package (DIP) was described by Kogon *et al.* in 1974.[12] In 1977, Siegel *et al.* proposed quantifying dental characteristics by giving weight to each in a changeable algorithm.[13] This was followed by the introduction of Computer Assisted Postmortem Identification (CAPMI) program by Lorton *et al.*[14] to be followed by publication of several programs with different matching philosophies.[15-18] Those programs have been assisting forensic odontologists in identifying victims of mass disasters by producing possible matches.

The purpose of the present study was to compare two dental identification systems; the WinID3, which is the latest version of WinID and the DAVID* programs with regards to accuracy of the matching process and time efficiency, and to compare their performance with the classical method of manually matching the same set of simulated remains.

MATERIALS AND METHODS

An open mass disaster situation with 52 badly mutilated victims was simulated. The victims were represented by 52 acrylic replicas of mandibles (n=26), maxillae (n=6), skulls (n=17) and jaw fragments (n=3) (Fig. 1). This was part of a national training set which has been used by the Australian Federal Police for multidisciplinary DVI training. The dental features were variable and included sound and missing teeth, restorations with various dental materials and root canal treatments created by using extracted natural human teeth which were embedded in the acrylic replicas, together with fixed and removable prostheses. All dental characteristics were charted onto Interpol F2 forms.

* During the writing of this manuscript, updated versions of the DAVID and the WinID3 programs were being produced. The algorithms and dental characteristics of both programs remained unchanged to the versions on which this study was performed.

Fig.1: *the DVI training set representing acrylic replicas of the fragmented remains. (Courtesy Mr. Ronn Taylor, forensic sculpture; and Mr. Chris Owen, photographer. School of Dental Science, The University of Melbourne)*

The antemortem data of imaginary victims was transcribed onto 52 Interpol F2 forms and was part of the DVI training kit. Some of those forms had the sentence “no records available” while others contained a variety of dental information ranging from simple dental data to complex dental treatment including multiple restorations and crown and bridge work. In order to simulate an open disaster, another 25 antemortem records, which were transcribed anonymously from actual identification cases performed by the forensic odontology team at the Victorian Institute of Forensic Medicine in Melbourne, Australia, were added to the antemortem collection.

All records were matched manually aiming at reaching maximum concordance. This process began by sorting antemortem and postmortem records into females, males and unknown gender. Then each gender group was divided into age groups by the date of birth (in case of antemortem records) and by chronological dental eruption pattern (in case of postmortem records); those age groups were: 0-5 years, represented by deciduous dentition; 6-12 years, represented by mixed dentition; and 13 and above years represented by permanent dentition. The records were further divided into those with fixed and removable prostheses, restorations, and no dental treatment groups. The outcome of the manual matching was classified as either “positive”, “possible”, or “inconsistent”. Positive identification was considered to be when there was sufficient concordance between antemortem and postmortem dental records to establish the identity beyond any reasonable doubt. Possible identification was considered to be when the dental information in an antemortem record was not identical with that in a postmortem record but could have evolved into it during life. Insufficient antemortem data was also designated as possible. Inconsistent identification was considered to be when there was obvious unexplainable inconsistency between antemortem and postmortem dental characteristics. In order to obtain the best outcome for comparison, only records which were considered positive were used in assessing computer matching results.

A period of familiarization with both programs was undertaken, following which the postmortem and antemortem dental records were entered separately and alternately (all antemortem records followed by all postmortem records into the DAVID program, then all antemortem records followed by all postmortem records into the WinID3 program). Data entry was performed by the same operator (SA) so as to avoid inter-examiner differences. The time for the data entry was measured.

The matching command for each program was activated; the “Most Dental Hits” option in WinID3 and the “Match” command in DAVID. The DAVID’s algorithm settings that applied in Australia were used (Table 1). Other identification tools such as a targeted search for a specific dental feature and other matching lists of WinID3 were not used. Each manually identified postmortem case was matched to all antemortem cases in the database. The

Table 1: *Algorithm of the “DAVID Web” program*

PM/AM	Bridge	Crown	Decayed	Dentures	Missing	No data	Sound	Restorations	Unerupted
Bridge	100	10	10	10	10	0	10	10	10
Crown	10	100	10	-1000	-1000	0	10	10	10
Decayed	10	10	10	-1000	-1000	0	100	10	10
Dentures	10	10	10	100	100	0	10	10	10
Missing	100	10	10	100	100	0	10	10	10
No data	10	10	10	10	10	10	10	10	10
Sound	-1000	-1000	-1000	-1000	-1000	0	100	-100	100
Restorations	0	0	0	-1000	-1000	0	10	100	10
Unerupted	-1000	-1000	-1000	-1000	10	0	-1000	-1000	100

	Match	Mis-match
Deciduous	100	-1000
Filling Surface	100	-1000
Root filled/Implant	100	-1000

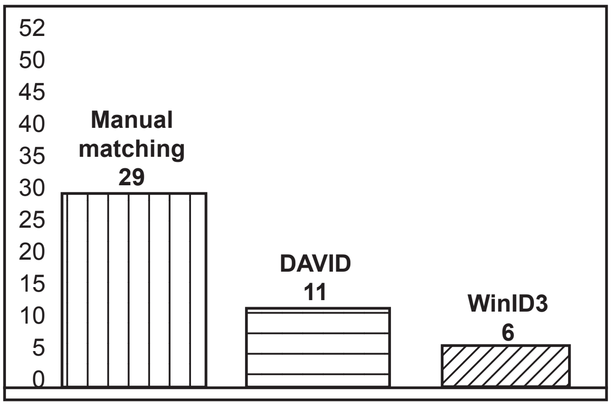

***Fig.2**: Results of the matching outcome of the 52 PM records using the three methods: manual, DAVID and WinID3 programs*

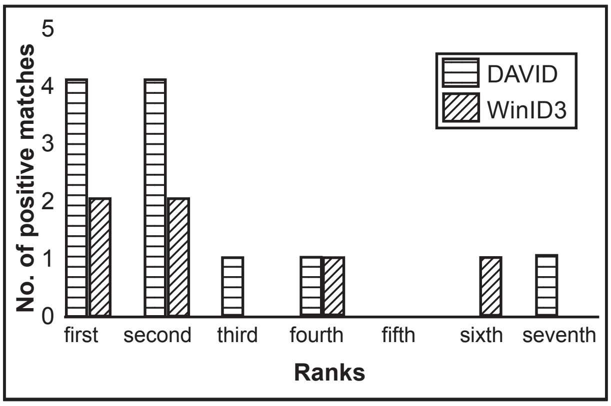

***Fig. 3**: Results of the first seven ranks performed by the DAVID and WinID3 programs whereby the first rank is the most likely match*

outcome of both programs was presented in a list starting from the most likely match (greatest score) to the least likely match (least score). The first seven matches of both programs were collected and the results were analyzed using the Chi-Square test with $p<0.05$ being taken as significant.

RESULTS

Time spent for data entry of the 129 dental records was approximately 7 hours and 30 minutes for DAVID and approximately 6 hours for WinID3 program. Time spent for manual matching was approximately 22 hours.

The number of postmortem records that were identified as "positive" using the manual method was 29/52 (Fig. 2). Of the 29 records, the DAVID program successfully identified 11 records (Fig. 2), four of those records were identified as the most likely match, four records were identified as the second most likely match and three records were in the remaining five matches of the list of seven (Fig. 3).

The WinID3 program was successful in identifying 6 postmortem records out of the 29 manually identified (Fig. 2). Two records were identified as the most likely match, two records were identified as the second most likely match and two records were in the remaining five matches of the list of seven (Fig. 3).

The manual method was significantly better than the DAVID and WinID3 programs ($p<0.001$), however, there was no significant difference between both programs ($p=0.185$).

Three records had sufficient characteristics that satisfied the matching criteria of both programs.

DISCUSSION

In the present study, the matching performance of the DAVID and the WinID3 programs was not significantly different. Data entry was quicker for WinID3. WinID3 is designed with an algorithm that is based on "hits and misses". A hit is equal to one point and a miss is equal to zero. The aggregate score is presented to the operator in five different data sets; most dental hits, least dental mis-matches, most identifier matches, most restoration hits and fuzzy dental logic. There are four dental characteristics designated "primary codes" used in the matching algorithm in addition to five restored surfaces of each tooth (one hit per matched restoration). The primary codes are: missing, missing crown, missing post-mortem, un-erupted and virgin.[19] The primary code "no info", although listed as a primary code, does not contribhute to the overall score". A crown is automatically changed into five restored surfaces and is given one hit. In addition to this, there are 12 secondary codes which are not part of the algorithm and do not contribute to the matching score. They do, however, provide additional information for the operator to assess possible matches suggested by WinID3 system.[16,19]

The algorithm of the DAVID program gives quantitative values to each dental characteristic depending on its significance and rarity in the community; the more unique the characteristic the greater its weight. Those weights range from "100" to “minus (-)1000” where 100 is the weight of matching a unique characteristic, such as matching a crown to a crown and -1000 is a penalty aimed at the exclusion of that match when there is an obvious inconsistency. Values in between indicate possible matches. For example, a match between an antemortem sound tooth and a postmortem extracted tooth results in a score of 10 points, whereas the opposite results in a score of -1000 and hence DAVID predicts, to some extent, the possible change of one characteristic into another. These algorithm values are changeable by a “superuser” according to their perception of dental features in a respective community. In the present study the settings that applied in Australia were used.[15,25]

In DAVID there are 11 dental characteristics, all of which are primary. Those characteristics are: sound, damaged, bridge, crown, denture, missing, socket, un-erupted, root, single-surface filling and multi-surface filling. Contrary to WinID3, each tooth receives one of those characteristics *plus* the type of dentition (deciduous or permanent) and the filled surfaces of each tooth which are weighted separately. Quantifying dental data has been proposed previously.[13,20-22] In the present study, it was observed that the DAVID program showed more ability to match fragmented remains by comparison with WinID3. This can be attributed to expanding matchable characteristics (including deciduous teeth) and to quantifying them. The WinID2 program (earlier version of WinID3), performed best when “most restoration hits” list was used.[23] In the present study the “most dental hits” list was used to assess the results. This option of the WinID3 program was considered most applicable to our study sample. Although DAVID’s Graphic-User Interface data entry was intended to be a simple way of entering dental records, WinID3 program’s data entry was quicker because it allowed characteristics to be entered by the keyboard as codes or by a mouse from a menu, contrary to DAVID where data entry was restricted to the use of a mouse. For example, a mesio-occlusal filling on a deciduous tooth can be entered as codes (MO B) in the WinID3 program, while in the DAVID program, the operator will need to click on the icon of the filling, then on the mesial and occlusal surfaces, then on the tooth number to change it to a deciduous

***Table 2**: Comparison of some of the main features of DAVID and WinID3 programs.*[25]

Feature	DAVID	WinID3
Matching algorithm	Qualitative and quantitative	Quantitative only
Primary dental characteristics	11 codes (+ 5 surfaces)	5 codes (+ 5 surfaces)
Secondary dental characteristics (not matchable)	None	12 codes
Deciduous teeth	Scored	Not scored
Password required	Yes	No
Auditing	Yes	No
Numerical systems	Only European system: kg, cm	European and North American systems: kg, cm and lb, inch.
Languages	English	English, French, German, Italian, Portuguese and Spanish
Accessing records	Slow: accesses one record at a time.	Quick: accesses multiple records.
Dentist details	Compulsory	Not compulsory
Image attachment	Not able	Able
Ability to work with more than one database	Yes, up to 7 databases	No
Ability to provide statistics	Not able	Able
Printing	Able to print records similar to Interpol F2 forms, in addition to disaster and dentist details.	Able to print records with physical and dental details.

tooth. The measuring of time of data entry was a crude attempt to assess the friendliness of both programs.

The cases which the DAVID program successfully identified in the first seven attempts and which WinID3 failed to identify were those with deciduous dentition, prosthodontic work and those which were severely fragmented. This highlights the value of including the type of dentition as a matchable dental characteristic. It also highlights the importance of having an algorithm which weights characteristics so that a fixed prosthesis would contribute significantly to the score producing a more probable match. The cases in which WinID3 was successful and in which DAVID failed, represented records rich in dental data which allowed accumulating a large number of hits. As was expected the three postmortem records that were identified by both programs reflected comprehensive antemortem dental records and less fragmented postmortem remains. The programs were not able to match fragmented remains with root canal treatments because neither program used in the present study was equipped in their algorithm to match this dental characteristic.

The manual matching, although time consuming, led to significantly better outcome than both programs ($p<0.001$). It was concluded that the diversity of dental characteristics exceeded the capabilities of the two software programs in their present format. Contrary to identification programs that are designed to match other antemortem and postmortem data (such as DNA profiles), dental identification programs have the additional task of accommodating changes to the dentition produced by dentists (sometimes in multiple records), hence it is not an easy task to write a program that can precisely match a changing dentition. This study should not be interpreted as failure of computer-aided dental identification rather it should stimulate further improvement of this vital and promising field of forensic odontology. DAVID and WinID3 programs offer a wide range of tools and options that are very useful and should assist forensic odontologists in the matching process. Some of the main features are listed in Table 2.

The present study was designed to assess the behaviour of both programs when used following a disaster that is characterized by sparse antemortem data and fragmented postmortem remains in most of the cases studied. The DVI training set used was not intended for dental identification alone, but for training other DVI disciplines and hence the manual dental method succeeded in matching approximately 55% of the cases on its own which is slightly less than would be expected in daily forensic dental identification cases.[22]

An important advantage of the computer-aided dental identification methods that probably would prevail over the manual matching is its use as a missing persons database whereby antemortem dental records are stored and any discovered dental remains can then be matched quickly to that antemortem bank of dental characteristics.[24,26] Both programs offer this option through their respective targeted search.

CONCLUSION

In this study, DAVID and WinID3's performance was less accurate by comparison with the more time-consuming classical manual matching method. Although both programs have different methods of matching antemortem and postmortem dental characteristics, the difference between DAVID and WinID3 was not significant. At the present time computers can assist with the initial sorting of records with confirmation made by manual method. Further improvement is clearly required to facilitate data entry and to produce more accurate matching outcome.

ACKNOWLEDGEMENT

The authors are indebt to Dr. James McGivney for providing generous support and assistance with WinID3 program. We also thank Ms Vickey Winship for her assistance with the DAVID program and Professor Emeritus Peter Reade for his assistance in preparing this manuscript.

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