ISSN 2219-6749

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The Journal of Forensic Odonto-Stomatology

Volume 27, n. 2 - Dec 2009

OFFICIAL PUBLICATION OF THE
INTERNATIONAL ORGANIZATION FOR
FORENSIC ODONTO-STOMATOLOGY

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EDITORIAL

WHAT IS OUR PROFESSION?

Conventionally, a profession has been defined in terms of provision of a given service that is based upon a defined and systematic body of knowledge. The possession of such knowledge affords a degree of status and authority to professionals. In return for the benefits of professional membership, members are expected to exercise informed judgement, perform relevant tasks at technologically high levels of skill, act ethically and maintain confidentiality. In other words, in dealing with a professional, there are the dual expectations of specific knowledge and of trust.

However, what this definition does not acknowledge is the flexibility inherent within each profession. In the words of Slaughter and Leslie[1], professions are neither static nor fixed, but are always in the process of being reconstructed. This raises the question; how specialised or technical must a body of knowledge be if a group of practitioners is to maintain its professional status? When maxillo-facial surgeons or endodontists, for example, sought professional status, other professions opposed this on the basis that their knowledge was not sufficiently unique or not sufficiently grounded in research. So how do we pinpoint the profession of Forensic Odontology? Can we define our own systematic, scientific body of knowledge? Do we have to? Or should we regard knowledge as flexible and ever changing rather than absolute?

A parallel challenge is the increased emphasis on competence-based professional practice. How does this affect what we consider the professional boundaries of forensic odontology? Are we equally competent to handle bitemarks and human identification? And what of dental ageing or bony evidence of trauma to the craniofacial region? In addition to a call for more fluid conceptions of what we are competent to do, there is a call for more inclusiveness – how do we accommodate Dental Therapists and Dental Technologists? And forensic anthropologists, how do they fit into our profession?

Rather than accepting at face value the boundaries of our profession, I think we need to examine our future. Recently, Dirkmaat and his colleagues[2] reminded us that costs and time were the only constraints to identification based solely on DNA. It is simply not a question of how these considerations will be overcome, but a question of when. If this happens, they warned, forensic odontology may become mostly superfluous. The way out, I suggest, is to broaden our body of knowledge and with it our scope of practice from simple dental identification to a larger range of activities, including trauma analysis, child abuse, dental ageing, taphonomy and forensic archaeology. So, though the challenges seem to be huge, the scope for future developments within our profession, seem exhilarating.

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Jules Kieser

OBJECTIVE HUMAN TOOTH COLOUR MEASUREMENTS AS A MEANS OF DETERMINING CHRONOLOGIC AGE *IN VIVO* AND EX *VIVO*

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ABSTRACT

Colour is a subjective sensation and as such is difficult to use in a quantitative study. However a number of clinical studies on extracted teeth have shown a good correlation between tooth colour and age.

The purpose of this study was to examine the usefulness of a specific spectrophotometer in determining tooth colour on extracted and non-extracted teeth and to look for a possible age relationship.

There were two parts in this study. An *ex vivo* study concentrated on collected tooth material. Single rooted teeth were selected out of each of the 5-year-age groups (ages ranged from 15-89 years). Colour measurements were performed on the mesial and vestibular aspects of the roots as well on the mid-vestibular aspects of the enamel crown. An *in vivo* study concentrated on the use of this specific shade taking system in living patients (n=70). Statistical analysis of the results revealed regression formulas for both *ex vivo* and *in vivo* situations displaying adjusted R-squares between 0.48 and 0.56. It may be concluded that age related trends were found. Having its shortcomings, the shade taking system was found to perform well as a convenient adjunct to dental age estimation in both the living and the deceased.
(J Forensic Odontostomatol 2009;27:2:2-8)

Keywords: age calculation, tooth colour, spectrophotometer, *in vivo*, *ex vivo*

INTRODUCTION

Identification of unknown corpses or human skeletal remains is often problematic because of lack of medical or dental ante mortem identifiers. In addition, the impact of trauma makes comparative means of identification impossible. In these cases reconstructive types of identification are then entertained As part of this biological profiling it is important to have an indication of the chronological age of the skeletal remains as well as information on biological group, gender and circumstantial evidence. In general, age estimation is important in the process of identification since it is helpful in concentrating or limiting the search within the target group of missing people and is an adjunct for court magistrates to help out in establishing verdicts.

Information on the age of a subject is also requested in other totally different forensic cases such as adoption cases, immigration issues or criminal cases. In the latter it is important to know whether a suspect has reached the age of majority.

Especially in the field of forensic odontology a large volume of research has been published on this subject. Dental age estimation in a forensic context has been performed on radiological as well as morphological parameters and the authors recently published a review of most commonly used dental age estimation techniques.[1] Amongst the latter, are techniques based on age related parameters such as attrition, periodontal ligament attachment, secondary dentin formation, translucency of root dentin, root resorption, and cementum deposition.[2-5] These techniques often require the forensic odontologist to prepare the tooth in thin sections or to produce a mid-tooth section for further analysis. These time consuming age-estimation techniques could be abandoned if a valid and time-effective alternative were available.

A method based on the evaluation of tooth colour could be such a technique, although the infrequent use of tooth colour for age estimation may already point out the difficulty in objective assessment. However, the general observation that teeth tend to darken with age has already been noted by some authors, trying to confirm the correlation between tooth colour and age. Ten Cate *et al*[6] compared teeth of unknown age with teeth of known age based on the colour of root surfaces as the only indicator of age. They showed that the age of the individuals to whom the teeth belonged was estimated within an age range of +/- 10 years. Solheim[7] reported a significant correlation between age and colour of both tooth crowns and roots. However, most results were obtained from visual grading, which is prone to subjective bias.

When the colour of an object, e.g. a tooth, is to be measured, two other parameters that influence colour perception must be standardized. These are light source and observer. Sunlight does not always have the same intensity of different wavelengths and can vary during the day, depending on the place or the environment. In addition, the sensitivity of the human eye is highly observer dependent.[8-10] A spectrophotometer and a colourimeter are instruments that use a constant light source, and transfer the measurements into tri-stimulus values according to the CIE-system[11] and thus exclude observer subjectivity. The CIELAB system, a modified CIE system specifies any colour into tri-stimulus values L, a, and b. L stands for lightness (the black-white factor), a for the red-green factor and b for the yellow-blue factor.

Lackovic and Wood[12] investigated the correlation between colour of tooth roots and chronological age. Their results strongly support the suspicion that chronological age is directly related to increased root colouration: they even found a significant difference between the colouration of the four root surfaces, especially for the mesial surface, as well as between non-molar and molar tooth roots.

In 2001 Odioso[13] investigated the impact of demographic variables (such as age, gender and ethnicity) on tooth colour. The measurements were taken from the crown surface of anterior teeth. They came to the conclusion that as a tooth ages, its colour becomes darker (-L) and more yellow (+b). Age is shown to be the most significant predictor of tooth colour. In a more recent study[14] models were created to predict the age of a human being based on the root colour of freshly extracted anterior teeth among others. The models show a linear correlation between chronological age and tooth colour enabling an age estimation based on tooth colour. However, such an estimate was only accurate up to 11,5 years.

The purpose of the present study was to evaluate the influence of colour on dental age estimation using a computer-aided shade taking system avoiding the bias inherent to observer subjectivity and to develop new mathematical regression models for age estimation based on objective colour assessment on extracted and non-extracted teeth

MATERIALS AND METHODS

Ex vivo study.

The tooth collection of Ten Cate *et al*[6] was used for this project. They obtained a sample of extracted teeth of known age and gender from Ontario (Canada) dental practitioners. These teeth were cleaned with pumice and stored in corked glass jars. The teeth were originally pooled by gender into five-year age groups: 15-19, 20-24, 25-29 and so on until 85-90. For the present *ex vivo* study, the single rooted intact teeth were selected out of each of the five-year-age groups. A total of 1332 colour measurements were performed: 560 on male and 772 on female teeth (Table 1). Colour measurements were performed on the vestibular aspect of the tooth crown (CV) as well as on the mesial (MR) and vestibular (VR) surface of the root. Each specific tooth surface was measured 5 times and the results were averaged. Colour evaluation was carried out with the ShadeEye-NCC™ Dental Chroma Meter (Shofu, San Marcos, CA, USA) [15-16]. The ShadeEye-NCC™is a technologically advanced shade taking system especially designed for its application in dentistry. The cordless measuring unit digitally analyses the shades and immediately transmits the data to the main unit via an infrared interface. It records L(brightness), a(red-green), b(blue-yellow) values according to the CIE-LAB system without being affected by lighting conditions. All colour measurements were done with this shade taking system while the tooth was held against a black background. The tip of the measuring unit made contact with the enamel or dentine surface at a vertical level of at least 4 mm a way from the vestibular cementum-enamel junction. Each single measurement consisted of an automatic run of three colour measurements that are automatically averaged. This procedure was repeated 5 times for each specific tooth surface evaluated. Apart from the results of the measurements, gender, age group and specific location on the tooth surface were recorded.

Table 1: *Representation of the amount of colour measurements performed for the ex vivo study, categorised according to gender and location of the measurement on the tooth. Each colour measurement represents a total of five consecutive measurements of which the data were averaged to obtain a single value for a specific location on a specific tooth. (Different locations are CV: crown vestibular; RM: root mesial; RV: root vestibular).*

	Male				Female				
Age group	CV	RM	RV	Subtotal	CV	RM	RV	Subtotal	Total
15-19	2	2	2	6	3	5	5	13	19
20-24	4	17	14	35	7	15	11	33	68
25-29	11	23	25	59	13	23	23	59	118
30-34	7	26	18	51	13	30	24	67	118
35-39	6	16	18	40	9	9	8	26	66
40-44	11	16	18	45	23	38	39	100	145
45-49	14	37	37	88	9	18	16	43	131
50-54	13	23	22	58	26	43	29	98	156
55-59	13	24	21	58	22	39	42	103	161
60-64	15	30	27	72	20	28	28	76	148
65-69	2	6	6	14	16	31	30	77	91
70-74	-	2	2	4	12	20	20	52	56
75-79	-	2	2	4	2	4	4	10	14
80-84	3	5	5	13	4	6	5	15	28
85-89	3	6	4	13	-	-	-	-	13
Total	104	235	221	560	179	309	284	772	1332

In vivo study

The *in vivo* part of this project consisted of the colour measurement of teeth in individuals seeking dental treatment at the University Hospitals of the Katholieke Universiteit Leuven. The same shade taking system as earlier reported was used to determine the L-, a- and b-values of three upper front teeth: left or right upper central and lateral incisor and upper canine. Measurements were performed on the vestibular enamel of the specific air dried tooth crown after cleaning them with a mixture of pumice and water, at least 2 mm coronal to the gingival border and after cleaning and rinsing of these surfaces with pumice and slow rotating devices. 70 subjects were randomly selected (Table 2). Selection criteria were: the evaluated teeth should be intact, unrestored, unbleached and free of calculus and specific discolorations. Subjects were non-smoking western European Caucasians. For each specific surface, three repeated measurements were performed while the patient was asked to sit completely still. A total of 210 measurements from 70 subjects were obtained and divided into 5 year-age groups. Again with each colour measurement, age, tooth, sex and ethnical group were recorded.

Table 2: *Representation of the amount of colour measurements performed for the in vivo study, categorised according to gender. Three colour measurements (upper central and lateral incisors and canine) represent 1 patient.*

Age group	Male	Female
15-19	3	6
20-24	24	21
25-29	9	15
30-34	9	9
35-39	3	12
40-44	15	3
45-49	6	9
50-54	3	6
55-59	3	3
60-64	3	12
65-69	9	9
70-74	0	6
75-79	3	3
80-84	6	0
85-89	0	0
Total	**96**	**114**

Table 3: *Regression models for age calculation based on the colour values obtained from both ex vivo and in vivo studies. For a specific age calculation, include the obtained L-, a- and b-values in the model if necessary. Different locations exist CV: crown vestibular; RM: root mesial; RV: root vestibular. For each location, a separate regression model is obtained: include either 1 or 0 into the model depending on whether the colour measurement was performed, respectively, on that specific location or not. Gender G=0 for male and G=1 for female. For the parameter Tooth substitute the numerical value (11, 12, 13, 21, 22 or 23) of the specific tooth that was evaluated into the specific regression parameter for that tooth. The other tooth parameters become zero. In case of tooth 13, all tooth parameters become zero.*

	r^2
EX VIVO **STUDY RESULTS**	
MALE	
Including location	
Age = 165.79 – 2.06 L – 4.95 a + 1.04 b + 38.90 CV + 2.89 RM	0.49
Including location and gender	
Age = 162.08 –2.15 L – 5.05 a + 1.43 b + 43.60 CV + 6.07 G	0.49
FEMALE	
Including location	
Age = 166.01 – 2.23 L – 5.31 a + 1.67 b + 48.20 CV	0.48
Including location and gender	
Age = 162.08 –2.15 L – 5.05 a + 1.43 b + 43.60 CV + 6.07 G	0.49
IN VIVO **STUDY RESULTS**	
Including interaction between tooth and parameter L	
Age = 247.58 – 3.34 L – 3.70 a + 1.07 b + 0.20 T11 +0.11 T12 + 0.35 T21 + 0.29 T22 + 0.12 T23	0.56

Statistical Analysis

Pearson correlation coefficients were calculated between the different mean L-, a- and b-values measured and age of the individual and multiple regression analysis was performed on the data obtained with and without integrating parameters like location of measurement, gender and type of tooth evaluated. In order to be able to perform multiple regression analysis the parameter age was converted into a continuous variable by averaging each age group (e.g. the class of 15-19 years was replaced by the continuous variable 17 years). This method is acceptable because there are 14 age-classes and they are all ordinal. A specific parameter was included into the model if it generated a significant difference of $p<0.01$. The final model thus included only the most relevant variables. Also an analysis of variance was performed to highlight whether there was an influence between the type of tooth evaluated and the colour measurement obtained and thus whether the type of tooth had an effect on the age estimation. All statistical procedures were run with the SAS statistical software package (SAS Institute, Cary, NC, USA).

RESULTS

Ex vivo study

Statistical analysis of the relationship between the L-, a-, b- values obtained through the shade taking system and the chronological age revealed a poor Pearson correlation coefficient (r) of approximately 0.44 and 0.49 for female and male teeth respectively. Multiple regression analysis delivered comparable results: $r^2 = 0.20$ and 0.26 respectively. When the specific location (CV, RM and RV) of the colour measurement was entered into the model as well as gender (G), then a significant influence was found. Pearson correlation coefficients rise up to 0.63 and multiple regression analysis comes up with r^2 equal to 0.49 (Table 3). That a significant influence of the parameter location on the colour measurement exists was confirmed after analysis of variance with $p<0.0001$.

A general conclusion of the statistical analysis was that whatever model was used, there was always a slight tendency present to underestimate the real age for the higher age categories and to overestimate the chronological age in the lower age categories based on the colour parameters L, a and b. These tendencies remained when integrating parameters location and gender into the regression model.

In vivo study

Table 3 represents the results of the *in vivo* study. Gender and parameter b had no effect on the age calculation and were left out of the regression model. On the other hand, a significant effect was noticed for the type of tooth (T). However, since all three teeth were measured for each individual subject, the parameter tooth would not have a large effect on the age prediction of an individual. But the interaction between tooth and a colour parameter (L, a or b) obtained might have a significant effect. Figs. 1a-c show a visual effect of tooth type on the colour measurements. Therefore, the possible interaction effect of both parameters was investigated with analysis of variance and a strong r^2 of 0.56 was found with a significant contribution of the interaction between the type of tooth evaluated and the parameter L (Table 3).

DISCUSSION

Since the goal of the study was to enable objective colour measurements of teeth, the object, light source and perceiver had to be standardized. Therefore a *colourimeter* device marketed as a shade taking system was used.

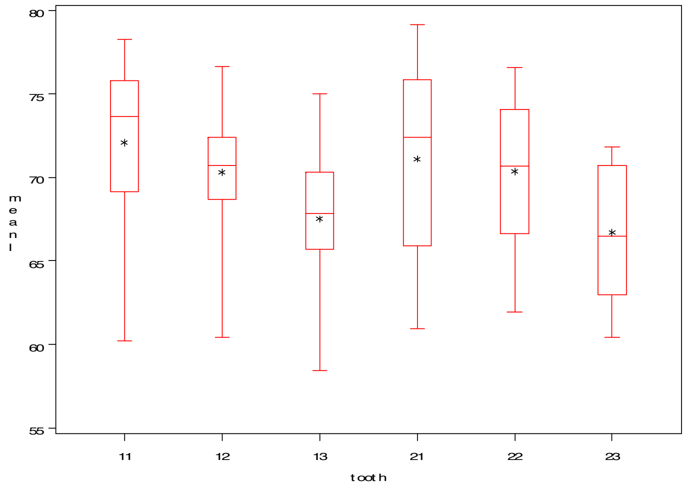
In this study a modified CIE system was used, namely the CIELAB system. There are two advantages in using this CIELAB system over the CIE system designed in 1971. Firstly, the specification is easier to interpret in terms of the psychophysical dimensions of colour perception in the CIE system namely brightness (L), hue (H) and colour (C). Secondly it is possible to estimate the magnitude of the differences between two colour stimuli using the chromaticity diagram. The L axis is known as the lightness and extends from 0 (black) to 100 (white). The other two coordinates (a and b) represent the red/green and yellow/blue fractions respectively.

The major drawback of the Shade-Eye NCC Dental Chroma Meter is that the cordless appliance has a measuring tip that analyses only a small area of the tooth surface. The tip needs to be in full contact and perpendicular to the investigated tooth surface. This is problematic when evaluating the curved surface of a small root. In that case full contact between tip and surface is impossible and this might have had an influence on measurements. This differs from the technique of Lackovic and Wood[12] who used colour measurements of tooth root surfaces that had been scanned.

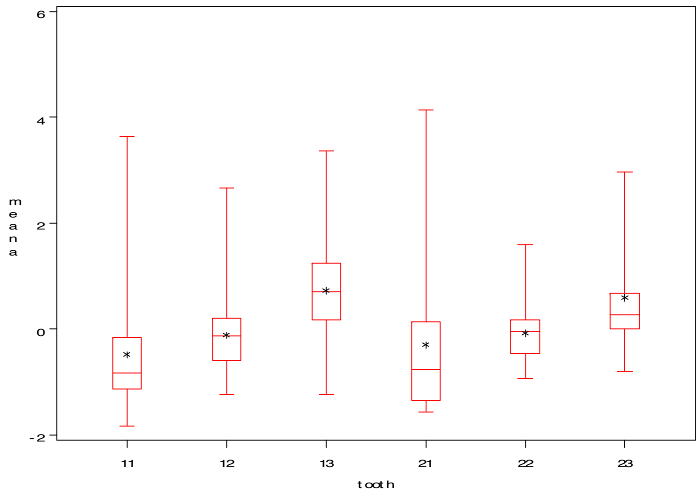
The present system is relatively easy to handle as far as data interpretation are concerned. The compact nature of the device should allow its inclusion as a complimentary dental age estimating procedure which may confirm the findings of other techniques but based on an additional parameter which is objectively obtained.

The results obtained from the *ex vivo* study gave similar results to those from earlier studies,[12,14] although not as high correlation coefficients could be achieved.

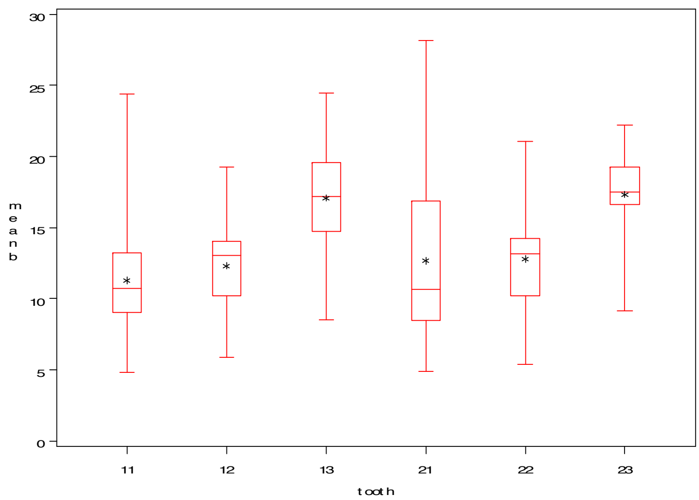
In Ten Cate's study,[6] a human observer was used as the measuring tool for colour determination whereas in the work of Lackovic and Wood[12] a flat bed scanner and six selected points for each tooth surface were used for colour determination and ultimately correlation with chronological age. While flat bed scanning devices are common-place there are many variables that need to be accounted for including scanner-bulb properties, position on the scanner and use of a colour standard, amongst others. The human eye-brain "tool" possesses a remarkable ability to integrate information. Perhaps using human vision as a measuring tool should be evaluated in further studies in this aspect of age determination. A study by Solheim[17] using visual analysis for age estimation performed relatively well when compared to more cumbersome methods. Finally it is conceivable that collections of other teeth from other ethnic groups and other geographic locales could result in higher or lower correlations. The teeth in the present study and the studies of both Ten Cate *et al*[6] and Lackovic and Wood[12] all used teeth that were grouped in five-year ranges of known gender and were stored dry. Further studies should investigate teeth of similar anatomic sites on precisely known chronological age and explore possible subtle changes of colour over time. Finally the present investigative system allows measurement *in-vivo* which is a new development. It would be unethical to extract teeth from a living person in order to determine age and it is interesting to note that the same trends towards increased coloration of the teeth is seen in both extracted teeth and teeth in live individuals.



1a.



1b.



1c.

Figs 1a-c: *L-, a-, b- values obtained from colour measurements in in vivo study represented in the form of box plots and categorised according to the type of tooth. Visual observation reveals differences in colour values between teeth (11/21: upper central incisor; 12/22: upper lateral incisor; 13/23: upper canine). The same trend is noted between contralateral teeth.*

ACKNOWLEDGEMENT
The authors wish to express their appreciation to the late AR Ten Cate for allowing them to use his material.

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MACROSCOPIC AND MICROSCOPIC CHANGES IN INCINERATED DECIDUOUS TEETH

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ABSTRACT
Teeth are amongst the most resilient elements of the human skeleton and are thus often utilised in routine forensic investigation involving the identification of unknown remains. Teeth exposed to thermal stress have the potential to not only aid in identification, but also in understanding the circumstances surrounding the fire. Children are twice as likely to become victims of house fire because of an inability to safely evacuate from areas of danger. The literature demonstrates, however, that research on the effects of incineration on teeth is mostly restricted to the permanent dentition. The apparent lack of knowledge on the effects of incineration on deciduous teeth thus necessitates further research in this area. To this end, this study aimed to relate colour changes that occur post heating with fragility to aid in proper handling of samples in a forensic scenario and to determine the possibility of identifying incineration temperature based on tooth condition.

A total of 90 deciduous teeth, extracted as a part of routine clinical treatment, were exposed to temperatures ranging from 100°C to 1100°C for 30 minutes using a laboratory Gallenkamp oven. Unheated deciduous teeth were used as controls for the project. Post-incineration the teeth were analysed under a stereomicroscope and SEM to assess the morphological changes. A colorimetric assessment was also undertaken to evaluate colour changes due to thermal stress. It was possible to identify incineration temperature based on tooth condition when the colour changes, stereomicroscopic findings and SEM images were utilised collectively. It was concluded that thermally induced changes in primary teeth occur at lower temperatures in comparison to the permanent teeth. It was also established that post-incineration deciduous teeth are fragile and show a tendency to fragment after minimal exposure to thermal stress.
(J Forensic Odontostomatol 2009;27:2

Keywords: Forensic investigation, deciduous dentition, incineration, identification.

INTRODUCTION

Teeth, as compared with most elements of the human skeleton, have an inherent resistance to damage. Under certain circumstances, however, the form and texture of teeth can be altered and occasionally total disintegration may occur. Fire is a leading cause of mortality and morbidity in adults and children. Investigators have long recognised the forensic potential of evaluating charred dental remains, as they yield important data regarding not only individual identity, but also circumstances surrounding the fire. In a report by the National Fire Protection Association (USA), it was suggested that children are twice as likely as adults to become victims of a house fire.[1] Children are more susceptible to the fatal effects of fires because of their inability to safely evacuate themselves. A child's risk is further increased due to their smaller airways which is associated with a greater incidence of mucous obstruction.[2]

All of the research analysing burnt dental remains currently available in the literature has been conducted on adult mono- and multiradicular teeth. The apparent lack of published data on the effect of incineration on the deciduous teeth thus necessitates research in this area. The present study, therefore, aims to investigate the type and extent of macroscopic and microscopic changes that can occur in deciduous teeth when exposed to high temperatures. The study also aims to relate post-incineration colour changes with the condition (in particular the fragility) of the teeth, to assist in the proper forensic treatment of samples. The present study also considers if there is any relationship between incineration temperature and tooth condition.

MATERIALS AND METHODS

A total of 90 deciduous teeth were studied; 45 molars and 45 anteriors. One deciduous molar and one anterior tooth were used as the control samples and were thus not exposed to the experimental temperatures. All of the teeth analysed were acquired as part of routine clinical therapeutic procedures conducted in dental hospitals in Central India. The ethics approval for the study was granted by the Human Research Ethics Committee of The University of Western Australia (RA/4/1/1931). As the extraction of clinically sound teeth in children is not justifiable in routine clinical practice, the deciduous molars used in the study were carious to some degree and the anterior teeth showed marked root resorption.

Following extraction each tooth was rinsed with saline water to remove blood deposits and salivary coating. The teeth were then stored in 10% formalin for 15 days, after which they were removed from the solution and sent to the first author. Formalin (10% concentration) was used as the storage medium for the teeth because it is known to have a minimal effect on dentin permeability, in comparison with other storage media such as 70% ethanol and distilled water with thymol.[3] Furthermore, 10% formalin has been demonstrated to be effective in disinfecting and sterilising extracted teeth without altering their hardness.[4,5]

Incineration

Incineration was performed using a Gallenkamp oven* at experimental temperatures starting at 100˚C and incrementally increasing by 100˚C up to a maximum of 1100˚C. The teeth were placed in a porcelain stub with the buccal surfaces facing the oven chamber and exposed to a sudden thermal shock by inserting them into the oven individually when the experimental temperature was reached. Once placed in the oven chamber, the teeth were incinerated for a period of 30 minutes; the teeth were then removed and allowed to cool to room temperature.

*Manufactured by Weiss-Gallenkamp (United Kingdom)

** Manufactured by Leica Microsystems Pty Ltd, North Ryde, Australia

Stereomicroscopic and Colorimetric Analysis

Each incinerated tooth was first examined under a stereomicroscope; a Leica MZ6** with a Leica L2 cold light source to assess the extent of heat induced alterations in the crown and root of the teeth. The colour of the enamel, dentin and cementum were then quantified using a Munsell soil colour chart (year 2000 revised washable edition).

Scanning Electron Microscopic Analysis

The SEM analysis was performed using the ESEM mode, which eliminated the high vacuum in the microscope chamber, replacing it with a high pressure gaseous atmosphere. Although the enamel is the least hydrated of all tissues, a tooth placed in the SEM will become dry and cracks will develop. These changes would adversely affect the final results, therefore, the environmental mode was used. Furthermore, to make samples conductive, conventional SEM analysis requires specimens to be coated with a thin layer of a suitable material, such as gold, gold-palladium alloy, platinum, silver or aluminium.[6] This would have involved further handling of the fragile teeth, leading to artefacts and further disintegration. Accordingly, to minimise potential damage from handling the incinerated teeth, double sided carbon tape was used to secure the teeth on a glass slide, which was then placed on the microscope stage.

During the imaging procedure, standardised values for the different working parameters such as spot size, working distance and kV were not used, as each image had to be optimised individually depending upon the magnification. The SEM analysis was performed using a Phillips XL 30 SEM from The Centre for Characterization, Microscopy and Microanalysis, The University of Western Australia.

RESULTS

All incinerated teeth analysed showed surface changes on the crown that progressed from the cervical end towards the incisal edge. At 100˚C the cervical enamel appeared to have a 'melted' irregular surface and was pale yellow in colour. The crown retained its surface lustre and perpendicular fissures that formed a chequered pattern were evident. Disintegration of teeth due to these deep fissures was present even at the initial starting temperature of 100˚C. The teeth incinerated at 200˚C were characterised by surface bubbling on the root, which was a shiny black colour. In addition to these heat induced changes, the teeth exposed to 300˚C showed a light gray colour, knob or globule like formations on the predentinal surface (Fig.1) and an amorphous deposit on it. The enamel and dentin began to separate at 400˚C and the very pale brown enamel shell had disintegrated into numerous fragments.

At 500˚C the light gray coloured enamel lost its surface lustre that was apparent at all previous incineration temperatures. Another important morphological change at this temperature was a decrease in dentinal tubular diameter near the dentinoenamel junction (Fig.2). The teeth were extremely fragile after exposure to 600˚C and the cementum colour had changed to bluish black. The prismatic structure of the enamel was still preserved at 700˚C (Fig.3), but the dentinal tubular diameter continued to decrease, with the tubules being completely obliterated in some areas (Fig.4). Despite the fissuring at 800˚C the surface characteristics (Tomes' process pits) of the bluish gray enamel were still identified on the fragments. Due to the melting of the inorganic crystals, the predentinal surface had changed in appearance from globular to a spicular configuration (Fig.5). The cementum had changed colour to a very dark bluish gray.

The surface of the dentinal tubules at 900˚C presented characteristic 'star shaped' structures (Fig.6). These crystalline structures appeared to be emerging from the peritubular dentin matrix and were observed in all of the teeth exposed to 900°C. The cementum surface in the teeth exposed to 900°C had no characteristic structure and was thus unrecognizable (Fig.7). The external surface appeared to have melted and was covering a granular layer. In the teeth exposed to 1000˚C the dentinal tubules remained identifiable, but the lumen was obliterated due to the granular changes in the intertubular dentin (Fig.8).

The crown and root of the molars exposed to 1100°C were neutral-white in colour, with a pink tinge in the cervical one-third. The predentinal surface was a light greenish-grey colour. The Tomes' process pits observed on the enamel surface were not identifiable in the teeth incinerated at 1100°C; at this temperature the enamel surface had a granular appearance and the crystallites appeared to be melting. The characteristic topography of the crystallites in the enamel structure was observed in some areas, thus the enamel remained recognisable, even after exposure to the extreme and sudden thermal trauma (Fig.9). The tubular structure of the dentin remained intact after the incineration process and they had narrowed due to extreme granulation of the intertubular matrix (Fig.10). The cementum surface remained unidentifiable post-incineration. The surface had melted and some granulation was apparent. Some areas on the root had developed vesicles due to the complete melting of the surface, which exposed underlying dentin (Fig.11). The results from the stereomicroscopic, colorimetric and SEM analysis are described briefly in Table 1.

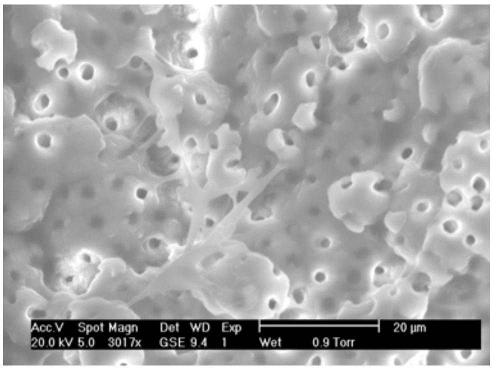


Fig.1: *SEM analysis of a deciduous mandibular second molar exposed to 300°C for 30 minutes. The predentinal layer showed knob like structures and the tubular diameter remained unaffected.*

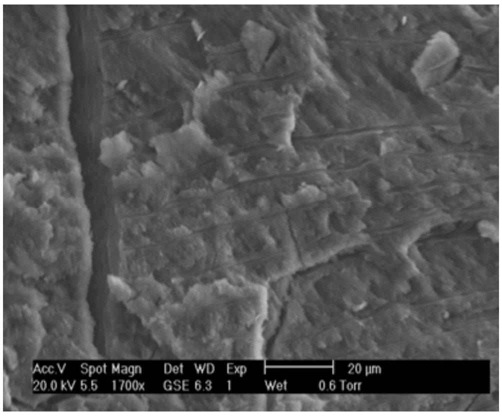


Fig.2: *SEM image of dentin after exposure to 500°C for 30 minutes. The tubular diameter near the dentino-enamel junction had decreased.*

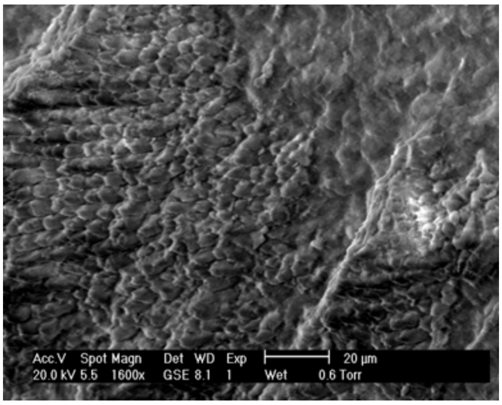


Fig.3: *SEM image shows the enamel subsurface structure. The morphology and the arrangement of the prismatic structure remained identifiable in the teeth exposed to 700°C for 30 minutes.*

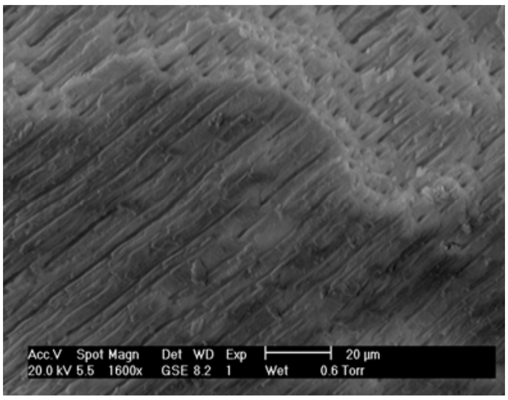


Fig.4: *The dentinal tubules at 700° appeared to be obliterated but the tubular morphology was well identified due to the hypermineralised peritubular dentin.*

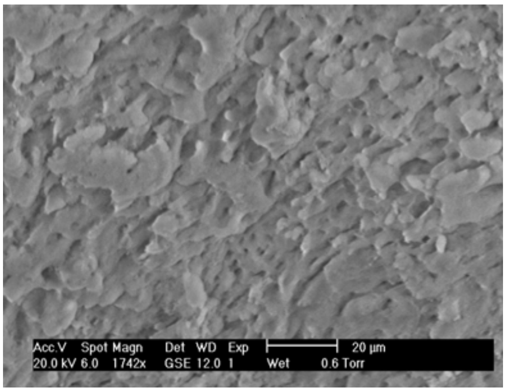


Fig.5: *SEM image of the predentinal surface exposed to 800°C showed a spicular appearance due to the melting of the inorganic salts.*

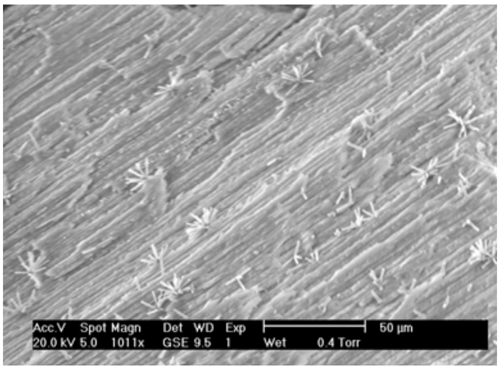


Fig.6: *SEM image of dentin after incineration at 900°C for 30 minutes. A characteristic feature observed was the presence of star shaped crystals, apparently originating from the peritubular dentin.*

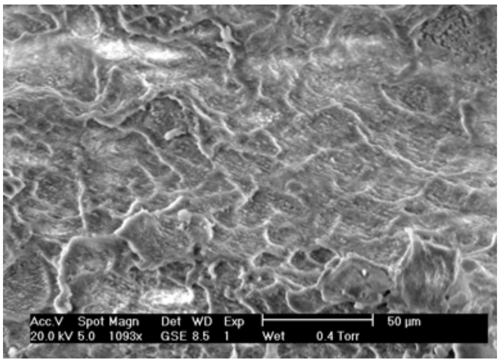


Fig.7: *SEM image of cementum after exposure to 900°C for 30 minutes. The surface had melted forming a continuous layer. This external surface was covering a granular tissue underneath it.*

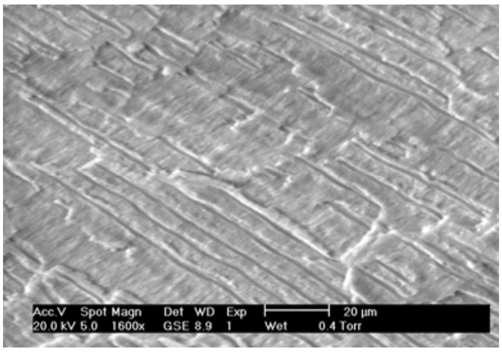


Fig.8: *SEM image of dentin incinerated at 1000°C for 30 minutes. Dentinal tubules remained identifiable but the lumen was obliterated due to the granular changes in the intertubular dentin.*

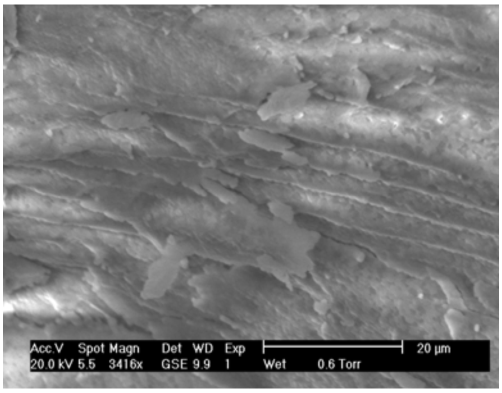


Fig.9: *SEM image of a tooth incinerated at 1100°C for 30 minutes. The arrangement of the organisational units was still preserved post-incineration.*

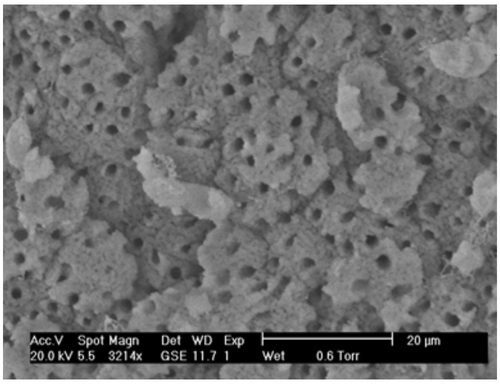


Fig.10: *SEM image of the predentinal zone of a tooth incinerated at 1100°C for 30 minutes showing the granulation of the intertubular dentin.*

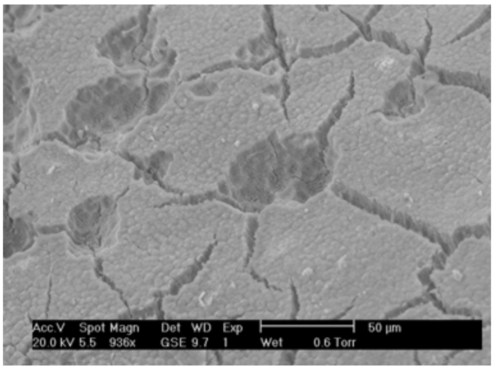


Fig.11: *SEM image of a tooth root exposed to 1100°C for 30 minutes. The cementum surface appeared to have melted into a granular tissue.*

DISCUSSION

The teeth, although resistant to most physical trauma, can become brittle and fragile when subjected to increased temperature. Disintegrated teeth are difficult to reconstruct for the purpose of post-mortem radiography and dental charting.[7] Understanding thermally induced changes in teeth can, therefore, assist forensic investigators to appropriately handle fragile dental tissues and then study the thermal record of the teeth. The purpose of the present study was to analyse thermally induced macro- and microscopic changes in deciduous teeth deemed to be important because children are more susceptible than adults to deaths in fires.

The teeth are protected from physical and thermal insults by the peri-oral musculature, lips and tongue. When exposed to fire, the soft tissues dehydrate and retract, thereby exposing the anterior teeth. As a result, the anterior teeth exhibit more thermal damage than the posterior teeth, which are protected by the tongue and buccal musculature. In a burns victim, therefore, the thermal damage observed in anterior teeth exceeds the damage in posterior teeth. The consequence of this differential damage is that estimation of temperature becomes complex due to the absence of uniformity in the structural changes in the hard tissues.[8]

It was observed in the review of current literature that there is an apparent lack of published data on effects of incineration on the deciduous teeth. This meant that a comparative analysis of the present results was limited. In this study the teeth were introduced in the oven at the experimental temperatures to simulate a thermal shock that would be induced by a fire; after 30 minutes exposure they were removed. This simulated exposure to a single thermal shock.

It was found that the colour of the teeth was the most important indicator of their relative fragility. This confirms previous research which suggests that blackened teeth are less fragile in comparison with remains that are grey or white in colour.[8] The results obtained from this study, however, also indicated that deciduous teeth disintegrated into smaller fragments (even at 100°C) when the colour change post-incineration was minimal. This has significant ramification for the forensic practitioner as due caution must be taken in handling remains which appear morphologically ‘normal’ (See below). Fragmentation of the teeth was also observed at 200°C and 300°C when the colour of the teeth post-incineration was shiny black. At temperatures of 600°C and above all the teeth were extremely fragile and could be fractured under digital pressure. The teeth disintegrated into larger fragments at lower experimental temperatures and into smaller and finer fragments as the experimental temperatures increased. At lower temperatures the teeth fragmented primarily due to fissures parallel to the long axis of the teeth.

On the basis of our experiments, we recommend that in an *in-vivo* forensic investigation, stabilisation of all deciduous teeth exposed to heat be performed, irrespective of colour change. This will minimise the possibility of subsequent fragmentation during examination and handling. This stabilisation could be achieved by impregnating with cyanoacrylate cement and with polyvinyl acetate (PVA). It has been suggested that clear acrylic spray paint is the preferred impregnation material that could be used to stabilise fragile dental remains post-incineration.[9] This would aid in conducting a conclusive radiographic and morphometric analysis of the teeth, and thereby retaining critical information for identification purposes.

At 100°C crazing of the enamel surface and colour changes were apparent. Fissuring of the enamel progressed from the cemento-enamel junction towards the incisal edge, which is expected because the enamel is thinnest cervically. When temperature increased, the colour of the teeth changed, and very dark brown patches were observed at the cervical margin at 200°C. The superficial enamel surface appeared to have melted as a result of the thermal shock it had been exposed to. This observation differed from those made in the permanent teeth by Harsanyi whereby colour changes were only observed up to 200°C.[10] The overall differences in colour and microstructure observed in the deciduous teeth, as compared to the permanent teeth, may be related to the fact that the deciduous enamel is more porous and has a larger area of organic/inorganic surface interface compared to the permanent teeth.[11] It is possible that the colour changes may be the result of the ultrastructural changes, such as the formation of intra- and inter-crystalline voids and the change in morphology and phase of enamel crystals. Furthermore, an increase in the positive birefringence of the enamel due to increased temperature is known to be associated with amplified opacity, thereby altering the colour of the hard tissue.[12]

The 200°C-300°C phase in the heating of deciduous teeth was characterised by bubbling on the root surface, which was more pronounced in the cervical one-third of the root. The root surface was shiny and silvery black from the remnants of organic distillation. This bubbly phase was described by Muller *et al*. at 300°C-400°C in the permanent teeth.[13] These changes were also observed at a lower temperature in the deciduous teeth, most likely due to the hypomineralisation of enamel and dentin, in comparison with the permanent teeth.[14] In the deciduous teeth incinerated at 300°C, the pulpal aspect of dentin was characterised by an amorphous deposit. A similar finding was reported by Wilson and Massey (1987) in the permanent teeth at 400°C.[15]

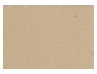
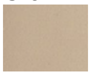
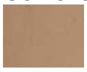
Enamel and dentin shrink with an increase in incineration temperature. As the water content of enamel is less than dentin, shrinkage is greater in the dentin and the resultant force leads to tissue separation progressing from the cervical margin; this is also likely related to enamel being thinnest cervically.[16] Also, the enamel did not separate from the dentin at the dentinoenamel junction, but during separation the enamel drew with it some portion of the coronal dentin, which was observed adhering to the under-surface of the enamel fragments. Separation of the enamel and dentin in the deciduous teeth was observed as early as at 400°C and by 500°C the enamel cap had completely undergone separation and had disintegrated into smaller fragments. This separation was observed at a lower temperature in the deciduous teeth, in comparison to the permanent teeth, where the enamel-dentin separation occurs at 450°C.[13] The reason for the early separation of enamel and dentin in primary teeth could be attributed to the higher organic content of the deciduous teeth.[16]

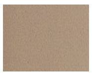
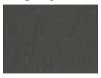
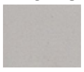
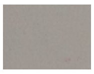
In the present study it was shown that at lower experimental temperatures the teeth fragmented into large particles, and as the temperature increased there was associated disintegration into numerous smaller fragments. The diameter of the dentinal tubules started to decrease at 500˚C; this morphological change was observed in the permanent teeth by Harsanyi and Muller *et al*, in both studies this did not occur until a temperature of at least 700°C.[10,13] The reduction in the tubular diameter of dentin gradually increased with the increase in the experimental temperatures. The tubules appeared to be obliterated due to the granulation of the inter-tubular dentin as early as at 700°C. A differential rate of obliteration of the tubules was observed at the experimental temperatures, which were more pronounced near the dentinoenamel junction. The differential rate of obliteration of the tubules could be attributed to their tapering structure. The dentinal tubules are approximately 2.5µm in diameter near the pulp and 900µm near the dentinoenamel junction.[16] Obliteration was also observed more in the dentin underneath the incisal edge and cusp tips. This is likely due to the dentinal tubules being more closely arranged in these areas. The tubular morphology was preserved because of the higher mineral content of the peritubular dentin.[16]

A unique feature observed in the dentin at 900°C was the presence of star shaped crystalline projections that appeared to arise from the peritubular dentin. The reason for this characteristic feature is currently uncertain. The cementum surface had melted into a continuous layer which covered a finely granular sub-surface and had lost its characteristic morphology. As the temperatures increased the enamel, dentin and cementum changed to a neutral white colour. At 1100°C the teeth had turned completely white with a pink tinge on the root and crown surface. The pulpal surface of the dentin at this stage was a light greenish gray colour in some areas, and pinkish in the coronal fragments, the reason for which could not be identified. A similar observation has been reported by Muller *et al*., where the root of permanent teeth appeared to be slightly pinkish at 1000°C.[13] The reason for this discolouration has not been ascertained in previous literature. The tubular morphology of dentin and the prismatic nature of enamel were identifiable at 1100°C.

The present study was a preliminary analysis of the changes induced by heat in deciduous teeth. Further extensive research is required to afford a more comprehensive insight into the effects of incineration on teeth. It was observed during the study that deciduous teeth underwent a post-incineration decrease in their weight as the experimental temperature increased due to the distillation of the organic components of the tooth. A statistical evaluation of this loss of weight would be important to correlate the temperatures and condition of the remains. It is also recommended that further research employ appropriate computer software such as Corel Photo Paint 12.0 (Corel Company, Canada) for the colorimetric analysis such as the methodology of Fereira *et al.*[17] This will reduce subjectivity and ensure the availability of an extensive range of colours.

Table 1: A summary of post-incineration changes in deciduous teeth.

Temperature	Colour	Stereomicroscopic and SEM Characteristics
100°C	Crown  Pale yellow  Very pale brown Root  Yellowish brown	Crown fracture in anterior teeth due to vertical fissures. Surface crazing. Melting of the external surface.
200°C	Crown  Pale yellow  Gray Cervical patches  Very dark brown Root  Shiny black	Surface bubbling and vesicle formation on the root surface. Silvery deposits on the root surface.
300°C	Crown  Light gray Patches  Very dark gray Root  Shiny black	Surface bubbling on the root surface. Globular knob like formations on the predentinal surface.
400°C	Enamel  Very pale brown Patches  Very dark brown Dentin  Very dark gray Cementum  Light yellowish brown	Enamel and dentin begin separation. Very deep fissures on the root surface and through the dentin.

500°C	Enamel  Light gray Patches  Dark gray Dentin  Dark bluish gray Cementum  Grayish brown  Light grayish brown	Crown-root separated. Complete separation of the enamel and dentin. Loss of enamel lustre. Reduction in the tubular diameter, especially near the dentino-enamel junction.
600°C	Enamel  Light gray Cervical patches  Very dark gray Dentin  Dark bluish gray Cementum  Bluish black	Extremely fragile remains with deep fissures in the dentin and cementum.
700°C	Enamel  Light bluish gray Dentin  Dark bluish gray Cementum Light bluish gray	Extreme reduction in the dentinal tubule diameter.
800°C	Enamel  Bluish gray Dentin  Very dark bluish gray Cementum  Very dark bluish gray	Predentinal surface had a spicular appearance.

900°C	Enamel Neutral white Dentin Light bluish gray Cementum Light bluish gray Patches Very dark bluish gray	Star-shaped fibrillar structures emerging from the intertubular dentin matrix. Cementum was unidentifiable at this temperature and had a granular appearance.
1000°C	Enamel Light bluish gray Dentin Light bluish gray Cementum-external surface Bluish black Cementum- subsurface Light bluish gray	Obliteration of the dentinal tubules was observed. Prismatic structure of the enamel and tubular morphology of the dentin remained identifiable.
1100°C	Enamel, dentin and cementum Light bluish gray Predentin Light greenish gray Pink discolouration of the crown.	Enamel and dentin remained identifiable. Granular appearance of intertubular dentin. Cementum was unidentifiable and had a granular appearance.

ACKNOWLEDGEMENTS

The authors acknowledge the facilities, scientific and technical assistance of the Australian Microscopy & Microanalysis Research Facility at the Centre for Microscopy, Characterisation & Analysis, The University of Western Australia, a facility funded by The University, State and Commonwealth Governments. We also thank the Department of Pedodontia at the Government Dental College and Hospital, Nagpur and Sharad Pawar Dental College and Hospital, Sawangi.

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TESTING STANDARD METHODS OF DENTAL AGE ESTIMATION BY MOORREES, FANNING AND HUNT AND DEMIRJIAN, GOLDSTEIN AND TANNER ON THREE SOUTH AFRICAN CHILDREN SAMPLES

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ABSTRACT

Dental age estimation of juvenile skeletal remains has utilized the methods of Moorrees, Fanning and Hunt (1963) [MFH] and Demirjian, Goldstein and Tanner (1973) [DGT] for many years with various results. The Demirjian *et al* method has been tested by several authors on their population groups with varying results. The use of these methods to age the skeletal remains of South African children by the author has not been successful. The aim of this study was to test the accuracy of the dental age estimation methods of MFH and DGT on samples of children of different ethnic groups. The study showed that the MFH method consistently under-estimates the age and the method of Demirjian *et al* over-estimates the ages.
(J Forensic Odontostomatol 2009;27:2:20-28)

Keywords: age estimation, juvenile, forensic dentistry

INTRODUCTION

Charts prepared from population surveys have been used to determine the age of individuals for orthodontic and forensic purposes for many years and have been regarded as sufficiently accurate to estimate chronological age of a juvenile. Standard charts show the bone age, dental age, height and weight, sexual development and secondary growth patterns of children and juveniles. These charts have become the standard references for age assessment used throughout the world.[1] Subsequent studies have used radiographs of the jaws to determine the state of development of the entire mandibular dentition; the maxillary teeth are not easily seen on pantomographic radiographs and little data is available for these teeth. These charts are based on dental surveys of cross sections of various populations and show the progressive states of dental development for each year of age.[2] Tanner (1962) suggested that the rate of skeletal growth had increased over the first half of the 20th century therefore creating the difference between the earlier age estimation charts and the recent ones.[5]

Moorrees, Fanning and Hunt (1963)[3] published charts based on a radiographic survey of the development of both the deciduous and permanent dentition. These charts indicate the average age and two standard deviations for the various developmental stages of the teeth. The range between ± two standard deviations represents an age range in which 95% of the population would be expected to reach the appropriate developmental landmark. These charts have proved useful for the assessment of a child's dental development with regard to the skeletal developmental stage and for planning orthodontic treatment. They have also been used for age estimation of skeletal remains.

A study of dental maturity by Demirjian, Goldstein and Tanner (1973)[4] using the pantomographic radiographs of 2928 boys and girls of French-Canadian ancestry between the ages of two and 20 was undertaken. The progressive developmental stages of the seven left mandibular teeth were allocated labels A to H. The various stages of dental development were recorded for each of the age groups. Maturity scores, based on the work of Tanner, Whitehouse and Healy (1962)[5] were developed and allotted to each tooth during its developmental stages. The total of the maturity scores of the seven teeth was then converted to tables for both boys and girls to obtain an estimated chronological age. Several authors have tested the Demirjian *et al* method against their child population groups with varying success.[6-11]

The aim of this study was to test the accuracy of the dental age estimation methods of Moorrees, Fanning and Hunt [MFH] (1963) and Demirjian, Goldstein and Tanner [DGT] (1973) against population samples of children of known chronological age from the Western Cape (Tygerberg sample), Black (Zulu) and Indian from Kwa-Zulu Natal.

MATERIALS AND METHODS

The data used for this study consisted of 914 pantomographic radiographs of children between the ages of three years to 16 years that had routine dental treatment at the Dental Faculty at Tygerberg. These were recorded as the Tygerberg sample and consisted of 472 males and 442 females of White and Coloured* origin. The pantomographic radiographs of 91 Black (Zulu) children (44 females and 47 males) with an age range of between seven and 15 years were obtained from an orthodontic practice in Durban. A sample of 153 Indian children (82 females and 71 males) with an age range of six to 16 years was obtained from two orthodontic practices in Durban. Only radiographs showing normal development and no pathological lesions were used. Each radiograph was numbered for further reference together with the name, sex, date of birth and the date on which the radiograph was taken. The chronological age of each individual was calculated by subtracting the date of birth from the date when the radiograph was taken. Each radiograph was then examined and the stages of development of each of the permanent mandibular teeth in the left mandibular quadrant were recorded. The age of each child was estimated firstly using the method of MFH (1963) and then that of DGT (1973). The estimated ages of the Tygerberg sample were then compared to their chronological ages. The data from the Indian and Zulu samples were analyzed in a similar manner. The data from each of the sample groups was used to analyze the error between the chronological age (real age) of each child with the age estimations of MFH and DGT methods respectively.

One examiner undertook all the observations.

RESULTS

The data from the Tygerberg sample was used to compare the real age (chronological age) to the estimated age by both MFH (1963) and DGT (1973) methods. Graph 1 shows a scatter diagram of the estimated ages using MFH method and compared to the real age; it was found that in the Tygerberg sample, this method under-estimated the ages in 89.2% of the sample on average by 0.91 years; the DGT method over-estimated the ages of these children on average by 0.89 years in 85.7% of the sample (Graph 2).

The data for each of the three sample groups i.e. Tygerberg, Indian and Zulu, were used to test the degree of error between the estimated age and the chronological age. The estimation error [EE] was represented graphically by comparing the real age [RA] to the difference between the estimated age [EA] minus the real age [RA] for both MFH and DGT methods (Graphs 3, 4, 6, 7, 8 & 9).

Graph 3 shows the estimation error compared to the chronological age of the Tygerberg sample of children by the MFH method. This graph shows that 96% of the sample lies below the chronological age. The error increases with age from 13 to 16 years. Graph 4 shows the estimation error compared to the chronological age of the Tygerberg sample by the DGT method. This graph shows that 86.3% of the sample lies above the chronological age. Graph 5 shows the degree of under-estimation of the ages of the Tygerberg sample by the MFH and DGT methods in age intervals. This graph indicates that the MFH method under-estimates 81% of

***Coloured people of South Africa.** The Coloured people were descended largely from Cape slaves, the indigenous Khoisan population, and other black people who had been assimilated to Cape colonial society by the late nineteenth century. Since they are also partly descended from European settlers, Coloureds are popularly regarded as being of "mixed race" although the amount of admixture from the parental populations is highly variable (Adhikari, 2006).[12]

individuals who are under 5 years of age; 94% between 5 and 7 years; 93% between 7 and 9 years; 97% between 9 and 11 years and 100% between 11 and 15 years. The DGT method therefore over-estimates 62% of individuals under the age of 5 years; 83% between 5 and 7 years; 86% between 7 and 9 years; 81% between 9 and 11 years; 94% between 11 and 13 years and 91% between 13 and 15 years (Table 2).

Graph 6 shows the under-estimation of the ages of the Indian children by the MFH method; 93.7% of the sample lies below the chronological age.

Graph 7 shows the over-estimation of the ages of 79.2% of the Indian children by the DGT method. Graph 8 shows the under-estimation of the ages of 96.7% of the Zulu children by the MFH method. Graph 9 shows the over-estimation of the ages of 90% of the Zulu children by the DGT method.
Table 1 shows that the average age under-estimation of the Tygerberg sample by the MFH method was 0.91 years in 89.2% of the sample; the average age over-estimation by the DGT method of this sample was 0.89 years in 85.7% of the sample.

Table 2 shows the percentage of the Tygerberg sample in which the ages have been under-estimated by the Moorrees *et al* method and the percentage that have been over-estimated by the Demirjian *et al* method in age intervals.

Table 3 shows the percentage of the 3 samples in which there was under-estimation and over-estimation of the chronological ages by the methods of MFH and DGT respectively. The method of MFH under-estimated the ages of 96% of the Tygerberg sample, 93.7% of the Indian sample and 96.7% of the Zulu sample. The DGT method over-estimated the ages of 86.3% of the Tygerberg sample, 79.2% of the Indian sample and 90% of the Zulu sample.

Table 1: *Average age estimation of the Tygerberg sample in years*

Moorrees *et al*	**Demirjian *et al***
-0.91 (in 89.2%)	0.89 (in 85.7%)

Table 1 shows that in the Tygerberg sample the Moorrees *et al* method under-estimated the chronological age of 89.2% of the sample by 0.91 years. The Demirjian *et al* method over-estimated the chronological age of 85.7% of the sample by 0.89 years.

Table 2: *The percentage under-estimation of the ages of the Tygerberg sample in age intervals by Moorrees et al and over-estimation by Demirjian et al methods*

Demirjian						
Age Interval	<5	5-7	7-9	9-11	11-13	13-15
% Over Est.	62%	83%	86%	81%	94%	91%
Moorrees						
Age Interval	<5	5-7	7-9	9-11	11-13	13-15
% Under Est.	81%	94%	93%	97%	100%	100%

Table 2 shows the percentage of the Tygerberg sample in which the ages have been under-estimated by the Moorrees *et al* method and the percentage that have been over-estimated by the Demirjian *et al* method in age intervals.

Table 3: *The percentage of samples where age is over-estimated and under-estimated*

	Under-estimation by Moorrees *et al*	**Over-estimation by Demirjian *et al***
Tygerberg (n = 914)	96%	86.3%
Indian (n = 153)	93.7%	79.2%
Zulu (n = 91)	96.7%	90.0%

Table 3 shows the percentage under-estimation of the chronological ages of all 3 sample groups by Moorrees *et al* and the percentage over-estimation by Demirjian *et al* for the Tygerberg, Indian and Zulu children.

DISCUSSION

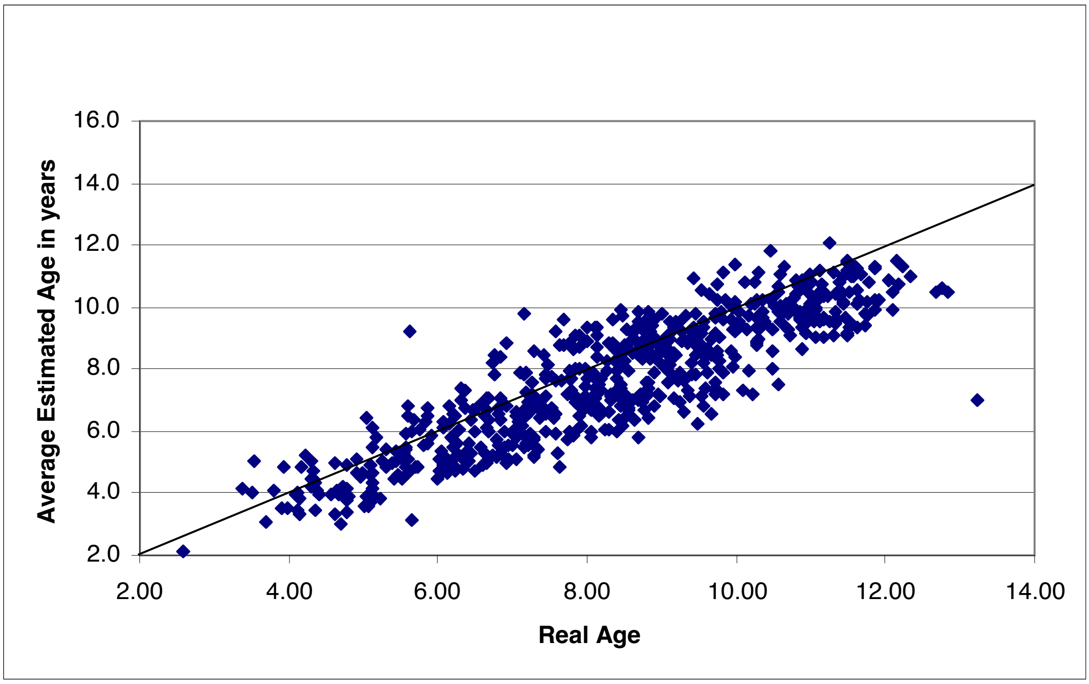
The method of Moorrees, Fanning and Hunt (1963) was used extensively for dental age estimation until Demirjian, Goldstein and Tanner (1973) published their new dental age estimation method. The MFH method was used to predict the stage of development of the teeth at a certain age whereas the DGT method was originally regarded as a better method of dental age estimation. Several authors have however shown that the use of DGT method was not accurate when applied to their population sample.[6-9] This study limited the age range of the samples to individuals between the ages of six and 16 years. The study showed that the method of MFH under-estimated the ages of the three South African sample groups and the method of DGT over-estimated the ages of these groups. The under-estimation of the ages of all three samples by MFH was over 90% in each sample group. The over-estimation of the ages of the samples varied from 79.2% for Indians, 86.3% for the Tygerberg children and 90% for the Black children.

The isolated individuals in the graphs where the age estimation by MFH (Graph 3) and that of DGT (Graph 4) are severely under-estimated or over-estimated respectively are either due to incorrect documentation of the date of birth on the radiograph or individuals that are genetically very advanced or retarded in their growth patterns. An increase in error with age was also noted especially with the DGT method. This could be due to the construction of the weighted tables in which a small change in weighted value is applied to the ages between 13 and 16 years.

CONCLUSION

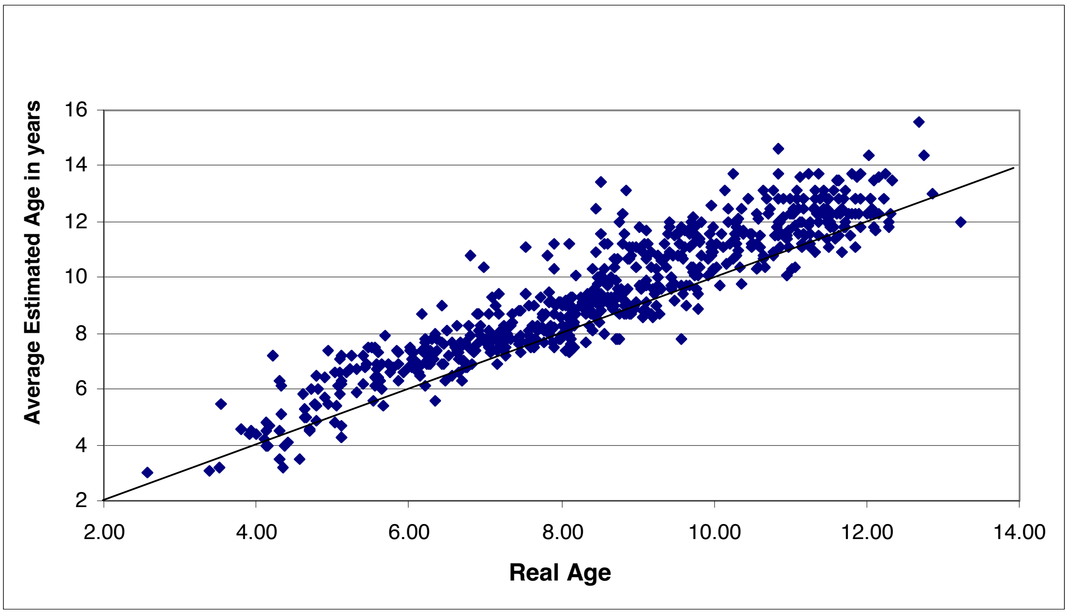
The Moorrees *et al* method consistently under-estimated the ages of the three samples of South African children. The Demirjian *et al* method over-estimated the ages of these samples. These methods are not applicable to accurately estimate the ages of South African juveniles. It therefore follows that dental age related tables for the different ethnic groups in South Africa are necessary for age estimation of these children.

***Graph 1:** Comparison between chronological age and the average estimated age of the Tygerberg sample by Moorrees, Fanning and Hunt (1963)*



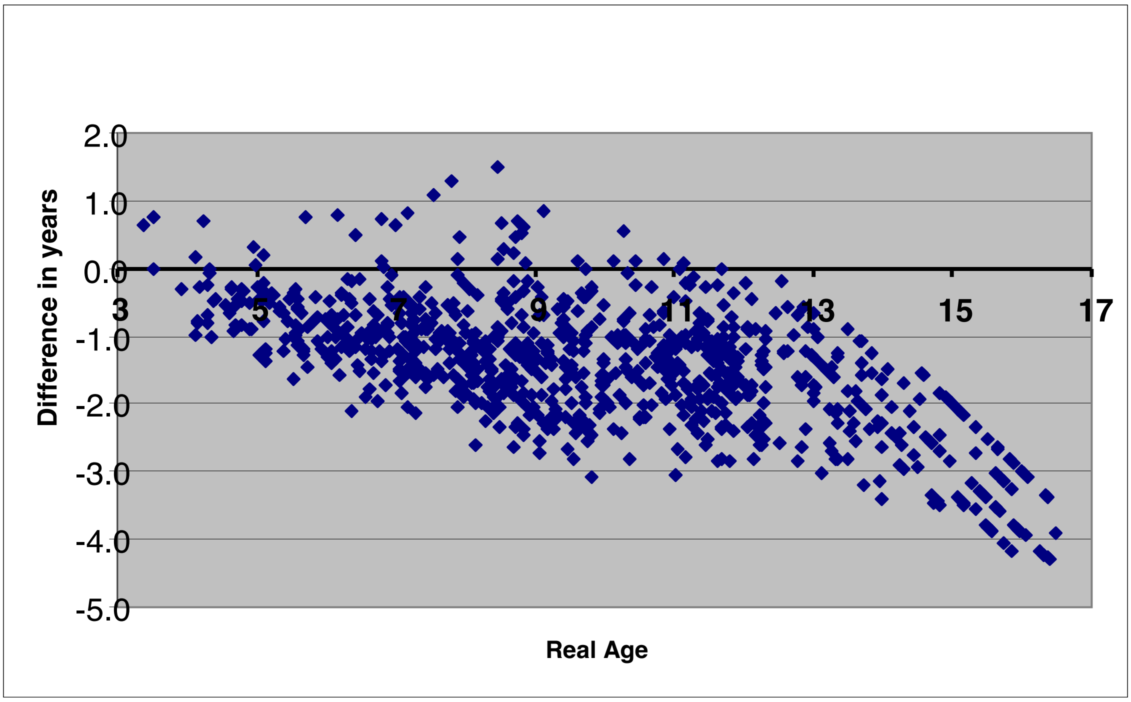
This graph shows the estimated ages using MFH method and compared to the real age; in the Tygerberg children this method under-estimated the ages in 89.2% of the sample on average by 0.91 years. The ages are in years

***Graph 2:** Comparison between the chronological age and the average estimated age of the Tygerberg sample by Demirjian, Goldstein and Tanner (1973)*



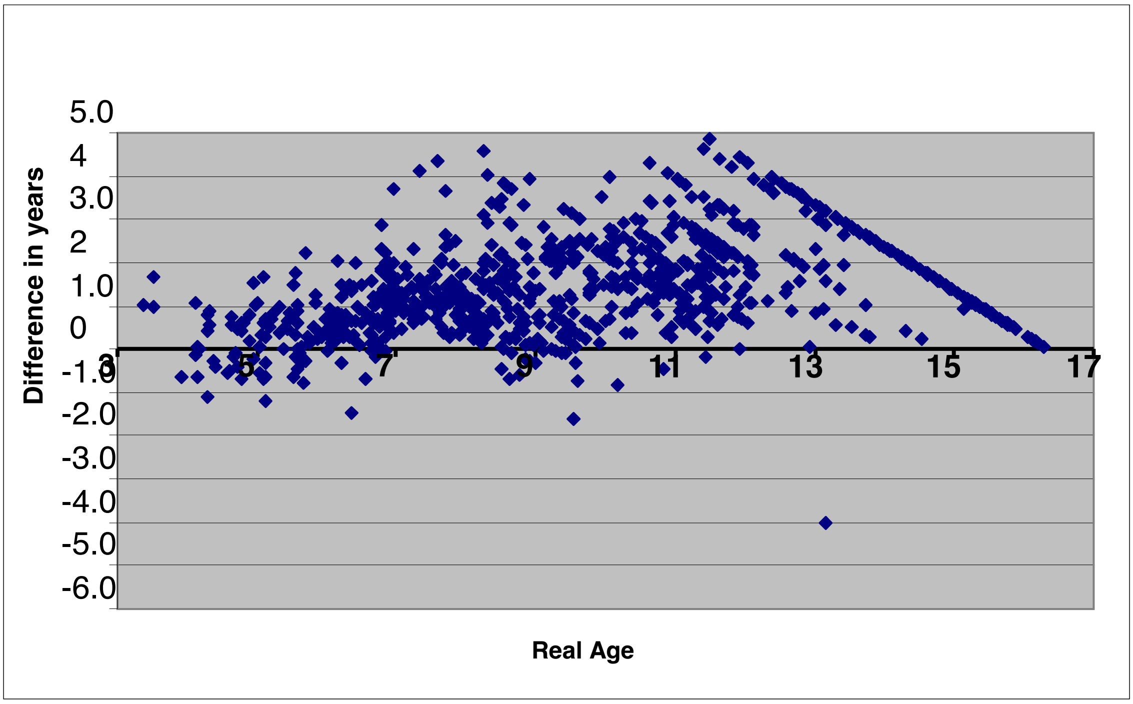
This graph shows the DGT method over-estimated the ages of the Tygerberg children on average by 0.89 years in 85.7% of the sample. The ages are in years.

Graph 3: *Tygerberg children. Age estimation error using the MFH method*



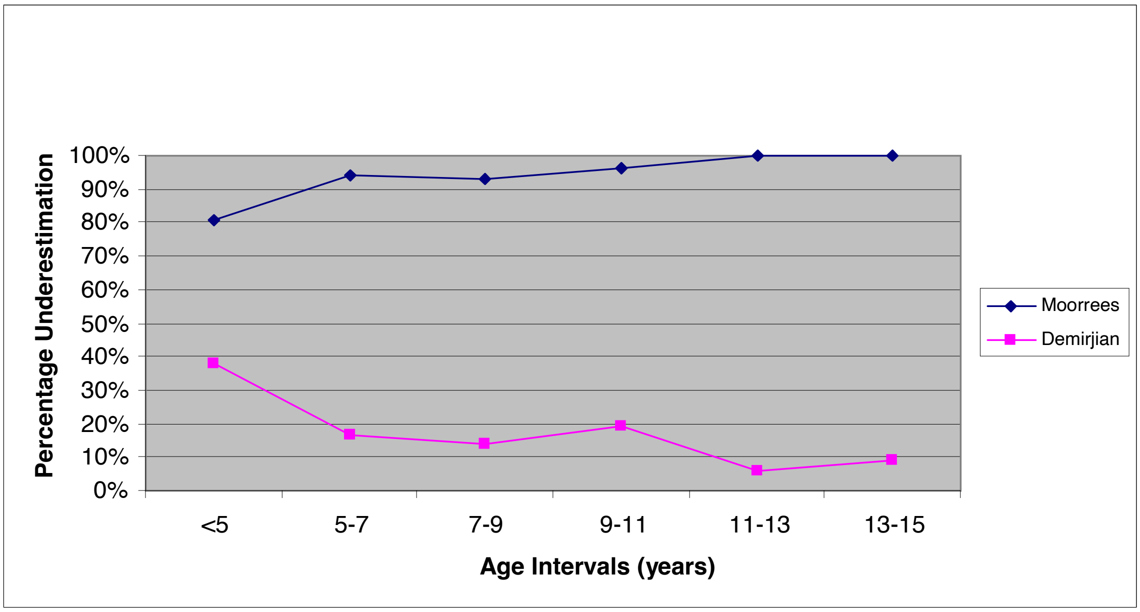
This graph shows the estimation error compared to the chronological age of the Tygerberg sample of children by the MFH method. It shows that 96% of the sample lies below the chronological age. The error increases from 13 to 16 years.

Graph 4: *Tygerberg children. Age estimation error using the DGT method*



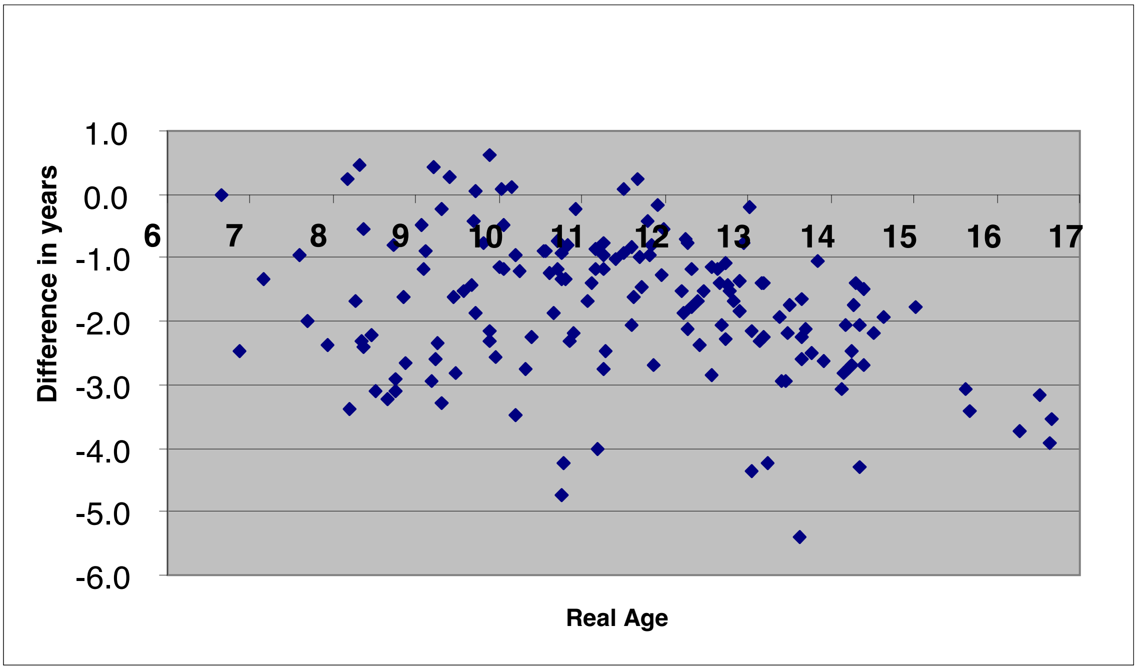
This graph shows the estimation error compared to the chronological age of the Tygerberg sample by the DGT method. This graph shows that 86.3% of the sample lies above the chronological age. The ages are in years.

Graph 5: *The percentage of under-estimation of the ages of the Tygerberg sample by the MFH and DGT methods in age intervals*



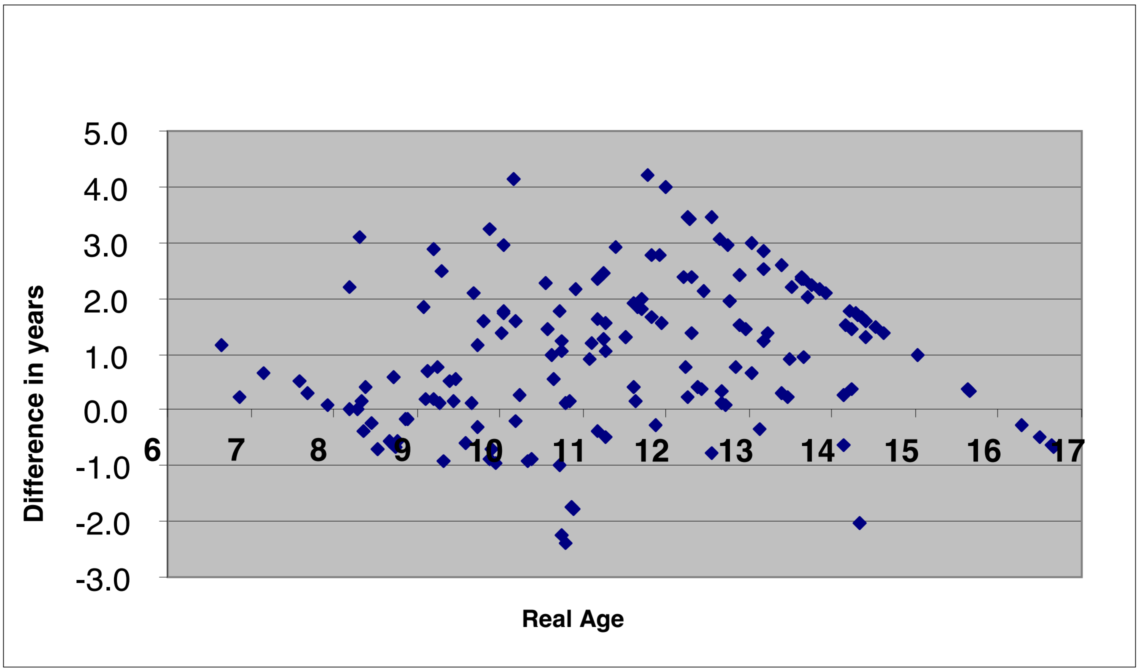
This graph shows the degree of under-estimation of the ages of the Tygerberg sample by the MFH and DGT methods in age intervals. This graph indicates that the MFH method under-estimates 81% of individuals who are under 5 years of age; 94% between 5 and 7 years; 93% between 7 and 9 years; 97% between 9 and 11 years and 100% between 11 and 15 years. The DGT method therefore over-estimates 62% of individuals under the age of 5 years; 83% between 5 and 7 years; 86% between 7 and 9 years; 81% between 9 and 11 years; 94% between 11 and 13 years and 91% between 13 and 15 years.

Graph 6: *Indian children. Age estimation error using the MFH method*



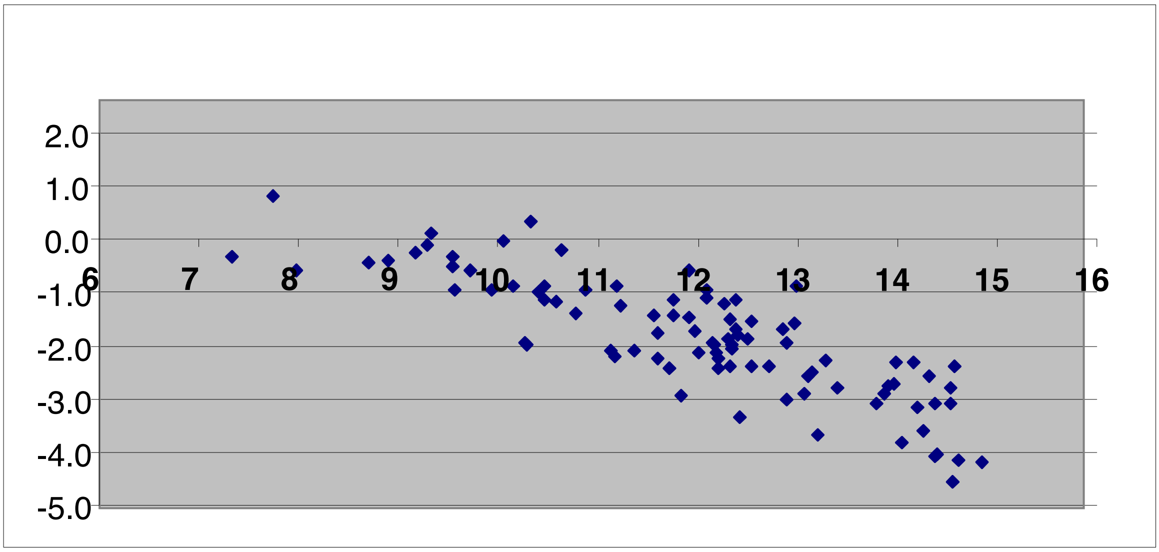
This graph shows the under-estimation of the ages of the Indian children by the MFH method; 93.7% of the sample lies below the chronological age. The ages are in years.

Graph 7: *Indian children. Age estimation error using the DGT method*



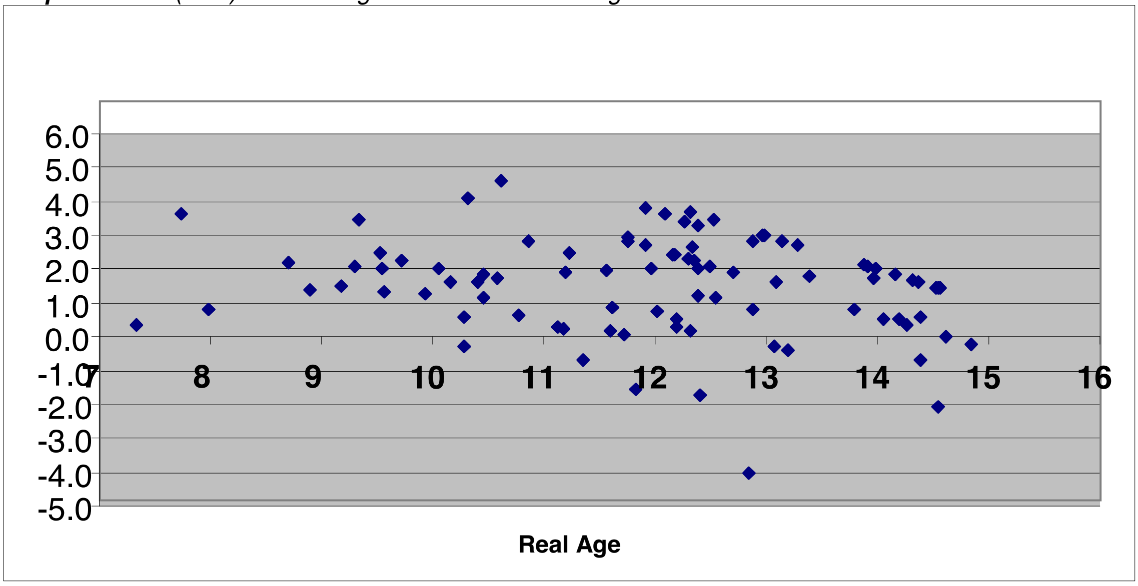
This graph shows the over-estimation of the ages of 79.2% of the Indian children by the DGT method. The ages are in years.

Graph 8: *Black (Zulu) children. Age estimation error using the MFH method*



This graph shows the under-estimation of the ages of 96.7% of the Zulu children by the MFH method. The ages are in years

Graph 9: *Black (Zulu) children. Age estimation error using the DGT method*



This graph shows the over-estimation of the ages of 90% of the Zulu children by the DGT method. The ages are in years.

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DENTAL AGE RELATED TABLES FOR CHILDREN OF VARIOUS ETHNIC GROUPS IN SOUTH AFRICA

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ABSTRACT

The standard age estimation methods of Moorrees, Fanning & Hunt (1963) and that of Demirjian, Goldstein & Tanner (1973) have been shown by several authors to be inaccurate when applied to their juvenile population. This was similarly found to be true in South African children. Pantomographic radiographs of samples of South African children of White, Coloured, Indian and Black origin were used to develop dental age related tables for these ethnic groups. These dental age estimation tables were tested and are presented.
(J Forensic Odontostomatol 2009;27:2:29-44)

Keywords: Age estimation, dental, radiology, juvenile

INTRODUCTION

Moorrees, Fanning and Hunt (1963) [MFH] published charts based on a radiographic survey of the development of the permanent dentition.[1] These charts indicate the average age and two standard deviations for the various developmental stages of the teeth. The range between ± two standard deviations represents an age range in which 95% of the population would be expected to reach the appropriate developmental landmark. These charts have proved useful for the assessment of a child's dental development with regard to the skeletal developmental stage and for planning orthodontic treatment. They have also been used for age estimation of skeletal remains. A study of dental maturity by Demirjian, Goldstein and Tanner (1973) [DGT] using the dental Pantomographic radiographs of 2928 boys and girls of French-Canadian ancestry between the ages of 2 and 20 years was undertaken.[2] The radiographic images of the progressive developmental stages of the 7 left mandibular teeth were allocated labels A to H and the various stages of dental development recorded for each of the age groups. Maturity scores, based on the work of Tanner, Whitehouse and Healy (1962) were developed and allotted to each tooth during its developmental stages.[3] The total of the maturity scores of the 7 teeth was then converted to tables for both boys and girls to obtain an estimated chronological age. Several authors have tested the Demirjian *et al* method against their child population groups with varying success rates.[4-17] Most of these authors found that the DGT method over-estimated the ages of their samples.[6-12, 14-17]

Research by Phillips (2008)[18] has shown that the standard tables of Moorrees, Fanning and Hunt (1963) and Demirjian, Goldstein and Tanner (1973) when used for age estimation on South African children was not as accurate as the results that were obtained by applying these methods on the original European samples.

The aim of this study was to construct dental age related tables for samples of South African children of different ethnic origins from dental record at the Dental Faculty of the University of the Western Cape and from Orthodontic practices in Durban, Kwa-Zulu Natal. The derivation of dental age related tables for the Tygerberg, Indian and African (Nguni) children described as Phillips Tables would then be tested on samples of White and Coloured children (Tygerberg); Indian children and African (Xhosa) children and the results statistically analysed.

MATERIALS AND METHODS

Dental Pantomographic radiographs were recovered from the archival records of patients treated at the Dental Faculty of the University of the Western Cape. The Tygerberg sample consisted of 1006 children of White and Coloured[19] origin. An Indian sample consisted of 234 children obtained from the records of two Orthodontic practices in Durban, Kwa-Zulu Natal. Most of the patients undergoing orthodontic treatment are between the ages of 7 to 16 years. A Black sample which consisted of 171 Zulu children was obtained from two Orthodontic practices in Durban, Kwa-Zulu Natal. A sample of 65 Xhosa children from the Western Cape informal settlement area were obtained from the dental records of recently treated children at the Tygerberg Dental School. These data were added to the sample of Zulu children and named the Nguni sample. The patients chosen for this study had all their developing permanent teeth visible on the Pantomograph. Those with missing teeth or severe malocclusions were rejected. Pivot tables were used to derive the median age and the standard deviation at which each stage of tooth development had taken place. Dental age related tables were constructed for Tygerberg (Table 1), Indian (Table 2) and Nguni (Table 3) children. The samples were not separated into males and females.

Dental age related tables were derived, and the standard error of the mean was calculated for each sample group. The author was the only observer of the radiographic images of the developmental stages of the teeth.

A new Tygerberg sample used for this part of the study was an additional set of individuals obtained from the files of children currently undergoing dental treatment at the Dental Faculty of the University of the Western Cape. The Tygerberg sample consisted of 91 children, 70 White, 21 Coloured. The Indian and Xhosa samples were a random selection of children from the original data bases used in this study. There were 112 Indian and 62 Xhosa children respectively. The Tygerberg, Indian and Xhosa samples were analysed in the following manner: the age of each child was estimated using the MFH, the DGT methods. Then the ages of the individuals were estimated using the Phillips Tables applicable for each sample. (Phillips Table 1 was used for the Tygerberg sample, Phillips Table 2 was used for the Indian sample and Phillips Table 3 was used for the Xhosa sample). The age estimation error for each method was calculated and depicted graphically. The real ages and the errors of the estimated ages of each method were subjected to regression analysis. All r-correlation coefficients were tested for significance and in every case the p-value was significant at the $p< 0.05$ level.

Table 1: *Dental Age Related Table for Tygerberg Children (SD in years) (n = 1006)*

	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F					4.44 (0.85)			8.85 (1.39)
Ci					4.74 (1.06)		4.13 (0.64)	9.29 (1.16)
Cco					4.97 (0.74)		4.74 (1.47)	10.40 (1.34)
Coc				3.26	4.78 (1.00)		4.75 (0.53)	10.98 (1.05)
Cr1/2			4.14	4.65 (0.65)	5.30 (0.80)		5.42 (0.82)	12.08 (1.12)
Cr3/4		3.96 (0.27)	4.70 (0.75)	5.16 (0.72)	6.21 (0.74)	3.26	6.28 (0.81)	12.62 (1.38)
Crc	4.06 (0.36)	4.74 (0.78)	5.30 (0.94)	6.29 (0.95)	7.39 (0.88)	4.04 (0.24)	7.56 (1.00)	13.38 (1.24)
Ri	4.53 (0.61)	5.27 (0.70)	6.11 (0.81)	7.13 (0.87)	8.23 (0.90)		8.29 (0.76)	14.18 (1.44)
Cli						4.70 (0.92)	8.77 (0.95)	15.09 (1.09)
R1/4	5.37 (0.65)	6.02 (0.60)	7.42 (0.94)	8.26 (0.90)	9.14 (1.17)	5.45 (0.86)	10.04 (1.00)	15.24 (0.96)
R1/2	6.07 (0.54)	6.78 (0.88)	8.52 (1.03)	9.63 (1.06)	10.45 (1.04)	6.25 (0.55)	11.05 (1.01)	
R3/4	6.89 (0.93)	7.35 (0.66)	10.00 (1.17)	10.50 (1.01)	11.09 (1.15)	7.25 (0.77)	11.73 (0.77)	
Rc	7.25 (0.58)	8.08 (0.70)	11.23 (1.10)	11.41 (0.83)	12.06 (1.02)	8.05 (0.76)	12.60 (0.91)	
A1/2	8.02 (0.68)	8.76 (0.78)	12.14 (0.96)	12.14 (0.77)	12.72 (1.16)	9.10 (0.85)	14.04 (1.06)	
Ac								

The Ac stage is omitted for age estimation. Only teeth that have not fully developed are used to estimate the age of the individual. The median age at which the stage of calcification is visible and the standard deviation are shown in brackets.

Table 2: *Dental Age Related Table for Indian Children (SD in years) (n = 234)*

	I 1	**I 2**	**C**	**Pm1**	**Pm2**	**M1**	**M2**	**M3**
Fi								
F								9.71
Ci								9.78 (1.06)
Cco								10.81 (1.33)
Coc								11.32 (1.10)
Cr1/2							6.87	10.86 (0.84)
Cr3/4					6.97 (0.14)		8.75 (1.30)	12.40 (1.26)
Crc				7.07	9.19 (0.92)		8.64 (1.10)	13.36 (1.18)
Ri				8.41 (1.30)	9.33 (1.01)		8.34 (0.86)	
Cli							9.59 (0.84)	14.09 (0.97)
R1/4			9.11 (0.87)	9.20 (0.87)	9.85 (1.00)		10.28 (1.15)	14.95 (0.68)
R1/2	6.76 (0.15)	7.72 (0.92)	9.64 (1.14)	10.36 (0.82)	10.40 (0.92)		11.04 (0.83)	15.30 (1.54)
R3/4	8.39 (0.66)	8.71 (0.88)	10.37 (1.08)	10.96 (1.52)	11.40 (1.22)	8.29 (1.93)	12.05 (1.12)	
Rc	9.58 (1.15)	9.57 (1.10)	11.62 (1.30)	11.53 (1.05)	11.60 (1.81)	8.62 (0.99)	12.66 (1.56)	
A1/2	9.41 (0.96)	9.57 (0.80)	12.47 (1.18)	12.15 (1.28)	13.04 (0.92)	9.65 (1.04)	13.89 (0.91)	
Ac								

The Ac stage is omitted for age estimation. Only teeth that have not fully developed are used to estimate the age of the individual. The median age at which the stage of calcification is visible and the standard deviation are shown in brackets.

RESULTS

The dental age related tables, derived from pivot tables, showed that there are differences in the developmental stages of the teeth in the left mandible for each ethnic group. Table 1 shows the various ages at which the calcification stages of the incisors, canine, premolars and molars of Tygerberg children are visible on Pantomographic radiographs. The median age at which the various stages of calcification of each tooth are visible is shown in years with the standard deviation in brackets. Table 2 shows the various ages at which the calcification stages of the incisors, canine, premolars and molars of the Indian children are visible on Pantomographic radiographs. The median age at which calcification is visible is shown in years with the standard deviation. Table 3 shows similar age related stages for the Nguni children. The median age for each stage and the standard deviation are shown. Table 4 shows the number of individuals per age group for each of the sample groups. Table 5 shows the standard abbreviation of developmental stages of teeth.

The MFH method of age estimation of the new Tygerberg sample resulted in 38.4% of the sample being estimated to within 1 year of the real age (Graph 1a). The *accuracy* of the MFH method is measured by the amount of scatter in relation to the trend line (Graph 1b).Regression analysis of the MFH method showed an R-value of 0.63 with a p-value of 1.6376×10^{-11}(Table 6).

Table 3: *Dental Age Related Table for Nguni Children (SD in years) (n = 236)*

	I 1	I 2	C	Pm1	Pm2	M1	M2	M3
Fi								
F								
Ci								8.50 (0.96)
Cco								9.64 (1.18)
Coc					5.94		5.94	10.91 (1.30)
Cr1/2				6.03 (0.12)	6.45 (0.64)		6.50 (0.67)	11.30 (1.47)
Cr3/4			6.12 (0.01)	6.57 (0.73)	7.32 (1.54)		6.94 (1.04)	11.93 (1.43)
Crc		6.12	6.35 (0.71)	7.72 (1.83)	8.07 (1.64)		7.87 (0.90)	12.54 (1.02)
Ri	6.12 (0.01)	6.03 (0.12)	6,74 (0.40)	7.80 (1.30)	8.46 (0.92)		10.03 (1.65)	12.76 (0.98)
Cli							9.45 (1.31)	13.82 (1.55)
R1/4	6.14 (0.40)	6.52 (0.66)	8.44 (1.25)	8.97 (0.81)	9.93 (0.96)		10.27 (0.89)	14.45 (0.97)
R1/2	6.79 (0.87)	7.01 (0.97)	9.29 (0.58)	9.82 (0.82)	10.48 (1.18)	6.22 (0.34)	11.43 (1.39)	15.64 (0.91)
R3/4	7.24 (1.26)	6.94 (0.44)	10.71 (1.31)	10.50 (1.11)	11.22 (1.21)	7.21 (0.95)	12.24 (0.87)	15.78
Rc	8.91 (1.14)	9.07 (0.86)	11.73 (1.42)	11.65 (1.32)	12.33 (1.29)	8.35 (0.97)	12.99 (1.29)	
A1/2	8.98 (1.01)	10.13 (1.21)	12.49 (1.26)	12.34 (1.07)	13.06 (1.37)	9.60 (1.05)	13.72 (1.01)	
Ac								

The Ac stage is omitted for age estimation. Only teeth that have not fully developed are used to estimate the age of the individual. The median age at which the stage of calcification is visible and the standard deviation are shown in brackets.

Table 4: *The number of children in each age group*

Children Age Groups for Tygerberg, Indian & Nguni Samples

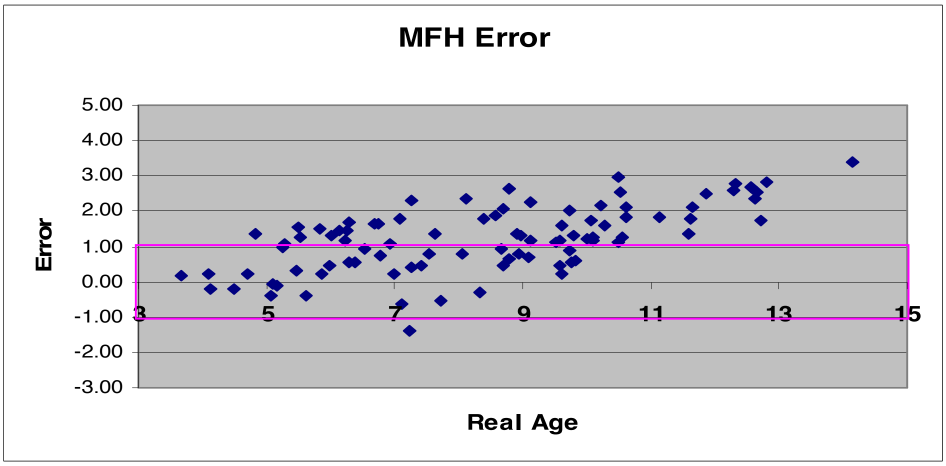
Age Group Years	**No. in Group**		
	Tygerberg	**Indian**	**Nguni**
3 to 4	10		
4 to 5	40		
5 to 6	70		2
6 to 7	98	2	7
7 to 8	115	5	6
8 to 9	133	20	13
9 to 10	110	37	22
10 to 11	89	39	26
11 to 12	128	42	36
12 to 13	74	33	47
13 to 14	54	28	26
14 to 15	30	20	27
15 to 16	41	4	15
16 to 17	14	4	9
Total	**1006**	**234**	**236**

Table 5: *The standard abbreviation of developmental stages of teeth*

Ci	Cusp initiation
Cco	Cusp coalescence
Coc	Cusp outline complete
Cr½	Crown half formed
Cr¾	Crown three quarters formed
Crc	Crown completely formed
Ri	Root initiation
Cli	Cleft initiation (molars only)
R¼	Root one quarter formed
R½	Root half formed
R¾	Root three quarters formed
Rc	Root complete
A½	Apex one half complete
Ac	Apex complete

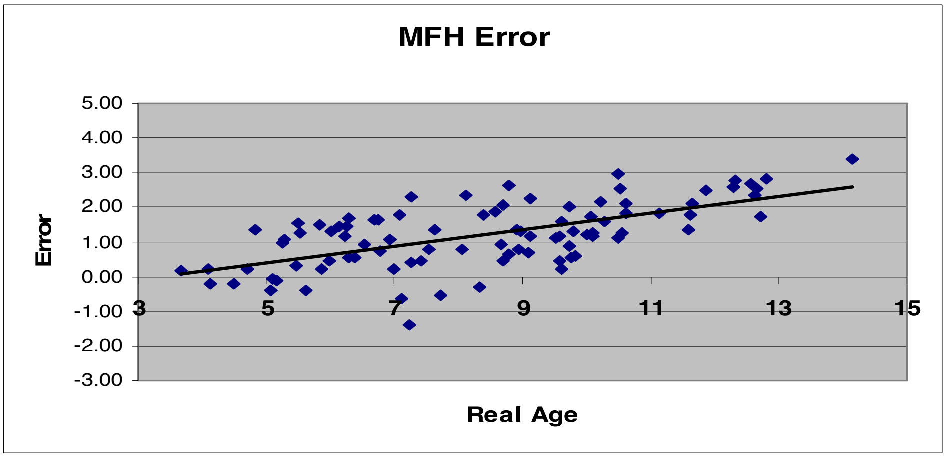
Moorrees, Fanning & Hunt (1963)

Graph 1a: *The age estimation error of the MFH method. Tygerberg (n = 91)*



The scale of the error is from -3.00 to 5.00. The *alignment* of the sample (Graph 1a) shows that 38.4 % of the sample is within 1 year of Real Age. The MFH method under-estimates the ages of the majority of the sample. [If the error is positive then the estimated age is less than the real age]

Graph 1b: *The age estimation error of the MFH method. Tygerberg (n = 91)*



The *accuracy* of the MFH method is measured by the amount of scatter in relation to the trend line (Graph 1b). The R-value (R = 0.633) indicates that the MFH method is strongly predictive. The regression correlation is significant ($p<0.05$)

***Table 6:**: Regression analysis of MFH method on the Tygerberg sample*

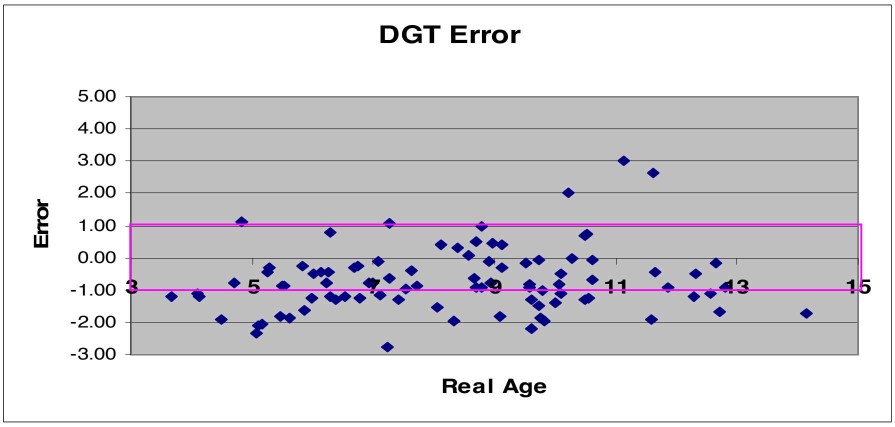
Regression Statistics	
R	0.633
R Square	0.401
Observations	91

ANOVA

	df	Significance F
Regression	1	1.63^{-11}

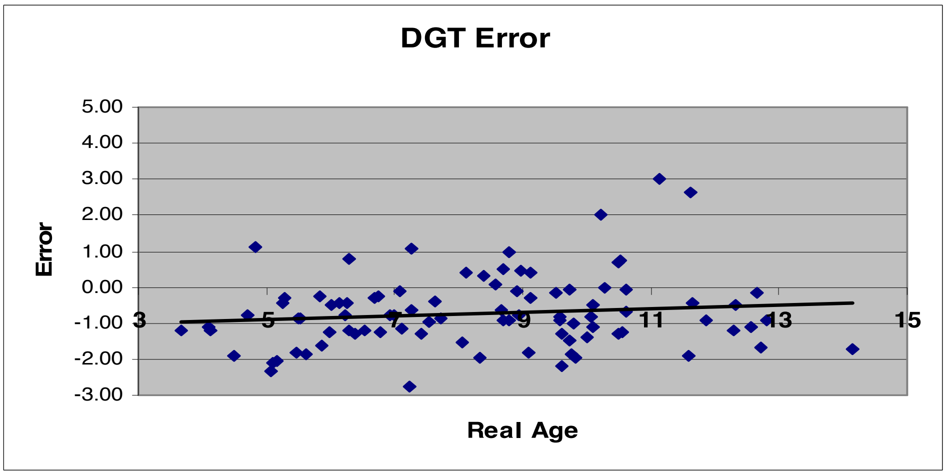
The DGT method of age estimation of the Tygerberg sample resulted in 53.8% of the sample being estimated to within 1 year of the real age (Graph 2a). The *accuracy* of the DGT method is measured by the amount of scatter in relation to the trend line (Graph 2b). Regression analysis of the DGT method showed an R-value of 0.91 with a p-value of 2.40 x 10^{-36} (Table 7).

***Graph 2a:** The age estimation error of the DGT method. Tygerberg (n = 91)*



The scale of the error is from -3.00 to 5.00.The *alignment* of the sample (Graph 2a) shows that 53.8 % of the sample is within 1 year of Real Age. The DGT method over-estimates the ages of the sample. [If the error is negative then the estimated age is greater than the real age]

***Graph 2b:** The age estimation error of the DGT method. Tygerberg (n = 91)*



The *accuracy* of the DGT method is measured by the amount of scatter in relation to the trend line (Graph 2b). The R-value (R = 0.913) indicates that the DGT method is strongly predictive. The regression correlation is significant (p<0.05)

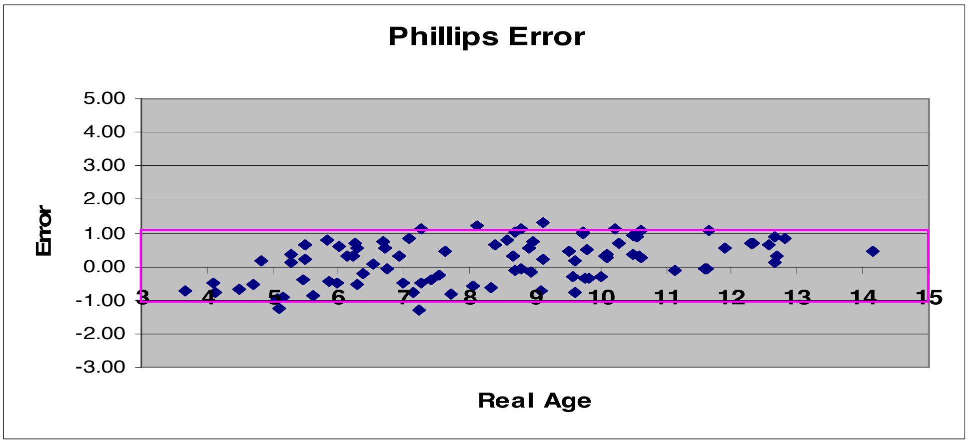
Table 7: *Regression analysis of the DGT method on the Tygerberg sample*

Regression Statistics		
R	0.913	
R Square	0.833	
Observations	91	
ANOVA		
	df	Significance F
Regression	1	2.40^{-36}

The R correlation is significant (p<0.05) and strongly predictive. This method is more accurate than the MFH method, but over-estimates the ages of 46.8% of the Tygerberg sample.

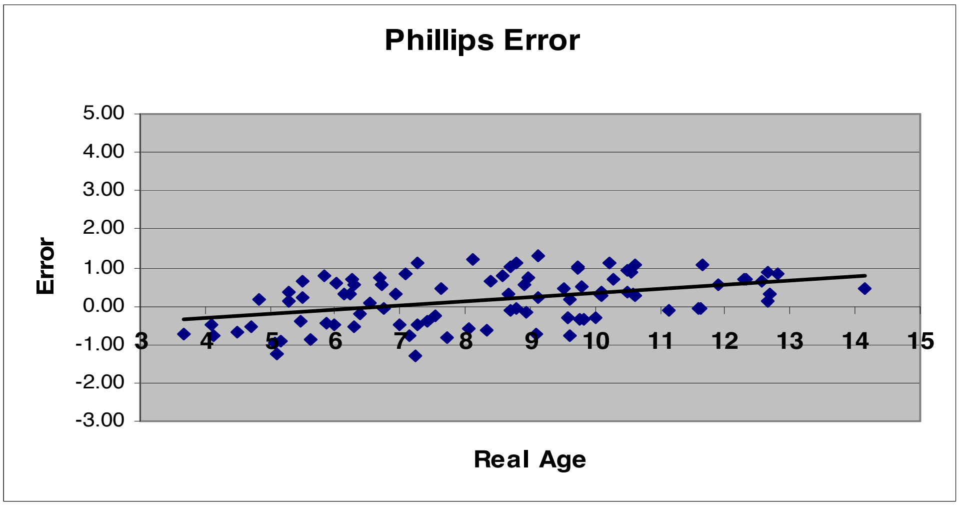
The Phillips Table 1 used for age estimation of the Tygerberg sample resulted in 88.4% of the sample being estimated to within 1 year of the real age (Graph 3a).
The *accuracy* of the Phillips method is measured by the amount of scatter in relation to the trend line (Graph 3b). Regression analysis of the Phillips Table 1 showed an R-value of 0.966 with a p-value of 3.18×10^{-54} (Table 8).

Graph 3a: *The age estimation error of the Phillips Table 1. Tygerberg (n = 91)*



The scale of the error is from -3.00 to 5.00. *The alignment* of the sample shows that 88.4 % of the sample is within 1 year of Real Age.

Graph 3b: *The age estimation error of the Phillips Table 1. Tygerberg (n = 91)*



The *accuracy* of the Phillips method is measured by the amount of scatter in relation to the trend line (Graph 3b). The R-value (R = 0.966) indicates that the Phillips method is strongly predictive. The R correlation is significant (p<0.05)

Table 8: *Regression analysis of the Phillips Table 1 on the Tygerberg sample*

Regression Statistics	
R	0.966
R Square	0.934
Observations	91

ANOVA

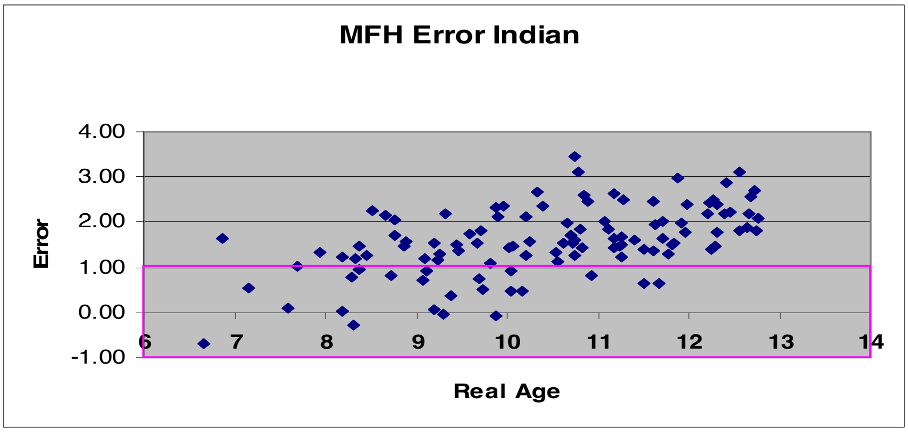
	df	Significance F
Regression	1	3.18^{-54}

The Phillips method is more accurate than the MFH and the DGT methods for ageing Tygerberg children.

The MFH method of age estimation of the Indian sample resulted in 19.6% of the sample being estimated to within 1 year of the real age (Graph 4a).

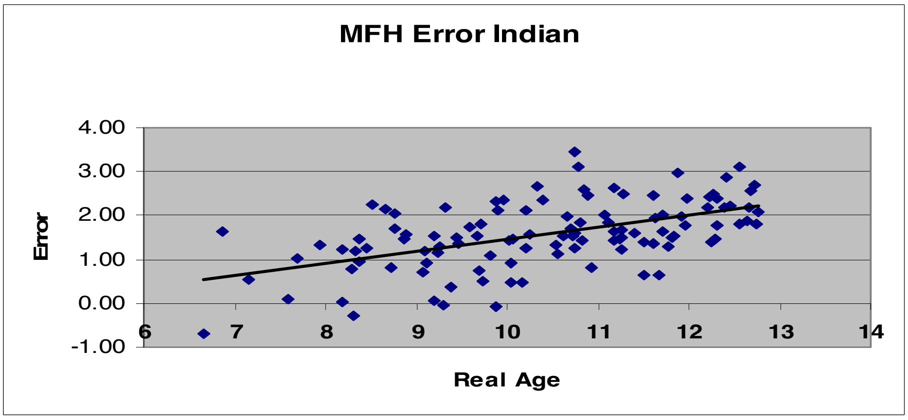
The *accuracy* of the MFH method is measured by the amount of scatter in relation to the trend line (Graph 4b). Regression analysis of the MFH method showed an R-value of 0.54 with a p-value of 7.704 x 10^{-10} (Table 4).

Graph 4a: *The age estimation error of the MFH method. Indian (n = 112)*



The scale of the error is from -1.00 to 4.00. The *alignment* of the sample (Graph 4a) shows that 19.6 % of the sample is within 1 year of Real Age. The MFH method under-estimates the ages of the majority of the sample.

Graph 4b: *The age estimation error of the MFH method. Indian (n = 112)*



The *accuracy* of the MFH method is measured by the amount of scatter in relation to the trend line (Graph 4b). The R-value (R = 0.540) indicates that the MFH method is predictive. The regression correlation is significant (p<0.05)

Table 9: *Regression analysis of the MFH method on the Indian sample*

Regression Statistics	
R	0.540
R Square	0.292
Observations	112

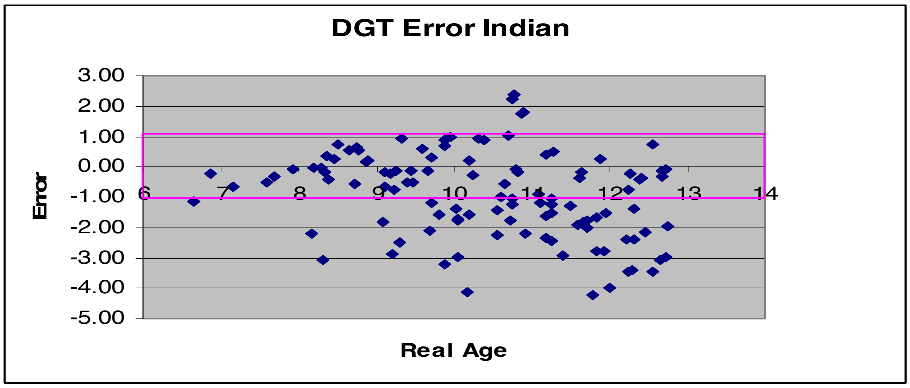
ANOVA

	df	Significance F
Regression	1	7.704^{-10}

The R correlation is significant (p<0.05) and predictive, but the MFH method under-estimates the ages of 80.4% of the Indian sample.

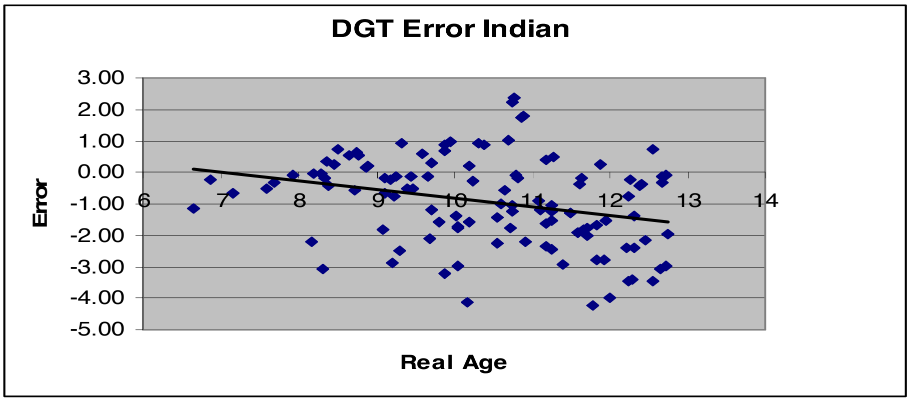
The DGT method of age estimation of the Indian sample resulted in 46.4% of the sample being estimated to within 1 year of the real age (Graph 5a). The *accuracy* of the DGT method is measured by the amount of scatter in relation to the trend line (Graph 5b). Regression analysis of the DGT method showed an R-value of 0.306 with a p-value of 0.001022 (Table 10).

Graph 5a: *The age estimation error of the DGT method. Indian (n = 112)*



The scale of the error is from -5.00 to 3.00. *The alignment* of the sample (Graph 5a) shows that 46.4 % of the sample is within 1 year of Real Age. The DGT method over-estimates the ages of the majority of the sample. [If the error is negative then the estimated age is greater than the real age]

Graph 5b: *The age estimation error of the DGT method. Indian (n = 112)*



The *accuracy* of the DGT method is measured by the amount of scatter in relation to the trend line (Graph 5b). The R-value (R = 0.306) indicates that the DGT method is predictive, but there is a significant amount of scatter around the trend line. The regression correlation is significant (p<0.05)

***Table 10:** Regression analysis of the DGT method on the Indian sample*

Regression Statistics	
R	0.306
R Square	0.094
Observations	112

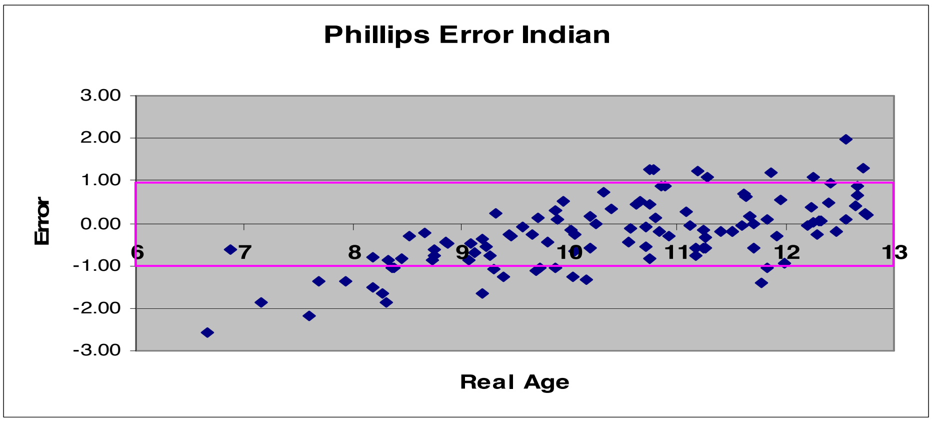
ANOVA

	df	Significance F
Regression	1	0.001022684

The regression correlation is significant ($p<0.05$) for the DGT method. The method overestimated the ages of 53.6% of the Indian sample.

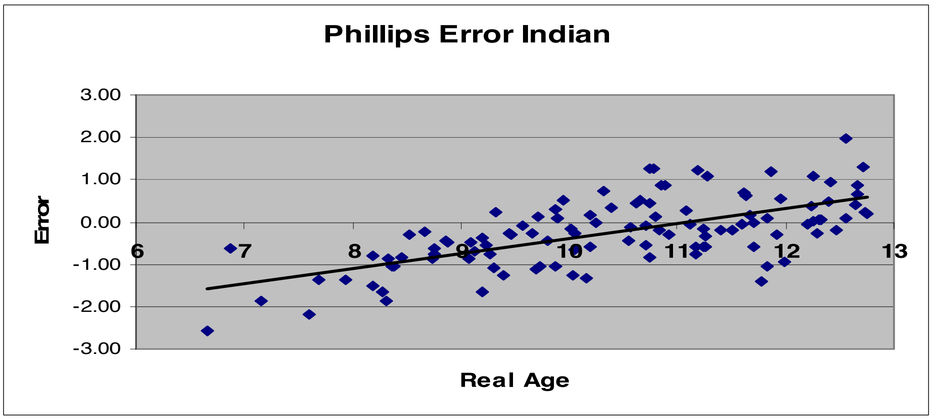
The Phillips Table 2 used for age estimation of the Indian sample resulted in 75% of the sample being estimated to within 1 year of the real age (Graph 6a). The *accuracy* of the Phillips method is measured by the amount of scatter in relation to the trend line (Graph 6b). Regression analysis of the Phillips Table 2 showed an R-value of 0.65 with a p-value of 8.22×10^{-15} (Table 11).

***Graph 6a:** The age estimation error of the Phillips Table 2. Indian (n = 112)*



The scale of the error is from -3.00 to 3.00. *The alignment* of the sample shows that 75 % of the sample is within 1 year of Real Age.

***Graph 6b:** The age estimation error of the Phillips Table 2. Indian (n = 112)*



The *accuracy* of the Phillips method is measured by the amount of scatter in relation to the trend line (Graph 6b). The R-value (R = 0.651) indicates that the Phillips method is strongly predictive. The R correlation is significant ($p<0.05$)

Table 11: *Regression analysis of Phillips Table 2 on the Indian sample*

Regression Statistics	
R	0.651
R Square	0.423
Observations	112

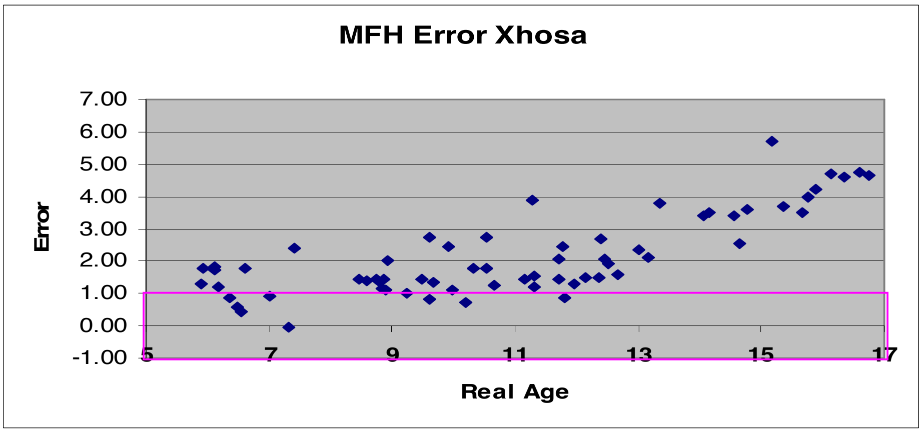
ANOVA

	df	*Significance F*
Regression	1	8.22^{-15}

The Phillips method is more accurate than the MFH and the DGT methods for ageing Indian children.

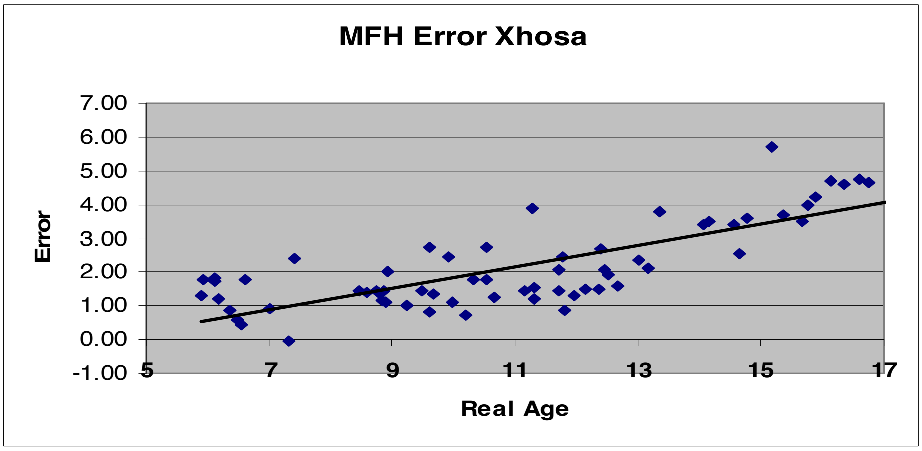
The MFH method of age estimation of the Xhosa sample resulted in 13.8% of the sample being estimated to within 1 year of the real age (Graph 7a). The accuracy of the MFH method is measured by the amount of scatter in relation to the trend line (Graph 7b). Regression analysis of the MFH method showed an R-value of 0.784 with a p-value of 1.069×10^{-14} (Table 12).

Graph 7a: *The age estimation error of the MFH method. Xhosa (n = 65)*



The scale of the error is from -1.00 to 7.00. The *alignment* of the sample (Graph 7a) shows that 13.8 % of the sample is within 1 year of Real Age. The MFH method under-estimates the ages of the majority of the sample.

Graph 7b: *The age estimation error of the MFH method. Xhosa (n = 65)*



The *accuracy* of the MFH method is measured by the amount of scatter in relation to the trend line (Graph 7b). The R-value (R = 0.784) indicates that the MFH method is strongly predictive. The regression correlation is significant ($p<0.05$)

***Table 12:** Regression analysis of the MFH method on the Xhosa sample*

Regression Statistics	
R	0.784
R Square	0.615
Observations	65

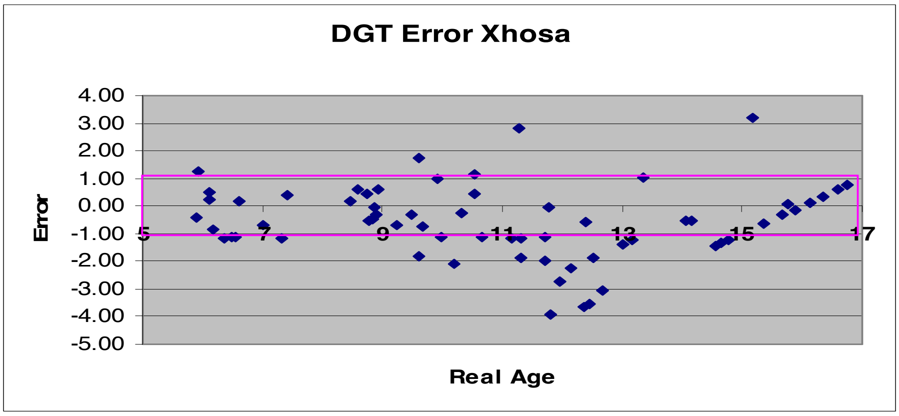
ANOVA

	df	Significance F
Regression	1	1.069^{-14}

The R correlation is significant (p<0.05) and predictive, but the MFH method under-estimates the ages of 86.2% of the Xhosa sample.

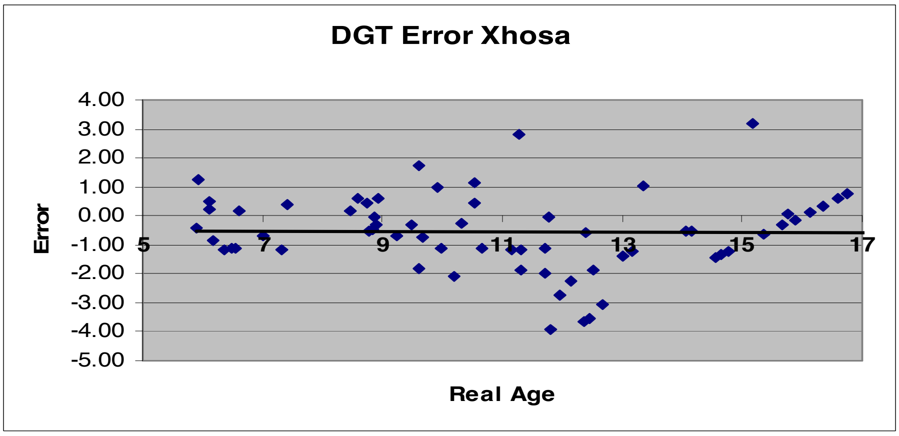
The DGT method of age estimation of the Xhosa sample resulted in 49.2% of the sample being estimated to within 1 year of the real age (Graph 8a). The *accuracy* of the DGT method is measured by the amount of scatter in relation to the trend line (Graph 8b). Regression analysis of the DGT method showed an R-value of 0.013 with a p-value of 0.912 (Table 13).

***Graph 8a:** The age estimation error of the DGT method. Xhosa (n = 62)*



The scale of the error is from -5.00 to 4.00. *The alignment* of the sample (Graph 8a) shows that 49.2 % of the sample is within 1 year of Real Age. The DGT method over-estimates the ages of the majority of the sample. [If the error is negative then the estimated age is greater than the real age]

***Graph 8b:** The age estimation error of the DGT method. Xhosa (n = 62)*



The *accuracy* of the DGT method is measured by the amount of scatter in relation to the trend line (Graph 8b). The R-value (R = 0.014) indicates that the DGT method is not predictive because there is a significant amount of scatter around the trend line even though this line is parallel to the X-axis. The regression correlation is not significant (p=0.912)

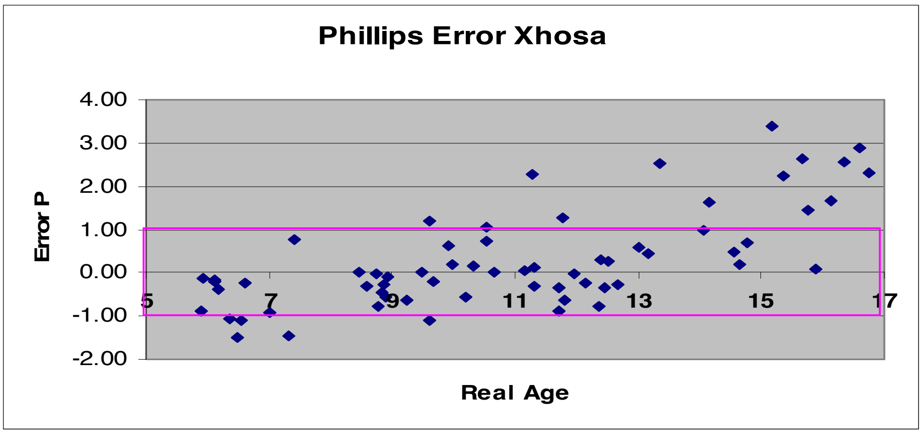
Table 13: *Regression analysis of the DGT method on the Xhosa sample*

Regression Statistics	
R	0.014
R Square	0.0001
Observations	65

ANOVA		
	df	Significance F
Regression	1	0.912

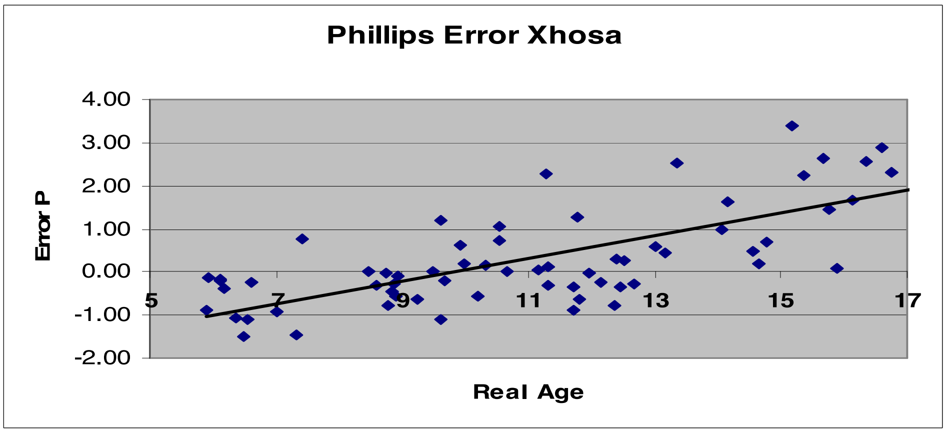
The DGT method is inaccurate for age estimation of this Xhosa sample.
The Phillips Table used for age estimation of the Xhosa sample resulted in 69.2% of the sample being estimated to within 1 year of the real age (Graph 9a). The *accuracy* of the Phillips method is measured by the amount of scatter in relation to the trend line (Graph 9b). Regression analysis of the Phillips Table 3 showed an R-value of 0.71 with a p-value of 2.10 x 10^{-11} (Table 14).

Graph 9a: *The age estimation error of the Phillips Table 3. Xhosa (n = 62)*



The scale of the error is from -2.00 to 4.00. The *alignment* of the sample shows that 69.2% of the sample is within 1 year of Real Age.

Graph 9b: *The age estimation error of the Phillips Table 3. Xhosa (n = 62)*



The *accuracy* of the Phillips method is measured by the amount of scatter in relation to the trend line (Graph 9b). The R-value (R = 0.716) indicates that the Phillips method is strongly predictive. The R correlation is significant (p<0.05)

Table 13: *The Regression analysis of Phillips Table 3 on Xhosa sample*

Regression Statistics	
R	0.716
R Square	0.512
Observations	65
ANOVA	
	Significance F
Regression	2.10552E-11

Table 14: *The percentages of the Tygerberg, Indian & Xhosa samples estimated to within 1 year of the chronological age using the methods of MFH, DGT and Phillips*

	Tygerberg	Indian	Xhosa
MFH	38.4	19.6	13.8
DGT	53.8	46.4	49.2
Phillips	88.4	75.0	69.2

Table 15: *The regression correlation for the MFH, DGT & Phillips methods*

	Tygerberg	Indian	Xhosa
MFH	R = 0.633	R = 0.540	R = 0.784
DGT	R = 0.913	R = 0.306	R = 0.014
Phillips	R = 0.966	R = 0.651	R = 0.716

The Phillips method is more accurate for the age estimation of Xhosa children than the MFH and DGT methods.

The age estimation errors for the Tygerberg sample using the MFH, DGT and the Phillips Table 1 resulted in 38.4%, 53.8% and 88.4% of the sample being within 1 year of the chronological ages of the individuals respectively (Table 14). The regression analysis of the estimated ages of the Tygerberg sample showed that the r-value of 0.966 and the p-value of 3.18×10^{-54} indicate that the Phillips Table 1 for White and Coloured children is more accurate than the methods of MFH and DGT (Table 15). The age estimation errors for the Indian sample using the MFH, DGT and the Phillips Table 2 resulted in 19.6%, 46.4% and 75% of the sample being within 1 year of the chronological ages of the individuals respectively (Table 14). The regression analysis of the estimated ages of the Indian sample showed that the r-value of 0.651 and the p-value of 8.22×10^{-15} indicate that the Phillips Table 2 for Indian children is more accurate than the methods of MFH and DGT (Table 15). The age estimation errors for the Xhosa sample using the MFH, DGT and the Phillips Table methods resulted in 13.8%, 49.2% and 69.2% of the sample being within 1 year of the chronological ages of the individuals respectively (Table 14). The regression analysis of the estimated ages of the Xhosa sample showed that the r-value of 0.716 and the p-value of 2.106×10^{-11} indicate that the Phillips Table 3 for Xhosa children is more accurate than to the methods of MFH and DGT (Table 15).

DISCUSSION

The comparison of the developmental stages of each tooth from the Tygerberg, Indian and the Nguni samples showed that the Tygerberg sample, which consisted of White and Coloured children, are slightly ahead of the Indian and Nguni children in the calcification of the apices of the incisors, canine, premolars and 1st molar. The calcification of the root apex in the 2nd and 3rd molars shows a reversal in the developmental ages. The Indian and Black children are slightly ahead of the Tygerberg children. The differences in the calcification stages of the teeth in the sample groups is marginally different and of importance when dealing with age prediction in living children who are undergoing orthodontic treatment or in clinical evaluation of relating their skeletal maturity to their dental development. If, however, one is estimating the age of skeletal remains of children, it would appear that the slight differences in the ages at the various developmental stages of the teeth are not as critical as originally believed. In the dental age related tables (Tables 1, 2 & 3) the sex difference has been omitted and generic tables for combined sexes were derived. A study by Phillips[18] has shown that there are slight differences in the ages of the calcification stages of the teeth of boys and girls; this varies by a few months and is not significant enough to influence the age estimation of skeletal remains.

It is often impossible to decide if skeletal remains of a child are either male of female and before secondary sex characteristics develop; it is also not possible to determine the ethnic origin of the skeletal remains of young individuals. It is therefore proposed that the tables for Tygerberg children be used if the ethnicity is known to be of White or Coloured origin. Similarly the Indian and Nguni tables are used if the individual is of Indian or Black origin.

The ‘Ac’ stage in the dental age related tables was omitted as no age can be assigned to age estimation when complete maturity of a tooth has been reached, because the individual has passed this transition by an unknown amount of time, as recommended by Smith (1991).[5] Age estimation is therefore established by assessing the developing teeth that have not attained root apex closure derived from the left mandible and calculating the mean age using only these teeth.

The MFH method consistently under-estimated the ages of the South African children. The performance of the MFH method for the White and Coloured children was poor as it only estimated the ages of 38% of the sample to within 1 year of the chronological age. The MFH method performed very poorly for the Indian and Xhosa children. The DGT method over-estimated the ages of the samples. The performance of the DGT method was relatively constant for all three samples, estimating the ages to within 1 year in approximately 50% in all cases. The Phillips Tables for White and Coloured, Indian and African (Nguni) children was found to be more accurate than the MFH and DGT methods when estimating the ages of South African children.

The Xhosa children came from a poor socio-economic area and age estimation of these children using the age related stages of tooth calcification derived mainly from Zulu children (Phillips 3), resulted in 69.2% of the sample estimated to within 1 year of the real age. This suggests that the socio-economic environment of a child may play a role in the calcification of the permanent teeth and influence the radiographic images of these teeth for aging purposes. This needs to be investigated.

CONCLUSION

The dental age related tables that have been derived for White/Coloured, Indian and Black children of South African origin show that there are differences in the ages at which tooth calcification takes place for the teeth of the left mandibular quadrant. These differences in the ages at which the various stages of tooth development are visualized for each of the sample groups varies enough to warrant specific dental age related tables for children of different ethnic origins. In the forensic analysis of the skeletal remains of South African children these tables will be beneficial in the age estimation of individuals. If the ethnic origin of the individual is known the use of these tables would result in a more accurate age estimation compared to Moorrees, Fanning and Hunt (1963) or Demirjian, Goldstein and Tanner (1973).

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MANDIBULAR THIRD MOLAR DEVELOPMENT STAGING TO CHRONOLOGIC AGE AND SEX IN NORTH INDIAN CHILDREN AND YOUNG ADULTS

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ABSTRACT

Age estimation is not only important for clinical but also for medico-legal purposes. The present study is an attempt to estimate the chronologic age based on the stages of third molar development following the eight stages (A–H) method of Demirjian *et al*[8] and to compare third-molar development by sex and age. We examined 250 orthopantomograms of young north Indian subjects of known chronologic age (range, 7-26 years). Statistical analysis was performed using the Mann-Whitney U-test and the Wilcoxon test between sex and age. Regression analysis was performed to obtain BR regression formulae for dental age calculation with the chronologic age. Statistically significant differences in mandibular third-molar development between males and females were revealed regarding the calcification stages D and G. The results further indicated that third-molar formation was attained earlier in females than in males. Statistical analysis showed a strong correlation between age and third-molar development for both the sexes.

(J Forensic Odontostomatol 2009;27:2:45-49)

Keywords: forensic odontology; mandibular third molar; chronological age; JB regression equation; North Indian; age estimation

INTRODUCTION

Teeth represent useful material for age estimation. In childhood, the observation of the dentition status results in highly accurate age assessment. However, this accuracy decreases simultaneously with the completion of a person's dental development.[1] The development of each individual can be affected by genetic, nutritional, climatic, hormonal and environmental factors.[2,3] It has been reported that dental mineralization is less affected by external factors when compared to bone mineralization.[4] In addition to its clinical importance, the radiographic diagnosis may have possible medico-legal implications, because it is one of the parameters proposed to determine the age of undocumented youths.[5,6] Numerous studies have been developed to estimate dental age.[3,7-9] Although this variability may mostly relate to population differences, other factors, such as sex, age, and degree of dental maturation of the individual in different samples, may also play a major role. In the past, several studies have been undertaken in different populations to explore the usefulness of the developing dentitions as a reliable age indicator.[10-31] These studies show that dental development varies slightly between different populations, making population-specific studies necessary. Recently, for different ethnic groups, numerous reports have been published on the evaluation of third molar development, and further studies were warranted for Indian populations.[11-27]

We hypothesize that North Indian children may have a different rhythm of third molar maturation than that of children in the countries from which the standards were derived. Hence, it was considered worthwhile to determine third molar developmental stages in a sample of young Indian people to assess chronologic age estimates based on developmental stages, to compare third molar development by sex and age, and to compare these data with the results of other studies.

MATERIALS AND METHODS

We examined 250 orthopantomograms of the middle class patients (124 males and 126 females between 7 to 26 years of age) taken from the Bhagwan Dental Clinic, Jind, Haryana, India and Jain Diagnostic Centre, New Delhi, India. The criteria for inclusion in the sample were the availability in their clinical records of an orthopantomography of adequate quality, and no history of medical or surgical disease that could affect the presence and development of permanent teeth. At the time of radiographic examination, the chronological age of each child was calculated on the basis of the reported date of birth. Examination and classification covered the development phase of the third right mandibular molar and, when not present, the contralateral molar was considered. Tooth calcification was rated according to the method described by Demirjian *et al,*[8] assigned to the third-molar tooth. Descriptive statistics were obtained by calculating the means, standard deviations, and range of the chronologic ages for the eight stages of dental development. Statistical analyses were performed using the Mann-Whitney U-test and Wilcoxon test between sex and age. Regression analysis was performed to obtain regression formulae for dental age calculation with chronologic age as the independent variable and third molar developmental stages as dependent variables. Data were tabulated and submitted for statistical analysis using SPSS version 11.0 and Student 't' test was performed. To test the reproducibility of the assessments of dental development stage, two investigators reevaluated randomly selected panoramic radiographs from 10% of the same male and female subjects 8 weeks after the first evaluation. Inter- and intra-observer agreements were determined using the Wilcoxon matched-pairs signed-rank test.

RESULTS

Inter-observer agreement was 96% while intra-observer agreement was 97%. Repeated scorings of a sub-sample of 25 radiographs indicated no significant intra- or inter-observer differences. The third molar formation process was observed in both the sexes, and the mean ages and standard deviations for the Demirjian stages are described in Table 1. Statistically significant differences ($p < 0.05$) were observed in third molar development between males and females regarding the calcification stage D and stage G. These differences indicated that third molar genesis attained the Demirjian formation stages earlier in females than in males. The linear regression coefficients were provided to assess the correlation of third molar development and chronologic age. Statistical analysis showed a strong correlation between age and third-molar development for females ($r = 0.63$) and for females ($r = 0.62$). Regression formula for whole sample and males and females separately, based on the number of third molar teeth present, were calculated. The following regression equations were derived:

Whole sample: Age = 9.34 + 1.75 stage
Males: Age = 10.34 + 1.68 stage
Females: Age = 9.12 + 1.96 stage

DISCUSSION

Age estimation for medico-legal (age at death, criminal cases *etc*) and clinical purposes represents a fundamental problem, and various methods have been established for age determination. It has been shown that dental development relates more closely to chronological age than skeletal, somatic or sexual maturity indicators.[2] Tooth formation has been more widely used than tooth eruption for assessing dental maturation, because it is a continuous and progressive process that can be followed radiographically, and most teeth can be evaluated at each examination. It has been reported that development of each individual can be affected by genetic, racial, nutritional, climatic, hormonal and environmental factors.[2,6,7] Demirjian *et al*[8] proposed a classification distinguishing four stages of crown development (stages A–D)

Table 1: *Means (in years) and standard deviations (SD) of chronological age using the methods proposed by Demirjian et al*[8] *for North Indian genders.*

Stages of third molar	Female	Male	Both genders	p value
A (15 F,16M)	11.51+ 5.34	11.93+ 4.93	11.76+ 6.47	NS
B (16F,15M)	11.70+ 4.62	11.51+ 4.63	11.62+ 4.24	NS
C (15F,15M)	12.61+ 6.39	13.01+ 4.77	12.85+ 4.36	NS
D (17F,16M)	13.00+ 4.33	14.79+ 5.62	13.51+ 5.44	S
E (17F,16M)	14.54+ 3.76	15.00+ 5.73	14.53+ 4.64	NS
F (16F,16M)	17.59+ 4.63	17.51+ 4.38	17.54+ 4.32	NS
G (15F,15M)	19.67+ 4.67	21.57+ 4.46	20.34+ 4.54	S
H (15F,15M)	23.34+ 4.33	23.58+ 4.45	23.54+ 5.62	NS

NS; $P < 0.05$.

and four stages of root development (stages E–H). The system avoids any numeric identification of stages so as not to suggest that the different stages represent processes of the same duration. The stages observed by these authors were defined by changes of shape, independent of speculative estimations of length. Dhanjal *et al* investigated the reproducibility of different radiographic stage assessment of third molars and concluded that the method of stage assessment of third molars developed by Demirjian *et al*[28] performed best not only for intra- and inter-examiner agreement, but also for the correlation between estimated and true age. It has been reported that mandibular third molars start to calcify between the ages of 7 and 9 years in Turkish Children and adolescents.[29] Hence, in the present study the minimum age limit was selected as 7 years for third-molar crypt formation. This was possible because the crypt may be visible as early as 7 years in the mandibular arch. Because previous studies that investigated sex differences showed rather diverse results, we compared the mean ages of each stage for male and female patients with a Turkish population.

Statistically significant differences in third molar development between male and female subjects were observed as in the present study, as in Turkish a population regarding calcification stages D and G. These results are however, contrary to two recent studies.[30,31] This may be due to different genetic, geographical and environmental factors. Our results indicate that females attained Demirjian formation stages 6 to 21 months earlier than males. This observation was contrary to previous studies,[21-30] which report that the mean age at some of the development stages was lower for males than for females in different population. Third-molar development among the north Indian population examined was found to occur at an advanced age relative to other populations.[21-30] The development staging of the third molar has a linear relation to the age in both the sexes and statistical analysis shows a stronger correlation for males than for females of North Indians. Hence, the proposed regression equations can be used for age estimation from mandibular third molar teeth.

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THE EFFECT OF MOTOR VEHICLE AIRBAG DEPLOYMENT ON TOOTH SURFACES

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ABSTRACT

Motor vehicle airbag technology is directed at the reduction of injury to drivers and passengers however a number of researchers have reported cases of injuries caused by airbags. Injuries to tooth surfaces, particularly tooth wear following the deployment of motor vehicle airbags, have never been studied. A review of the literature and clinical experience does not suggest tooth enamel abrasion to be a likely outcome following airbag deployment.

This *in vitro* pilot study was conducted to assess the effect on tooth surfaces following the deployment of motor vehicle airbags, and in particular to attempt to reproduce the injuries claimed in a case report published in the Journal of Forensic Odonto-Stomatology in December 2007. A sample of extracted upper anterior teeth (n = 20) were analyzed using unaided visual observation, photographic and microscopic observation pre- and post- airbag deployment. Teeth were mounted on a fabricated head form (similar to those used in crash test dummies) using dental putty. The tests were performed using a modified airbag test rig with airbags deployed in 5 different positions relative to the head, with respect to distance and angulations.

The result of the tests showed no changes to the teeth with unaided observation, macro photography or under the microscope. Tooth wear patterns described in the case report were not observed. Although accurate reproduction of an *in vivo* situation is not possible, this study has given some insight into the effects of motor vehicle airbag deployment, and suggests that significant tooth wear is an unlikely outcome from airbag deployment.
(J Forensic Odontostomatol 2009;27:2:50-55)

Key Words: forensic odontology, airbag injury, tooth wear

INTRODUCTION

The airbag was first introduced as a safety feature in cars to reduce injuries to drivers following frontal collision.[1] A typical airbag system consists of three main components: an airbag module that houses the inflation system and the rubber-lined nylon bags, crash sensors and associated wiring harness that detect sudden deceleration of the vehicle and activates the deployment system of the air bag, and an electronic diagnostic unit that monitors the system's operation.[2] Driver airbags are installed at the centre of the steering wheel and their design depends in part on the governing design regulations. Airbag systems vary in the type and location of sensors, the chemicals used for inflation, the rate of inflation, construction and deployment conditions.[3,4] For example, in the USA, airbags are approximately 60 cm in diameter when fully deployed, with a volume of 70L.[3] However, in Europe, airbags are approximately 30L in volume.[3] Airbags inflate under high pressure in about 50ms.[3]

There are a number of case reports which have cited injuries due to the deployment of airbags during road traffic accidents.[5-15] Non fatal injuries range in severity from superficial abrasions to burns and bone fractures.[16] An article published in the Journal of Forensic Odonto-stomatology in December 2007 reported a case of tooth wear following a motor vehicle accident.[17] An adult male was involved in an offset frontal collision with an oncoming vehicle. Intraoral "injuries" in the reported case were described as buccal ring abrasions extending from the upper right lateral incisor (12) to the upper left second premolar (25). A review of the literature found no reports of injuries similar to those claimed in this case. Experience of dental wear observed clinically suggested that it is highly unlikely that the injuries are the result of airbag deployment.

This paper describes a study in which airbag laboratory test facilities were utilized to examine the effects of airbag deployment on teeth under controlled conditions. The aim of the study was to observe the possible occurrence of tooth wear during contact with a deploying airbag *in vitro.* The hypothesis is that there would be no changes to the tooth surfaces following the event.

MATERIALS AND METHODS

Ethical approval for the use of extracted human teeth was granted by the Human Research Ethics Committee, University of Adelaide and a convenient sample of 20 human upper anterior permanent teeth, extracted for clinical purposes, was collected. All teeth were treated with 10% Neutral Buffered Formalin by trained personnel in accordance to the Safe Operating Procedure for the safe use of extracted teeth guidelines provided by the School of Dentistry, University of Adelaide.

In order to ensure that pre-existing conditions such as tooth wear, fillings, caries or crack lines were well documented, all teeth were subjected to three levels of examination including unaided observation, photographic examination using a Nikon® Digital Single Lens Reflex (DSLR) camera (*Nikon, Tokyo, Japan*) with a basic 18-55mm lens, and microscopic examination utilising a Leica MZ16FA® Stereomicroscope (*Leica Microsystems, Heerbrugg, Switzerland*). The same stereomicroscope was also used to accurately profile the tooth surface to give an amount of surface roughness.

Teeth were mounted on a featureless free-motion headform (FFMH) derived from a modified Hybrid III dummy head using Aquasil dental putty *(Dentsply Caulk, Milford USA)*, as shown in Fig. 1. The airbag deployment exercise was undertaken in a purpose-built laboratory designed specifically to assess the quality and performance of airbags by various car manufacturers. The airbag test rig met the designated requirements for airbag testing but was modified to meet the needs of this research by incorporating four movable metal tubes to assist in the placement of the dummy head. Airbags were deployed in five different positions relative to the head, with respect to distance and angulations, as shown in Table 1. The deployment is demonstrated in Fig. 2.

A few months after the first episode of airbag deployment, a supplementary test was performed. Two teeth were re-exposed to a second airbag deployment, at half the original distance in order to accentuate potential injury.

Fig. 1: *Tooth mounting on crash test dummy head*

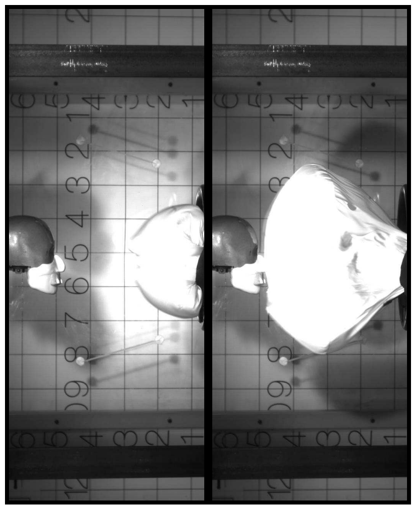

Fig. 2: *Dummy head position during airbag deployment*

Analysis of the existence of crack lines and wear was limited to describing presence or absence of such features. Quantitative analysis was performed by measuring the surface roughness of the tooth surface and determining peak-to-valley surface roughness (Ra) values. Surface profiles were generated relative to an initial plane of reference for selected segments (incisal 1/3, middle 1/3 and cervical 1/3). The data were tabled and centre-line-average values were determined.

Table 1: *Details of the position of each tooth*

Sets of teeth	Tooth	Position on dummy head	Distance from steering wheel (cm)	Angulation from steering wheel
Set 1	1	13/14 area	40.0	Central
	2	12/11 area	40.0	Central
	3	21/22 area	40.0	Central
	4	23/24 area	40.0	Central
Set 2	5	13/14 area	25.0	Central
	6	12/11 area	25.0	Central
	7	21/22 area	25.0	Central
	8	23/24 area	25.0	Central
Set 3	9	13/14 area	25.0	Offset to the right
	10	12/11 area	25.0	Offset to the right
	11	21/22 area	25.0	Offset to the right
	12	23/24 area	25.0	Offset to the right
Set 4	13	13/14 area	25.0	Offset to the left
	14	12/11 area	25.0	Offset to the left
	15	21/22 area	25.0	Offset to the left
	16	23/24 area	25.0	Offset to the left
Set 5	17	13/14 area	25.0	(25.0 cm) Above from the centre
	18	12/11 area	25.0	(25.0 cm) Above from the centre
	19	21/22 area	25.0	(25.0 cm) Above from the centre
	20	23/24 area	25.0	(25.0 cm) Above from the centre

Table 2: *Surface roughness (Ra) values of all teeth pre and post deployment*

SET	TOOTH	INCISAL 1/3		MIDDLE 1/3		CERVICAL 1/3	
		PRE	POST	PRE	POST	PRE	POST
SET 1	1	3.274	2.687	2.729	2.434	1.903	1.640
	2	1.079	1.276	2.306	2.479	3.056	3.389
	3	4.031	3.196	1.644	2.010	2.018	2.050
	4	1.427	1.310	1.535	1.472	2.841	2.770
SET 2	5	1.046	0.941	1.741	1.673	3.124	2.740
	6	1.764	1.705	2.598	2.546	2.259	1.909
	7	1.995	1.499	1.862	1.827	4.938	4.615
	8	3.751	3.654	2.240	2.107	3.751	2.870
SET 3	9	1.197	1.109	1.934	1.820	1.394	1.466
	10	0.782	0.839	1.275	1.286	1.135	1.061
	11	1.240	1.388	1.428	1.300	1.314	1.373
	12	4.250	4.195	2.666	2.300	1.337	1.291
SET 4	13	3.639	3.751	1.404	2.388	0.801	0.821
	14	1.077	1.087	1.659	1.100	1.759	1.870
	15	1.481	1.514	1.664	1.500	0.568	0.845
	16	1.181	1.173	3.128	3.173	1.780	1.581
SET 5	17	2.335	2.351	3.193	3.100	5.777	5.689
	18	3.723	3.807	1.756	1.725	1.428	1.493
	19	1.081	1.032	1.995	1.797	3.043	3.569
	20	1.643	1.660	1.441	1.087	1.857	1.990

RESULTS

A comparison between all observation data of pre- and post-airbag deployment showed no changes to tooth surface. Pre-existing crack lines and areas of wear were unchanged after deployment event. The tooth wear pattern documented in the case report was not observed on any tooth. Table 2 shows the calculated surface roughness (Ra) value (in μm) for each area on each tooth pre- and post-airbag deployment. Student T-test showed no significant difference between Ra values pre- and post-deployment for all teeth ($p>0.05$), and no significant difference between the different sets of teeth.

DISCUSSION

The phenomenon of tooth wear refers to a non-carious loss of tooth structure and is generally classified into four categories; attrition, erosion, abrasion and abfraction.[18] Attrition results from tooth on tooth grinding. Erosion reflects the chemical dissolution of tooth substance without the presence of plaque. Abrasion results from the friction of exogenous material forced over the tooth surfaces, while abfraction refers to the microstructural loss of tooth substance in areas of stress concentration.[18,19] The object of the study was to reproduce a tooth wear pattern attributed to airbag injury.[17]

The sample size for the study was set to twenty teeth in order to simulate the angles and positions of the teeth affected in the previous report. Conservative clinical practice limits the availability of upper anterior teeth. The rationale behind the three levels of observation was to replicate typical observational modus operandi (i.e naked eyes, clinical photographs and enhanced observation). If these initial tests showed some effects on the tooth surfaces, the sample size would have been increased to further statistically defined the changes. Different variables such as the effect of friction from the air bags, the actual gas from the air bags or the combination effect of both factors would then have been assessed. However, not only did the testing fail to produce the same pattern described by De Salvia *et al.,*[17] no evidence of tooth wear of any type could be demonstrated visually or microscopically. A comparison of pre- and post-airbag deployment surface roughness, considered a measure of "micro-wear" caused by the airbags, showed no significance differences.

The only demonstrable difference was in the supplementary test, where two teeth were re-exposed to a second airbag deployment, at half the original distance. Additional minor vertical cracking only was noted, however, the close proximity of the dummy head to the steering wheel was not realistic, representing an extreme 'out of position' scenario. Driving so close to the steering wheel, even for people of short stature, would be uncomfortable and dangerous. The teeth were also exposed for a second time which in real life would be a rare event. In addition, extracted teeth, especially if they are dry, are more brittle and are predispose to fracture. It is acknowledged that a severe force on teeth can cause cracks and/or fracture – features documented in motor vehicle accidents; however this is not tooth wear as described in the case report.[17]

In this study the unconventional arrangement of the teeth in the dummy head was deliberately designed to maximise the forceful interaction between the airbag and the teeth. The intention was to promote tooth wear if possible; therefore, no "soft tissue" simulation over the teeth was contemplated. The extreme measure of deploying the airbags onto the unprotected teeth further demonstrated that deployment forces are incapable of any form of wear, whether at a macro or micro scale. Although the cushioning effect of the putty used to hold the teeth in place may have reduced the forces to some degree, we argue that such an effect is negligible and no different to the effects of the periodontal ligament in real life.

Although saliva found in the mouth acts as a lubricant and has the effect of reducing wear[20] this was purposely not considered in the experimental design. The aim was to encourage wear to occur.

Airbags are usually made of woven nylon.[2] The woven type stitching increases the strength of a fabric especially if it needs to withstand high temperatures, such as those resulting during airbag deployment. Although, this type of fabric can be considered "rough" and abrasive and the surface may be capable of causing other surfaces to abrade (i.e soft tissue), it is unlikely to be able to wear a harder surface like enamel with a single deployment.

This study was limited to one type of airbag. Although most airbag design is based on similar principles, it would be interesting to see whether differences in airbag materials and construction would produce different effects. The distance between the dummy head and the steering wheel could take into account the typical head positions at deployment based on kinematic reconstruction of actual crashes.

More in depth experimentation on the effect of motor vehicle airbags on tooth surfaces may be an appropriate topic for future research. Accident reconstruction is a very complex process but provided that enough information is collated, the kinematic sequence of an occupant in an accident can sometime be reproduced. In general the study of the wearing process of teeth is ongoing and multifaceted. These two complex issues when combined require detailed planning if one wishes to really understand both mechanisms.

CONCLUSION

The primary intention of this study was to examine the possibility of tooth wear following airbag deployment and to recreate the tooth wear pattern described in the referred case report.[17] This *in vitro* study did not reproduce changes to the teeth reportedly following the airbag deployment in the actual crash. Macroscopic and microscopic examination of the labial surface of all incisors tested appears to show no evidence of change after various directional forces from airbags were applied.

Compensation for injury is common in many countries; however in case of liability, it is usually necessary to prove, on the balance of probability, a direct causal relationship between the injury and the accident. Clinical experience and the *in vitro* testing in this project suggest that the damage to the teeth in the documented case was not caused by the deployment of the airbag in the crash.

ACKNOWLEDGEMENTS

Mr Tony Faure of Bridgestone TG Australia; Mr Andrew van den Berg and Mr Guilio Ponte of Centre for Automotive Safety Research; Mr Angus Netting of Adelaide Microscopy Centre; the Minister for Police in South Australia and South Australian Police; and School of Dentistry, University of Adelaide.

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DEVELOPMENT OF THE AUSTRALIAN SOCIETY OF FORENSIC ODONTOLOGY DISASTER VICTIM IDENTIFICATION FORENSIC ODONTOLOGY GUIDE

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ABSTRACT
The need for documented procedures and protocols are important in every specialist group to ensure a consistent service to the community. They provide guidance to members of the specialist group about responsibilities and appropriate practices, and confidence to the community that the services are of the highest possible standard. In a Disaster Victim Identification (DVI) incident, by enabling the process to be audited, they also serve to ensure that identifications are reliable.[1]

Following the Bali Bombings of 2002 and the 2004 Asian Tsunami the Australian Society of Forensic Odontology recognised the need for a practice guide to assist the management of their members in DVI incidents. 31 members of the Australian Society of Forensic Odontology participated in the development of a guideline document for Disaster Victim Identification using a Delphi based model.

The advantage of using the iterative Delphi process is that it encouraged participants to think about the processes used in the forensic odontology aspects of a DVI incident and their expectations of a guiding document.

The document developed as a result of this project is comprehensive in coverage and places the Australian Society of Forensic Odontology at the vanguard of professionalism in the forensic odontology and DVI community.
(J Forensic Odontostomatol 2009;27:2:56-63)

Keywords: Disaster Victim Identification, forensic odontology, guidelines

INTRODUCTION
Society accepts that each and every person has an identity, and would in fact cease to function if this were not the case. This concept is enshrined in the United Nations Universal Declaration of Human Rights[2] where Article 6 states "*Everyone has the right to recognition everywhere as a person before the law*". The need for this identity is also paramount after the death of the individual and represents a basic human right.[3-5] It is well accepted within the forensic community that to have identification of the deceased carried out with dignity and respect requires the establishment of practical guidelines and provision of technical support.[6-10]

The only truly international guidelines that currently exist for Disaster Victim Identification (DVI) are those published by Interpol.[11] These guidelines contain overarching principles for the management of a mass fatality incident, and provide forms for the collation of all relevant ante- and post-mortem data, but they do not direct specific operating procedures for each of the activities of the response. In 2004 the International Organisation of Forensic Odonto-Stomatology (IOFOS) did attempt to compile and promulgate guidelines for identification practices using forensic odontology, but these are yet to receive international agreement and acceptance.[12-13]

The difficulty of both developing and obtaining agreement for international guidelines were discussed by Vermylen.[14] He concluded that any international guidelines can only be broadly descriptive and outline general principles that should apply to the management of the incident response and to the successful and timely identification of the deceased. It is thus imperative for local jurisdictions and disciplines to develop procedures and protocols directly relevant to their own laws and conditions. It would be expected that these would be based on the principles outlined in the international guides.

To this end many police jurisdictions have developed DVI manuals including, but not limited to, the US Department of Justice (NIJ), the Royal Canadian Mounted Police (RCMP), Association of Chief Police Officers of England, Wales and Northern Ireland, the Australasian Disaster Victim Identification Committee (ADVIC) and the Disaster Mortuary Operational Response Team (DMORT).[15-20]

In addition, some groups have developed protocols and procedures specific to forensic odontology, including the American Board of Forensic Odontology[21] and the British Association of Forensic Odontology.[22] Many authors have documented the necessary contents of such documents which included membership criteria, chain of command, team notification details, standardised methods of charting, and supply and payment issues among others.[23-26]

Brannon and Kessler,[27] and Nuzzolese and Di Vella[10] have reinforced the difficulties that are regularly encountered in the management of multiple fatality incidents. They cited: condition of the human remains mentioning in particular fragmentation, co-mingling and incineration; determination of a potential victim list; collection of reliable ante-mortem information; legal and political issues both of the jurisdiction involved and as part of the overall organisational structure; documentation and communication; experience of workers and the application of universal human forensic identification codes. Stressing the importance of planning and coordination in the successful management of a multiple fatality incident, they commented that well constructed and precise guidelines can contribute to the amelioration of regularly experienced complications.

Subsequent to participation in the DVI processes after the 2002 Bali Bombings and the 2004 Asian Tsunami the Australian Society of Forensic Odontology determined that it would be well served by the development of an overarching and consistent set of operating principles that could be adopted nationally and used when assistance of AuSFO members was requested internationally.

This paper will discuss the techniques used to develop the Australian Society of Forensic Odontology Disaster Victim Identification Forensic Odontology Guide.

MATERIALS AND METHODS

Initially, the author prepared a draft guideline document using the Interpol Guide to Disaster Victim Identification,[11] various Australian state procedures,[28, 29] the ABFO Body Identification Guidelines,[21] the IOFOS guides for single and disaster identification[12, 13] as directive documents, combined with 20 years personal experience as a practicing forensic odontologist. This draft guideline was edited once by a group of senior Australian forensic odontologists, each with considerable experience in DVI. This provided the first draft of the document which was distributed to participants in the research.

The original document was divided into 16 sections. The first 6 sections could be defined as the preamble and included an introduction, a brief summary of AuSFO, the mission statement, a description of the scope of the document, terms and definitions, and current AuSFO representation on DVI related Committees. The ‘role organisation and management’ section addressed the structure of an odontology team in a DVI incident and interactions with other stakeholders while the ‘personnel’ section defined qualifications and experience necessary to participate in national and international incidents and to assume certain roles of responsibility within the DVI team. “Documentation’ related to the keeping of a register of suitable qualified and available personnel. The ‘procedures’ section was essentially a duty statement for each of the roles and ‘competencies/responsibilities’ looked at the tasks that needed to be completed by each of these roles. The final sections covered equipment, mainly who and how it would be provided; training, both prior and on-going, and how complaints and review processes would be managed. Section 16 provided the appendices that included progress logs for procedures, recommended standards for acceptance of identification, templates for standard forms, the equipment list, annual review of proficiency and recommended remuneration levels.

All members of the Australian Society of Forensic Odontology (AuSFO) who were resident in Australia were invited to participate in the project, under ethics approval from the University of Newcastle, Australia. As the final document would only apply to forensic odontologists deployed within or from Australia it was considered inappropriate to invite members not resident in Australia to contribute to the development, as application and implementation of the document would not apply to them. At the commencement of the project (September 2005) the study group comprised 41 members. Members not resident in Australia (3 in number) and 2 forensic odontologists known to the researcher and not members of the AuSFO were invited to participate in validating the first round questionnaire prior to the initial mail out to Australian members.

In addition, DVI Police Commanders from each state and territory in Australia, the Australian Federal Police and an individual from the private disaster management sector (11 in total) were invited to participate in Round 1 only. The rationale behind the inclusion of this group was that as members of the AuSFO work under the command of police jurisdictions during DVI incidents, any obvious shortcomings, inconsistencies or discrepancies evident to these stakeholders needed to be identified. Disaster Victim Identification work also requires considerable collaboration and cooperation between members of the various specialist disciplines, including the police, and an appreciation by them of the goal and principles of forensic odontology in a DVI incident could only be of benefit. It was stressed to both first round groups of participants that the opinions of this second group may not necessarily lead to change in the opinions of AuSFO members or the content of the document.

The Delphi technique[30] is one of a number of formal methods used for obtaining consensus from groups of individuals or experts, and was selected as the most appropriate tool for use in this project for a number of reasons. The ability to incorporate a large sample size while not requiring the group to meet was a distinct advantage for AuSFO which has members across all states and territories of Australia. All interactions were completed via written questionnaire, and the comments expressed by each respondent were provided as feedback to all in subsequent rounds to encourage further deliberation and consideration. The anonymity of these responses allowed people free reign which may have been removed in face to face setting. The number of rounds required to achieve consensus, or acknowledge that the point beyond which benefits are negligible, is not predetermined, enabling as much discussion about an issue as the group feel appropriate or necessary.

The iterative nature of the methodology is said to produce more robust levels of consensus. The Delphi technique has been recommended as a tool for the development of treatment protocols and best practice guidelines.[31]

The process involved preparation of an initial questionnaire based around the draft guidelines. The first round of the survey also required participants to nominate the level of consensus for the project. The range of responses, and comments provided by participants were summarised, and areas of the draft practice guide that failed to achieve consensus were reviewed and edited according to the comments made. The summary of responses and comments and the revised draft practice guide were distributed with the Round 2 questionnaire. Subsequent rounds (4 rounds in total) followed a similar format.

At the completion of the four rounds of the Delphi survey, a final version of the document was prepared and forwarded to the executive of the AuSFO for ratification as required by the constitution of AuSFO. All members of the AuSFO, including those who had participated in the project and those who had not, were eligible to vote. Ratification was conducted by electronic voting in accordance with the rules of the constitution of AuSFO.

RESULTS

Thirty seven members of the AuSFO responded to the invitation to participate, which was 90 percent of the eligible membership and 84% of the total membership of the AuSFO. Four members did not reply to the invitation. Of those who responded 6 members declined to be involved. This resulted in 31 participants at the beginning of the project. Two members withdrew from the project during the course of the research. Including members who participated in the validation of the first round questionnaire, and the researcher who did not answer questionnaires but was nonetheless an active participant, 79% of the membership of the AuSFO contributed to the final document.

The personal details survey revealed that 24 (77%) respondents were male and seven (23%) female. The age range of respondents is presented in Figure 1.

Twenty six (84%) of the respondents indicated their experience in forensic odontology. The range of years of experience working as a forensic odontologist was from 1 to 50 years, and is presented in Figure 2. Collective experience of the participants totalled approximately 400 years. Eighteen (58%) of the respondents had graduate qualifications in forensic odontology, and 13 (42%) did not. Five (16%) respondents had received these qualifications in the last 5 years, 3 (10%) in the last 10 years and 10 (32%) more than 10 years ago. The least time since graduate qualification was 1 year and the greatest 29 years. Twenty-nine (94%) of the respondents had DVI experience, while 2 (6%) did not. Twenty-five people (81%) had previously been deployed internationally and 6 (19%) had not.

The first round of the survey saw the consensus level being set at 80 percent. At the completion Round 1 only two of the 16 sections of the document achieved consensus regarding the contents. These two sections were in the introduction section of the document. By the end of Round 2 it became apparent that for a number of issues, particularly the call out activation mechanism; detailed standard operating procedures and responsibilities; training; and continuing professional development, it was going to be extremely difficult to achieve this high level of agreement. Consequently, at an annual meeting of AuSFO the participants requested that the consensus level be reduced to 66 percent, which enabled considerable progress to be made.

The four rounds of the survey generated considerable comment from participants. In total 955 comments were made over the 4 rounds, 30 comments by police respondents and 925 by AuSFO members. The distribution of these comments over the rounds is seen in Figure 3.

As can be seen the areas of Personnel which incorporated the call out mechanism, Standards Operating Procedures and Remuneration generated the most comment.

At the end of Round 4 the document had undergone considerable modification but all sections achieved agreement from the participants. The levels of consensus achieved over each of the four rounds are presented in Table 1. As multiple questions were asked about each section and the questions differed in each round some of these results represent the lowest level of agreement for each section. Some sections (Training in Round 2, and Requests for assistance and Code of Conduct in Rounds 1-3) did not appear in each round of the survey. This final document was then accepted by the membership of AuSFO as a formal, and thus binding, document of the society.

DISCUSSION

Identification of the deceased is not only a legal necessity, but also a human right and dignity that society has a duty to preserve. It is imperative that those tasked with identifying the deceased do so with respect and professionalism. Overarching guiding principles and documented procedures are one mechanism to ensure this humanity is always delivered.

Prior to this project the Australian Society of Forensic Odontology did not have a reference document to assist in the management of responses to DVI incidents, either national or international. Previous responses ran the risk of being *ad hoc*, exclusive of some members and inconsistent with respect to procedures and practices.

Thirty one members of the Australian Society of Forensic Odontology participated in the project. This group had considerable forensic experience and knowledge of the DVI process with 58%

having completed formal graduate training in forensic odontology, 94% having had DVI experience and 81% having been deployed internationally. One aspect worthy of discussion is that of the age and experience of members of AuSFO. Sixty one percent of the respondents in this study (Fig.1) were aged over 50 years of age. Pretty, Webb & Sweet[32] reported a similar distribution in a survey of experienced odontologists and commented that major recruiting for younger practitioners was needed to address this skew in age toward older practitioners. While experience is a benefit in DVI and forensic odontology generally, all countries need to find a way of encouraging younger dentists to become interested in the field. A majority of male practitioners was also seen in both studies, with 89% of the Pretty, Webb and Sweet sample and 77.5% of this cohort being male.

The strengths of the Delphi technique proved beneficial for the development of the Australian Society of Forensic Odontology Disaster Victim Identification Forensic Odontology Guide. A large number of the members of AuSFO (84%) participated in the project, which is undoubtedly more than would have been able to attend a face to face meeting or meetings. Additionally, it was highly unlikely that all the discussion and consideration generated by the Delphi process would have been possible in one or even more face to face meetings as evidenced by 955 well considered comments generated over the process. The content of some of these comments also supported that participants felt comfortable with the format and were not intimidated as can occur in face to face meetings. This reinforces that all members of the group were able to make a contribution. That consensus was ultimately achieved supports the use of the Delphi technique as it enables reflection and offers the ability to change an opinion without embarrassment.

The level of support for the project also indicated that the participants felt a level of ownership of both the project and the final practice guide. This can only be of benefit for AuSFO as a guiding document that has been developed by the majority of the membership will be likely to be respected and the principles abided by when the document is put to use.

Considerable modifications were made to the original document during the progress of the project. The resultant document entitled 'Disaster Victim Identification Forensic Odontology Guide' and copyrighted to the Australian Society of Forensic Odontology, included a preamble addressing the use and scope of the document which remained largely unchanged from the original. The 'role, organisation and management, and 'personnel' sections were similarly unchanged. The 'documentation' section became 'deployment register' and two sections; 'requests for odontology assistance' and 'code of conduct' were added. The 'procedures' and 'competencies/responsibilities' sections were considerably redrafted and enhanced to became 'responsibilities' and 'recommended standard operating procedures' these being much more descriptive and applicable than the original versions. The final sections, although refined, were also largely unchanged apart from the equipment list and the recommended remuneration sections.

Brown[33] commented in 1988 that true professionalism in forensic odontology required "… *financial support by the government of every country to establish within their borders a central identification agency and procedures which are internationally compatible. Well organised protocols will not only expedite the identification process and improve morale of the personnel involved, but more importantly, will project an image of professionalism that will inspire the confidence of relatives of the deceased thus minimising their mental trauma and distress*". Importantly, the Australian Society of Forensic Odontology now has clear guidelines, and consequently the Australian community can be assured that should they require these services they will be delivered to the highest professional, scientific and ethical standards.

The value of these guidelines was evidenced by their use in the odontology response to the Victorian bushfires of February 2009. The application of the principles and practices contained in the guidelines enabled the Forensic

Odontology aspect of the DVI response to be well co-ordinated and the standard operating procedures provided a ready template for an operating structure to be easily and rapidly developed. Future research should be directed at developing similar procedures and protocols for other areas of forensic odontology.

Table 1: Levels of consensus (as percentages) for each section for the four rounds: Delphi survey.

	Round 1	Round 2	Round 3	Round 4
Introduction	83	83	93	94
AuSFO	69	88	93	100
Mission Statement	66	88	93	100
Scope	83	83	93	100
Terms & Definitions	72	72	78	100
AuSFO Representation	66	68	96	100
Role, Organ & Mngmnt	75	71	96	100
Personnel	60	71	96	100
Document/Deploy Reg	76	76	86	100
Requests for assist	-	-	-	100
Code of Conduct	-	-	-	100
Procedures/Responsibilites	62	54	85	100
Competencies/SOP's	69	39	93	97
Equipment	69	96	86	88
Training	79	-	93	94
Complaints	55	60	89	100
Review	57	58	96	100
Remuneration	50	40	93	94

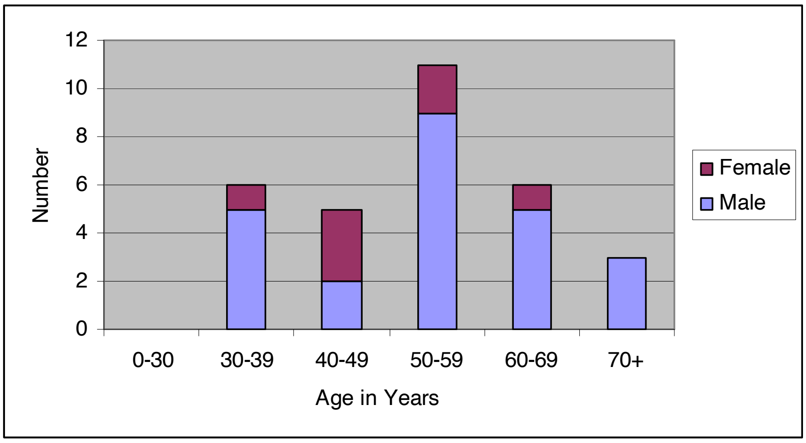

Fig. 1 *Age range of respondents*.

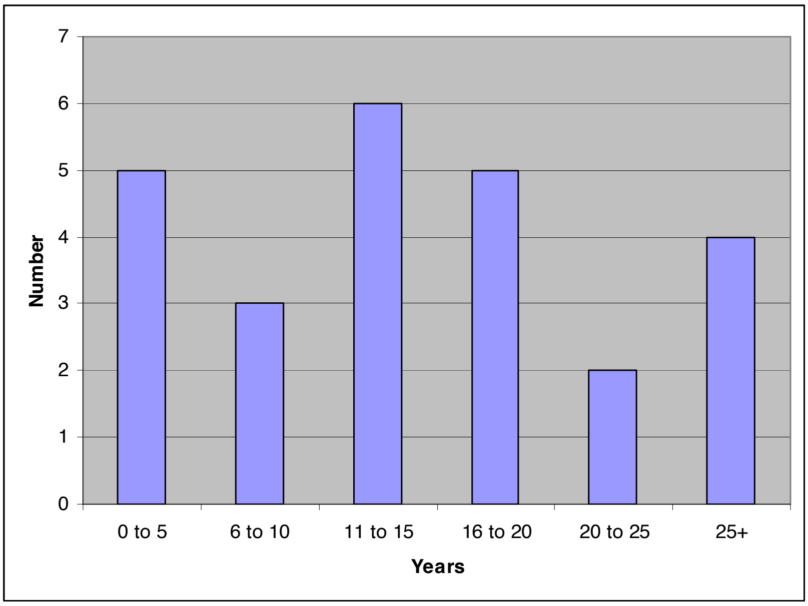

Fig. 2: *Distribution of years of experience in Forensic Odontology.*

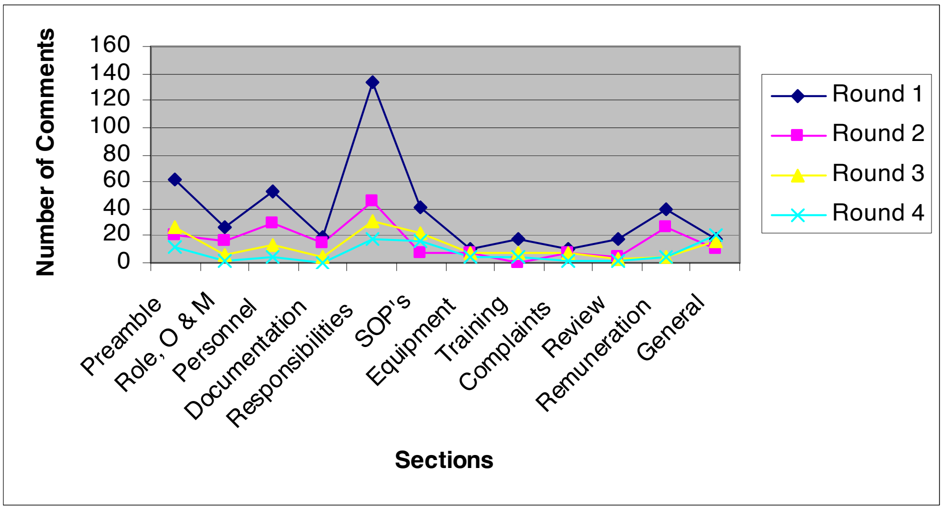

Fig. 3: *Comments per section per round for the four rounds: Delphi survey.*

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A BRIEF HISTORY OF FORENSIC ODONTOLOGY AND DISASTER VICTIM IDENTIFICATION PRACTICES IN AUSTRALIA

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ABSTRACT
Today we consider forensic odontology to be a specialised and reliable method of identification of the deceased, particularly in multiple fatality incidents. While this reputation has been gained from the application of forensic odontology in both single identification and disaster situations over a number of years, the professional nature of the discipline and its practices have evolved only recently.

This paper summarises some of early uses of forensic odontology internationally and in Australia and discusses the development of both forensic odontology and Disaster Victim Identification (DVI) practices in each of the states and territories of Australia.

The earliest accounts of the use of forensic odontology in Australia date to the 1920's and 30's, and were characterised by inexperienced practitioners and little procedural formality. An organised and semi-formal service commenced in most states during the 1960's although its use by police forces was spasmodic. Today the service provided by qualified and experienced forensic odontologists is highly professional and regularly utilised by police and coronial services.

The development of DVI Practices in Australia began following the crash of a Vickers Viscount aircraft into Botany Bay in 1961 and, as with practices internationally, have evolved into an equally professional and reliable specialist discipline of policing in which forensic odontology plays a significant part.
(J Forensic Odontostomatol 2009;27:2:64-74)

Keywords: Disaster Victim Identification, forensic odontology, history, Australia

INTRODUCTION
Today we consider forensic odontology to be a specialised and reliable method of identification of the deceased, particularly in multiple fatality incidents. While this reputation has been gained from the application of forensic odontology in both single identification and disaster situations over a number of years, the professional nature of the discipline and its practices have evolved only recently.

This paper summarises some of early uses of forensic odontology internationally and in Australia and discusses the development of both forensic odontology and Disaster Victim Identification (DVI) practices in each of the states and territories of Australia.

While the identification of victims of mass fatality incidents (DVI) is now perceived as a sub-speciality of human identification, this has not always been the case. The development and evolution of forensic odontology identification skills in both single and multiple victim situations were inexorably linked in the beginning of the discipline. Not unreasonably, interest and advancement of forensic odontology in a given area was often linked to a disaster.

FORENSIC ODONTOLOGY AND DISASTER VICTIM INTERNATIONALLY
Histories of forensic odontology frequently refer to cases such as the identification of Lollia Paulina by Agrippina using visual recognition of 'distinctive teeth' in AD49; Charles the Bold from a missing upper tooth in 1477; General Joseph Warren by Paul Revere via a fixed wire silver bridge in 1776 and Dr Parkman by Nathan Keep from the fit of dentures on study models in 1849 as evidence of the long standing use of dentistry for identification purposes.[1-6] These cases are more accurately just serendipitous applications of dental information to identification and do not

really constitute the rigorous and reliable application of dental science that we understand to be forensic odontology today.

Strom[7] reported that the use of teeth to aid identification in the modern understanding had been proposed by Godon in 1887, but a report by M'Grath in 1869[8] described the use of dental characteristics to differentiate between two incinerated females, and a paper by Reid in 1884[9] discussed many cases using dental science for both personal identification and age assessment, one as early as 1835. Schirnding[10] noted that the *Coroners Act of 1886*, the Prussian Regulations of 1875 and Austrian Instructions of 1855 for the holding of an inquest, all contained reference to the use of teeth to establish identity.

Although it has been reported that forensic odontology was used to identify victims of a fire in the Vienna Opera House in 1878[7,11] the modern era of forensic odontology is said to have commenced with the identification of the victims of the Bazar de la Charité fire, which occurred on May 4, 1897 in Rue Jean-Goujon, Paris. One hundred and twenty six members of the Parisian aristocracy perished after an ether-oxygen film projector ignited a rapidly destructive fire. All but 30 of the victims were identified visually or by personal effects, mainly jewellery, on the day after the fire.

The honour of being the 'father of forensic odontology' is often bestowed on Oscar Amoedo, a Cuban dentist working in Paris at the time of the fire, but he did not in fact do any of the odontology work at this incident. The author of "L'Art dentaire en Medecine Legale",[12] which was an important contemporary text on many aspects of the use of teeth for legal purposes, merely reported the outcomes of the work done by other dentists after the fire. The credit for the idea of using dental information to assist the final identifications actually belongs to the Paraguan Consul, Mr Albert Haus. With the identification of the last 30 victims seeming almost impossible Mr Haus suggested consulting the dentists who had treated the remaining missing persons. One of the unidentified victims was the Duchesse d'Alencon who was a daughter of the Duke of Bavaria and sister of Elisabeth, Empress of Austria and Anne, Queen of Naples. A Dr Isaac B Davenport had provided dental services to the duchess and many of the other victims. He was apparently a trained botanist as well as a dentist and his detailed notes included excellent drawings of the dentition.[13] He examined the majority of the remaining unidentified bodies and was eventually able to identify the duchess via her dentition. Subsequently, a number of other dentists were invited to examine the remains of the deceased, and eventually all but 5 of the victims were able to be identified. The police accepted these dental identifications and released the bodies to the families.[5,6,13,14]

After the Bazar de la Charité fire many authors published case studies on the use of odontology in both single and multiple fatality incidents which indicated an increasing awareness of the value of the dentition in the identification of the deceased. Rosenbluth[15] described a murder case in the United States in 1898 where dentistry played a pivotal role. Ryan[16] mentioned the identification of US Sailors from an accident in 1927, commenting on the high quality of the dental records kept by the Navy, and Gustafson[17] recounted the identification of the 29 victims of a fire in Oslo in 1938. Simpson[18] summarised a number of English cases of the early 20th century where the use of dental evidence had been significant. Strom[7] and Gustafson[17] reported on the identification of victims of the Second World War via forensic odontology. Teare[19] discussed the identification of the 28 victims of a plane crash in 1950; Frykholm[20] described a Swedish shipping accident in 1950 where 15 were killed and Mercer, Reid & Uttley[21] and Warren[22] a rail accident in New Zealand in 1953 where 151 perished, all where dental identification made a contribution. The odontology aspects of the identification of the 118 victims of a fire aboard the SS Noronic in Toronto Harbour were described in detail by Grant, Prendergast & White in 1952.[23] While these cases provide evidence of the increased formalisation and consistency of methods of victim recovery and scientific identification practices, the use of forensic odontology was still sporadic in most countries even until the 1960's.

There does not appear to be a universally acknowledged incident which served to initiate the development of consistent disaster victim identification practices. Strom[7] and Gustafson[24] reported that Norway is considered to have established the first Identification Committee in 1945. In the police orders of 1948 relating to this Committee the following was reported; *"In all cases where several victims are found at the same spot, the local prefect of police should appoint an identification committee consisting of three members; a police officer, a dentist and a doctor. This committee has the whole responsibility for the procedure of identification. The committee has to give a report of all details concerning the identification in relation to each body. Each single identification certificate is to be signed by all members of the committee. A body, therefore, is not considered identified unless the committee members are in complete agreement as to a positive identification. In cases of doubt the Prefect of Police should decide either whether the body is to be considered as identified or whether it should be buried as unknown. In the last event or in cases where it is impossible to establish the identity at that time, the body should not be buried until an exact description of the teeth is obtained."* This was very forward thinking for the time, and is still sound policy sixty years later as it codifies the key principles that continue to underpin DVI today. The FBI report having formed a disaster squad in 1940[25] but the identification emphasis of this group was on the use of fingerprints, although the report does mention dental charts as a '*valuable identification tool'*. With no pathologists and odontologists on the squad the DVI activities were not as comprehensive as the Norwegian model.

Several incidents served to progress the development of international standards in both DVI practices and the use of forensic odontology for identification in multiple fatality incidents. A fire aboard the S.S. Noronic in Toronto Harbour in 1949 claimed 118 lives. The investigation and DVI process employed many of the now currently recommended procedures for body recovery and identification. This incident was also the first reported use of elimination tables to simplify and add strategy to the final reconciliation process.[23]

Pedoussaut[26] reported on the identification procedures used after a plane crash in France in 1950 killed 50 people. Of particular note was the use of an identification questionnaire which applied similar reasoning to the post-mortem and ante-mortem forms now promulgated by Interpol. The presentation of conclusions in a formal identification report for each victim was also an important development. The author also commented on the potential role of the International Criminal Police Commission (later Interpol) in the coordination of the identification procedures where international victims were involved. Indeed, the editor of the journal included a draft of an international convention then being considered by the International Criminal Police Commission for the identification of victims of air accidents. This could be considered as the first attempts at drafting what are now the Interpol DVI guidelines.

The recovery and identification of the victims of the plane crash into Mt Erebus in the Antarctic in 1979 was reported as the first use of a grid reference for recording the scene and the location of body and body parts.[27, 28]

Spurred by a fuel tank explosion tragedy in Spain in July 1978, Interpol explored the need for improved co-ordination and consistency in the identification of victims of mass fatality incidents and established a working party on Disaster Victim Identification in 1982. In this incident, a road tanker carrying liquefied petroleum gas (LPG) exploded outside a camping ground during the European summer holidays, killing over 200 people from a number of countries.[29-31] Victim identification had proved difficult and highlighted the need for guiding principles that would enhance international cooperation and improve the coordination of responses to similar incidents. Interpol's working party evolved into a Standing Committee, and built on the work of Pedoussaut.[26] The Standing Committee still meets annually and a section of its agenda is devoted to analysis of case presentations, to enable practitioners to learn from the experiences of actual incident responses. The first Guide to Disaster Victim Identification was published in 1984,[32] and is now considered international best practice for disaster victim identification.[33, 34]

FORENSIC ODONTOLOGY AND DISASTER VICTIM IDENTIFICATION IN AUSTRALIA

Pounder and Harding[35] have reported that the first autopsies were conducted in Australia in 1790, one on a victim of inanition (starvation) and the other on the governor's gamekeeper who was allegedly murdered by Aborigines.

It is not really known when forensic odontology was first used in Australia. A report in the New South Wales Police News in 1943 reported the identification in Melbourne, Victoria of a murder victim, Bertha Couphlin, in 1923 and of Norman List in 1924, using dental evidence.[36] That article also mentioned that the identity of three victims of a plane crash in the Dandenong Ranges in 1938 "*could only be established by means of the teeth*". Cleland[37] mentioned the identification of a New Zealand citizen in Western Australia in 1930, although this identification appeared to rely more on circumstantial dental evidence than to be a true dental identification.

The most famous identification case from that era occurred in New South Wales in 1934. Colloquially known as the Pyjama Girl Case, the outcome highlights the value of dentistry in identification, but also the pitfalls that can derail the well intentioned but ill-prepared, both dental practitioners and investigating police officers. It involved a murdered woman who remained unidentified for 10 years, ostensibly due to unreconciled dental information. The badly burned remains of the victim were discovered by a farmer in a road culvert near Albury in September 1934. The body was clothed only in pyjama remnants and revealed little other identifying information. A post-mortem was carried out and a local dentist, Dr Francis Jackson, was asked to complete a dental autopsy. His unorthodox procedures can best be explained by his inexperience in forensic odontology, but mitigated by the fact that few people had any experience at that time. At the subsequent Supreme Court trial he admitted that this was his only experience of forensic odontology and he found the process "*revolting and unnerving"*.[38, 39]

Dr Jackson's unconventional examination occurred over three visits. On the first he made some observations and extracted two teeth, on the second he extracted an additional four teeth and on the third he took upper and lower impressions of the jaws. The extracted teeth were then mounted into the stone dental models made from the impressions "*in approximately the same position as they were in the mouth*". During the course of these examinations Dr Jackson incorrectly identified one tooth and failed to observe restorations in two other teeth. These inaccuracies proved pivotal in the inability to identify the remains for 10 years. Photographs of the casts with the extracted teeth in situ were distributed to dentists in Australia and New Zealand, and every dentist in metropolitan Melbourne and Sydney was personally contacted by police. Information about this case, including images of the extracted teeth, was also displayed as 'ads' in movie theatres. Unsurprisingly, none of these activities yielded any useful information.

The police relied on public appeals to attempt to identify the victim. Apparently over 500 women who had been reported missing were located in the course of the investigation. Ultimately the remains were preserved in a formalin bath and it became quite a social outing to visit "the body in the bath" at Sydney University. Many false identifications were offered to police from these viewings. About 9 months after the victim was found police interviewed a man, Antonio Agostini, whose wife Linda had been reported missing by a family friend. This gentleman indicated that he did not recognise the lady in the bath but provided police with the details of his wife's dentist.

The information provided by this dentist did not match the post mortem information provided by Dr Jackson and the investigation continued. Interestingly the dental information provided by the treating dentist was also somewhat unorthodox. It transpired that he kept no formal clinical records and the information he provided was an amalgamation of personal recollection and ledger entries of fees paid.

In 1944 new investigating officers decided to review all the information relating to the case and asked another dentist, Dr Magnus, to re-examine the body. Dr Magnus was more thorough in his work, correctly identifying all the teeth and locating previously unobserved restorations. On comparison the new charting matched the ante-mortem dental information of Linda Agostini. Antonio Agostini subsequently admitted to having murdered his wife in 1934.[38-40]

This case highlights that forensic odontology was not a widely practiced or well understood discipline in Australia in the 1930's, even though it was recognised that dental characteristics had great potential to aid identification.

The first regularly cited use of DVI practices in Australia followed the crash of a Vickers Viscount aircraft, leased to Ansett Airlines by Trans Australian Airlines (TAA), into Botany Bay on 30 November 1961 resulting in the death of 15 people. The chief investigating officer, Detective Sergeant WB Ross, realised the challenge that would be faced in identifying the victims and indicated in his final report that he had researched extensively prior to planning recovery and identification procedures.

Ninety four body parts were recovered over 12 days. All identifications were confirmed by visual recognition by family and friends. Several references to the use of teeth and dentistry are made in the case file. Several of the identification summaries of the victims made reference to "*favourable comparison of dental charts*". There is no explanation as to why this comparison was favourable, except in one instance where reference is made that "*..dentist identified the teeth mentioned in the morgue book as that of the deceased*". There is no indication of what the entries in the morgue book contained, or who made them. It would also seem that the dentist making this comparison was the dentist of the victim and had no experience in forensic odontology.

One outcome from this investigation was the development of a Disaster Victim Identification Form for use by the NSW Police. Detective Sergeant Ross indicated that he modelled these forms on those of Pedoussaut.[26] Both these forms bear a striking resemblance to the current Interpol DVI forms, and it is reasonable to surmise that they provided the basis from which the Interpol forms evolved as both French and Australian police officers attended early Interpol standing committee meetings.[32]

THE DEVELOPMENT OF FORMAL FORENSIC ODONTOLOGY SERVICES IN AUSTRALIA

The development of formal services in forensic odontology in Australia has followed a similar path in most states and territories, with the spasmodic use of dentists to assist police in identification procedures occurring from around the early 1960's. This was generally an informal arrangement with little or no remuneration which meant that the dentists providing the services frequently had to complete examinations and prepare reports after hours and at weekends. It also meant that each practitioner developed their own forensic techniques and practices in isolation. Limited training in forensic odontology was available to these dental practitioners and it is a credit to their dedication and professionalism that the discipline has developed to the high standard and international reputation it enjoys today.

Dr Norbert Wright, then the Chief Dental Officer of New South Wales, in conjunction with Drs Max Bullus and John Wild, provided the odontology services for New South Wales from the early 1960's. After retiring from military service in 1981 Associate Professor Chris Griffiths returned to Sydney and began assisting Dr Wright. Even at that stage the service was still relatively unstructured and minimally remunerated, so Associate Professor Griffiths commenced the process of getting forensic odontology formally recognised and funded in New South Wales through the Health Service.

Despite the experiences of the Botany Bay crash the police in New South Wales used odontology regularly for single identifications but not routinely in multiple fatality incidents. The 83 victims of the 1977 Granville train accident were identified visually and using jewellery and documents, and the formal review of this case saw the NSW Police form a dedicated DVI squad. It was the Grafton bus crash in 1989 that highlighted the limitations of visual identification and changed practices in New South Wales. One of the 21 victims of the Grafton accident had been initially incorrectly identified visually so when, just over 2 months later, 35 people were killed when 2 buses collided near Kempsey forensic odontology was used to identify the majority of the victims.

Subsequently, forensic odontology has been used as part of the identification repertoire in all mass fatality incidents in New South Wales including the Newcastle earthquake in 1989 (13 deceased), the Thredbo landslide in 1997 (18 deceased), the Glenbrook train accident in 1999 (7 deceased) and the 2003 Waterfall train disaster (7 deceased).[32,41]

Dr Gerald (Gerry) Dalitz provided the early forensic odontology services in Victoria. In 1961 he was awarded a Doctor of Dental Science for a thesis entitled 'Some aspects of dental science - Identification of human remains' by the University of Melbourne. While collecting data for his research his expertise came to the attention of the Victoria Police and they gradually began utilising his services.[42] Dr Ross Bastiaan started working with Dr Dalitz in 1979, continuing until 1989.

The Victorian DVI odontology team was formed in 1981, and over 35 dentists volunteered to help Dr Bastiaan when the need arose. Twenty two of these volunteers assisted after the Ash Wednesday bushfires of 1983 claimed 47 lives in Victoria. Fourteen of the 22 (64%) Victorian victims who could not be visually recognised were identified via forensic odontology.[43]

Professor John Clement arrived from the UK in 1989 to take up a position in the dental school at the University of Melbourne. Upon arriving in Melbourne Professor Clement was instrumental in establishing a broader and more professional forensic odontology service in Victoria, including the introduction of the first graduate training program and the only Chair in Forensic Odontology in Australia. Forensic odontology now forms a routine part of single and multiple death investigations in Victoria, including the Kew Cottages Hostel fire in 1996 (9 deceased), the Linton bushfires in 1998 (5 deceased), a light plane crash at Myrrhee in 2002 (6 deceased), the Mt Hotham plane crash in 2005 (3 deceased), a car accident at Donald in 2006 (8 deceased), the Kerang train crash in 2007 (9 victims), the crash in the Burnely Tunnel in 2007 (3 deceased), and the bushfires of February 2009 (171 deceased).[44,45]

Dr Kenneth Brown's interest in forensic odontology was sparked in 1961 when he attended a lecture in Adelaide entitled 'Dental aspects of forensic medicine' presented by Professor Gosta Gustafson who was the Professor of Oral Pathology at the University of Lund in Sweden. In 1967 he responded to a request by the South Australian Police Department who were looking for volunteer dentists to provide them with dental expertise. Dr Brown had read widely but as there were no formal training programs in Australia at the time he used a Churchill Fellowship in 1976 to travel internationally to increase his knowledge and experience in the field of forensic odontology. His honorary work for the South Australian Police continued until a formal post in forensic odontology, the first such position in Australia, was created at the University of Adelaide in 1980.[46]

The largest mass fatality incident in the recent history of South Australia was the 'Ash Wednesday' bushfires of 1983. Twenty eight South Australians lost their lives in fires in the hills surrounding Adelaide and in the south east of the state near Mount Gambier. This incident saw the first activation of the newly written State Disaster Plan. Eight (29%) of the South Australian victims were identified by dental comparison.[47] Prior to this at accidents such as the 1970 crash of a passenger train and bus at Gawler (17 deceased) and the 1972 crash of a light aircraft at Golden Grove (8 deceased) scene recovery protocols were well established but not the use of the standardised forms to document body recovery, ante-mortem and post-mortem information. Identification of the victims of these incidents was achieved through personal effects and fingerprints. South Australian Police used these experiences and those of the New Zealand Police after the Mt Erebus plane crash to develop DVI protocols and procedures to be used in South Australia, including the routine use of dental identification. In subsequent cases including the Truro murders (7 victims), the 'Family' murders (5 victims), the Whyalla airlines crash (8 deceased) and the Snowtown murders (11 victims) forensic odontology figures largely in the identification of the victims.[48-50]

Pocock,[51] in his 1979 paper on the provision of a forensic pathology service in Western Australia, commented that a part-time forensic odontologist was "*available* *for consultation in and problem of identification*". This position had been established in early 1960s and was held by Dr Frank Digwood, and became a formal part-time position in the 1980s. Dr Stephen Knott provided assistance to Dr Digwood from 1991, and succeeded him on his death in 1993.

Significant cases in Western Australia where forensic odontology has made a valuable contribution include the Sideris murder in 1981; the Merredin bus crash in 1982 and the 1988 crash of a light aircraft near Leonora which killed 10 people. It is thought that DVI practices were probably first used seriously in WA at the Gracetown cliff collapse which killed 18 teenagers in 1998.[52,53]

Dr Kon Romaniuk moved from New Zealand to take up a position in the dental school at the University of Queensland as an oral pathologist in the early 1970's. Typical with most developing services in Australia he provided an honorary consultation service in forensic odontology, later establishing a more formalised arrangement that provided a modicum of remuneration. Dr Alex Forrest started working as an assistant to Dr Romaniuk in 1985, and became the consultant forensic odontologist in 1994 after a traffic accident necessitated Kon's retirement.[54]

The Queensland Police Service has been very forward thinking with regard to DVI. In 1981 approximately 40 officers were seconded to a new "DVI Squad" and instructed to be prepared to "*recover dead bodies from disasters and identify them"*. This was prior to the establishment of the Interpol DVI Standing Committee and little in the way of formal guidelines and documentation existed so the new team had to learn and refine as they went. The first incident for the new squad occurred after a boarding house fire in the inner city suburb of Highgate Hill claimed 7 lives. Although the identification of the victims was completed via visual recognition and circumstantial evidence, the incident highlighted to the DVI officers that training and use of scientific identification techniques were very important to the future success of the squad. Over subsequent years the team attended many incidents including a bus crash in October 1994 where 11 people lost their lives, the Moura coal mine explosion in 1986 (13 deceased) and the crash of 2 Blackhawk helicopters near Townsville in June 1996 (15 deceased). The identification of the victims in these incidents was completed using a variety of methods including visual recognition and forensic odontology. Subsequent to the Blackhawk accident all major mass fatality incidents in Queensland have employed forensic odontology identification techniques as first preference. These events included the Childers Backpackers Hostel fire in June 2000 (15 victims) and the Lockhart River plane crash in May 2005 (15 victims).[54,55]

In the Northern Territory, Tyas[56] reported the use of dental evidence to identify a skeleton discovered near Alice Springs in 1971. It is believed that early forensic odontology services were provided by Dr T Paul Boyd who worked part time as an oral surgeon in the public health system. Dr John Plummer had an interest in forensic odontology from his undergraduate years but his first exposure came in the late 1970s when he was the government dentist in Katherine and was asked to help identify a family who had been drowned after a flash flood had washed away their homestead. Dr Plummer continued his professional development in forensic odontology by using a Churchill Fellowship, awarded in 1985, to travel extensively and meet and work with a number of forensic odontologists internationally. As a health service employee Dr Plummer continued his involvement in forensic dentistry on an honorary basis until his retirement in 2002. Dr Mark Leedham, a Darwin based orthodontist, currently provides the forensic odontology service for the Northern Territory.

Although the Northern territory has not experienced many mass fatality incidents, one of Australia's largest occurred in Darwin. Cyclone Tracy, which struck on Christmas Eve in 1974, resulted in the death of 71 people. While it is believed that those who were recovered at the time of the cyclone were identified visually, a number of victims who were recovered later were identified via forensic odontology. All 13 victims of the collision of two hot air balloons over Alice Springs in 1989 were also identified via dental comparison.[57]

Dr Canning, a non-practicing dentist who worked in the anatomy department at the

University of Tasmania, provided the early forensic odontology service in Tasmania. Dr Canning assisted in an ad hoc arrangement with the Tasmanian Police and would have assisted in identifying some of the victims of the 1967 bushfires (62 victims), the Mt St Canice Boiler explosion in September 1974 (8 victims) and the Tasman Bridge collapse in January of 1975 (12 victims).[58,59]

Dr Paul Taylor has been the consultant forensic odontologist in Hobart since 1990. The DVI case of note in recent memory for Tasmania is the Port Arthur massacre of 1996, where Martin Bryant shot and killed 35 and wounded 19. Three of these victims were subsequently burnt beyond visual recognition in a fire set by the gunman in a nearby guest house where he had held them hostage overnight. The identification of these three victims was assisted by odontology evidence. The identification of the other 32 victims was completed by visual recognition by family and friends, and use of engraved jewellery and documents found on the deceased.[59,60]

Covering a small geographic area, the Australian Capital Territory has not experienced many multiple fatality incidents. Incidents such as the 1991 plane crash in the Brindabellas (4 killed) and the 1993 MIG Jet Fighter crash at Canberra airport were co-ordinated and managed by the Search and Rescue division of the Australian Federal Police ACT with identifications being completed via dental comparison. These identifications were performed by Dr David Griffiths who has been the ACT consultant forensic odontologist since 1991. His desire to be involved in forensic odontology was heightened after a murder in Canberra in 1988 where the victim remained unidentified for approximately 3 months. Dr Griffiths thought this was both unacceptable and unnecessary and after completing some training courses offered his services to the ACT police.

The Australian Federal Police increased their experience and involvement in DVI with their participation in the investigation and identification of the victims of the 2002 Bali bombings (Australian Federal Police 2003). This, and involvement in the identification of victims of the 2004 Boxing Day Tsunami in Thailand, have led the AFP to refine their practices and equip themselves with a considerable amount of readily deployable equipment.[61,62]

SUMMARY

The value of dental characteristics to identify deceased individuals has been well recognised since the late nineteenth century. Interestingly, the use of dental science to aid the identification of the deceased appears to have been originally driven by external agencies, for instance police, coroner's and courts rather than from within the dental profession. Once the value of forensic odontology was recognised by dentists, the obligation to demonstrate efficacy through scientific rigour was embraced and has seen the evolution and maturity of what is now regarded as a specialty within the dental profession.

The earliest accounts of the use of forensic odontology in Australia date to the 1920's and 30's and were characterised by inexperienced practitioners and little procedural formality. An organised and semi-formal service commenced in most states sometime in the 1960's although its use by police forces was spasmodic. Today the service provided by qualified and experienced forensic odontologists is highly professional and regularly utilised by police and coronial services. The majority of Australian forensic odontology specialists have considerable experience in the identification of victims of mass fatality incidents, both within Australia and internationally.

Disaster Victim Identification principles have been employed by some international police services from the 1940s, but it was the establishment of the Interpol Standing Committee on Disaster Victim Identification in 1982 which brought the importance of a coordinated and well documented response to both the recovery and identification of the victims of a mass fatality incident to the attention of most western police forces and associated forensic specialities. In Australia, the 1961 crash of a Vickers Viscount aircraft into Botany Bay was the first use of structured DVI practices. The development of state and territory specific DVI activities, including the use of forensic odontology as a core identification tool, was frequently linked to a specific incident. The activities of the Australian Disaster Victim

Identification Committee, established in 1996, have seen consistencies in practice and procedures promulgated across the various Australian police jurisdictions. Australian DVI practices are now regarded as representing international best practice.

ACKNOWLEDGEMENTS
My thanks to all the Forensic Odontologists and State DVI Commanders who willingly gave of their time, experience and memories. The interviews to collect the information presented in this article were conducted as part of a PhD project by the author under the University of Newcastle Ethics number H-091-0805.

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CASE NOTE

FUSED ATLANTIC POSTERIOR ARCH HYPOPLASIA — RACHISCHISIS?

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ABSTRACT
Bony fusion between the skull and the vertebral column is a sufficiently rare skeletal anomaly that we may never have the opportunity to see it during our career. An 'evidential' discovery led to an example being made available for detailed study. This illustrated paper presents the findings of the study, reviews other studies, and discusses the genetic origins of such an outcome.
(J Forensic Odontostomatol 2009;27:2

Keywords: atlanto-occipital joint, bony fusion, forensic anthropology, odontology, rachischisis

INTRODUCTION

Knowledge of bony fusion between the cranial base and the first cervical vertebra (Figs.5,6,7) is critical for neurosurgeons, neurologists, radiologists and physiotherapists. Menezes[1] assesses its incidence as being 0.25% among the general population, while its incidence among Caucasoids has been reported as being 0.5 – 1.0 %.[2,3] According to Harcourt and Mitchell[4] it was first described by Rokitansky in 1884. Since then a plethora of titles has been bestowed on it - assimilation of the atlas,[1,5,6] atlanto-occipital fusion,[7–10] fusion of the atlas,[11] fusion[12] or ankylosis[13] of the atlanto-occipital joint, occipitalization of the atlas,[3,14-19] occipitocervical fusion[12] and occipitocervical synostosis.[20] This craniovertebral abnormality may involve the anterior arch of the atlas, the lateral masses, or the entire atlas,[3] ranging from a fibrous band uniting juxtaposed small areas of atlas and occiput, to a bony ridge, to multiple bony 'welds' as in the present case, or a complete fusion. Given the radiodensity of bone mass this craniovertebral interface is a notoriously difficult region to view. This anatomical abnormality may go unnoticed unless, given its proximity to the spinomedullary region, a patient presents with neurological compression syndrome, and a wide variety of associated signs and symptoms that may require a CAT scan or MRI[21] to reveal their cause. Otherwise an individual may be fortunate enough to go through life blissfully unaware of the abnormality,[15,22] which may then be revealed by surgery, autopsy, or commercial preparation for study. This paper describes such a case.

MATERIALS AND METHODS

In September 2008, a human skull that had been recovered from a domestic dwelling during a New Zealand Police operation, was received for comment. The skull was assessed by gross, visual examination only. The mandible was maintained in articulation by light-gauge wire, and the accompanying first cervical vertebra was fused in three places to the occiput.

The material was generally in well-preserved condition. It had been kept in a dry state for some time - dust fibres were visible at the medial foramina of both carotid canals. The medial wall of both orbits had suffered *post–mortem* damage from hand-grasping (Fig.1). The *dorsum sellae* had been broken off after death (Fig.3), as had the pterygoid hamulus of the left side. Some teeth had been lost after death.

The cranial vault had a drilled, round hole in the midline immediately posterior to vertex. The corresponding circular rust stain inside the vault, where a washer had been fitted, indicated that the skull had been suspended in the past (presumably with its missing postcranial skeleton). The vault had been sectioned transversely; two metal retaining pins projected from the inferior surface of the

Fig.1: *The anterior and posterior aspects of the skull; the extremity of the atlantic right posterior arch is indicated by the black arrow.*

cut (Fig.3), and slotted into corresponding holes in the superior surface. On both sides of the cut, aligned holes indicated the position of clips for securing the vault. A single smaller hole, anteriorly on each side, indicated the position of a spring for securing the mandible. The conclusion is that at some time in the past the skull had been held in an anatomical training facility or in a medical practitioner's surgery.

Subsequently, the mandible had been painted luminescent, lime green (Figs.1,2); there were red paint traces round the inferior cut surface of the cranium, and a single fleck of white paint above the larger of the two right supraorbital foramina - the 'holder' of these human remains claimed to have purchased them from a "travelling horror show" around 1986.

Fig.2: *An open-mouth view, showing thinning of the orbital roof, the degree of occlusal wear, and indicating the centre of the atlantic anterior arch by an asterisk.*

The skull was sexed subjectively as female, using morphological features given in standard textbooks of anatomy and forensic science.[23–25] At time of death she was aged in her late twenties, based on the limited occlusal wear of the three remaining molar teeth and the patent petro-occipital suture[26] on the left side. Given the generally gracile nature of the skull, sectioning of the vault, evidence of suspension, this skull had been prepared for teaching purposes and, in the New Zealand setting, it is therefore most likely that the individual came from continental India.

There are three small 'button' exostoses on the external surface of the cranial vault.[27] There is marked thinning, to the extent of translucency, of the orbital roof of both sides (Fig.2). Examination with a 5x *Lupe* eyepiece revealed some pitting anteriorly in the roof, a bony reaction to subperiosteal bleeding, earlier thought to be a symptom of anaemia[28] but more likely indicative of poor nutrition at some stage of her life.[29]

There appears to have been a marked overbite, particularly on the anterior teeth (Fig.1). There is marked dentine exposure on most of the occlusal surfaces and also interproximal attrition (Fig.2). Calculus is present. No carious lesions were observed on the remaining teeth. The 41, 42, and 43 teeth are misaligned. The roots of the 45 and 46 had been functioning as occlusal surfaces. On the buccal surface of the mandible is a bony reaction to an apical abscess of the proximal root of the 46 tooth (Fig.1).

Fig.3: *Intracranial and inferior views of the skull. Intrusion of the right atlantic posterior arch into the foramen magnum is indicated by the black arrows.*

RESULTS AND DISCUSSION

The striking feature of this skull is the bony fusion between the occiput and the first cervical vertebra.

Apart from a slit above the anterior arch of the atlas (Fig.6) the fusion extends, solidly, to just beyond the site of both occipital condyles. Then, approximately midway along the posterior arch of the right side, there is a further fusion site - the left posterior arch of the atlas is missing entirely. In addition, there appears to be torsion between the skull base and the orientation of the fused atlas, which is rotated slightly to the left. Its right posterior arch is encroaching markedly into the foramen magnum (Figs.3,4). The right arch terminates shortly before the midline and, when I examined the medial sagittal end of this arch, its slightly 'scooped–out' nature led me to suspect that it has never fused with its left-side partner, that is, we are looking at a case of spina bifida posterior, or posterior arch rachischisis.[17,21]

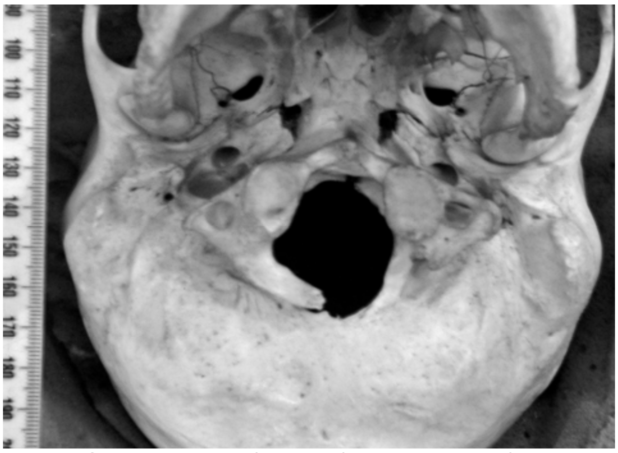

Fig.4: *Closer detail of the inferior aspect of the skull.*

Contrary to the findings of Merbs and Euler,[10] and Nayak *et al*.,[30] the vertebral transverse processes do carry vertebral canals, much larger on the left side than the right (created by thinning of the anterior limb (Green's 'costal lamella'[7]) of the foramen transversarium), (Fig.4). Much-enlarged hypoglossal canals are present bilaterally, as are the foramina for the first cervical nerves. Within the cranial cavity the right transverse and sigmoid sinuses are larger and more deeply marked than those of the left side, a finding corroborating that of Gladstone and Erichsen-Powell.[11] The left condyloid canal is much larger than that on the right, and both open directly into the termination of the sigmoid sulcus (again, a corroboration of Green[7]). In agreement with Merbs and Euler,[10] the inferior atlantic condyles are larger than normal (slightly more so on the right). Both are ovoid, and slope inferomedially and posteriorly, corroborating both Gladstone and Erichsen-Powell's[11] and Green's[7] findings. There is a marked exostosis at the site for articulation with the odontoid process of the second cervical vertebra (Fig.6).

Fig.5: *Right lateral aspect of the skull. The three sites of fusion of the atlas with the occiput are indicated by the black asterisks.*

Fig.6: *Posterior aspect of atlas and skull, in eccentric relationship, showing the odontoid articulation facet flanked by the inferior atlantic condyles.*

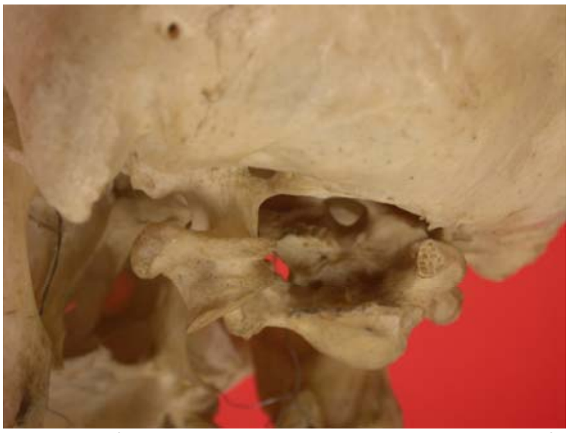

Fig.7: *Left posterolateral aspect, showing the left fusion post and an end-on view of the honeycombed, scalloped, right posterior arch of the atlas.*

The earliest record of fusion between occiput and atlas, in English, that I found was an 1893 paper by Macalister[5] discussing various rare assimilations or 'abnormal attachments' of the atlas to the skull base and citing those found by both Langerhans and Luschka. Unfortunately the findings by Struthers, which were published in the same journal in 1874, were not cited. Thanks to the kindness of an unknown referee I have learned of this, possibly the earliest publication on this subject. In 1915 we read of a 'partial liberation of one of the vertebral elements which normally enter into the composition of the occipital bone'.[11] A trickle of single case reports of developmental anomalies of the craniovertebral border followed[3] from out of what Karl List called, "the twilight zone between neurology and roentgenology"[18] until, in 1953, McRae and Barnum[18] presented 25 cases of occipitalization of the atlas, and an extensive review. Some thirty years later, Merbs and Euler[10] published a case where not only was the atlas fused to the occiput but cervical vertebrae three and four were also fused. The flattening of the left half of the atlantic posterior arch was curiously reminiscent of the flattened left border of the foramen magnum in the current case (Fig. 4). In 1989 Kalla *et al*.[9] published the first systematic study of genetic predisposition to atlanto-occipital joint anomalies. In a radiographic study of 115 close relatives of their 20 cases they discovered a further 4 cases with the same anomaly. Since then, there has been an avalanche of cases of this rarity,[3,8,12,14–17,21,30–33] probably because detection technology has vastly improved.

Given, from the above, the apparent rarity of atlanto-occipital fusion, one might suspect that more might be out there remaining undetected - that is, they are asymptomatic. Indeed Currarino *et al*.[31] in a study sample of seven patients with congenital anomalies of the posterior arch of the atlas found four to be asymptomatic; Torriani and Lourenço[33] went so far as to say that 'in general such abnormalities are asymptomatic'. On the other hand, Smoker[21] provides a comprehensive list of signs and symptoms of craniocervical junction anomalies, pointing out that atlanto-occipital assimilation invariably results in basilar invagination, and cites Vakili *et al*.,[34] 'in some instances, atlanto-occipital assimilation may be associated with sudden death.' Jayanthi *et al*.[8] are equally cheerful. Nevertheless, atlanto–occipital fusion will inevitably shorten the neck and, as the patient grows older, shrinking of the intervertebral discs may force the odontoid process upward into the foramen magnum, adding to the compression of the spinal cord which, in the current case, is already compressed posteriorly by the right posterior atlantic arch. Our case's least problem will be her head directed to the right, with limited lateral head movement due to the angulation of the inferior atlantic condyles, followed by, variously, headache, neck pain, numbness and pain in the limbs, weakness, tinnitus, visual disturbances, and lower cranial nerve palsies leading to dysphagia and dysarthria.[8,10,18,30,32]

How did the atlanto-occipital fusion occur in the present case, assuming that the lack of fusion of the right half of the posterior arch with the missing left half makes it unlikely that trauma or infection are causative agents here? The pattern for future development of the vertebral column is set during the third and fourth weeks of intra–uterine life.[15] The caudal part of the fourth occipital somite fuses with the cranial part of the first cervical somite, forming the 'proatlas'.[11] In some lower vertebrates this remains as a separate bone between the occiput and the atlas, but in humans it is assimilated into the occiput as the occipital condyles, and it also forms the apex of the odontoid process.[15] The caudal part of the first cervical sclerotome segment (possibly with some resegmentation from the cranial part of the second cervical somite) forms the whole of the atlas plus the odontoid process of the axis. Sclerocoele formation within this recombined segment separates the odontoid process from the anterior arch of the atlas. Should this separation not occur, the odontoid process would remain fused to the posterior surface of the anterior arch of the atlas – Fig.6 shows that this separation has been only partial.[18,35] The body and neural arch of the axis is then formed from the fusion of the caudal part of the second cervical somite with the cranial part of the third cervical somite. Should an intrasegmental fissure fail to develop, there will be no intervertebral joint. Thus, occipitalization of the atlas arises when the first cervical somite fails to split into its cranial and caudal components. Consequently, the atlas becomes assimilated into the occipital region, because the fourth occipital somite has fused with the entire first cervical somite and the cranial portion of the second cervical somite.[8,15,16,18,36,37] We can now see that segmentation is one of the crucial prerequisites in vertebrate development.[3] The question we are left with is, why does this segmentation fail to occur?

Incidentally the marked asymmetry shown by this skull is also remarkable - if you look solely at the left side (Fig.1), you see the 'square' orbits (breadth 43.34 mm), small mastoid process (length 16.03 mm), and general gracility of a female. If you now look at the right side, starting from the protruding glabella, the rectangular orbit (46.30 mm), the large mastoid process (length 17.50 mm), the dehiscence of the right tympanic plate, the larger vertebral canal, the wider inferior atlantic condyle (14.35 v. 13.55 mm), the bulk of the mandible... the general 'robustness' of the whole presents a 'male' picture - this lady in death has not only given us the opportunity of studying two atlantic anomalies, she has given us all a useful lesson in sex determination as well.

ACKNOWLEDGEMENT
I acknowledge the kindness of Professor Jules Kieser in allowing me to study this skull.

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CASE REPORT

"CHOUMPS" ENAMEL TATTOOS – REVISITED

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ABSTRACT
Because all humans have an identity in life, compassionate societies require that this identity be recognized after death. Traits that are incorporated purposefully into the teeth as a result of cultural considerations are common. The positive identification of living or deceased persons using the unique traits and characteristics of the teeth is a cornerstone of forensic science. As an adjunct to the previously published article on "CHOUMPS" Enamel Tattoos, (Journal of Forensic Odonto-stomatology 2007;25;61-2), the present report provides an insight into more patterns of highly individual enamel tattoos, various instruments and procedures to perform it and discusses the myths and beliefs associated with this practice.

KEY WORDS: *enamel tattoo, "choumps", forensic odontology, dental mutilations*

INTRODUCTION
Since time immemorial the teeth, the mouth, and face have held a seemingly intrinsic fascination for mankind. They have been and continue to be the subject of many oral and written beliefs, superstitions, and traditions and the object of wide range of decorative and mutilatory practices. Decorating and mutilating the human body are carried out for a variety of reasons ranging from motives related to aesthetics and concepts of beautification to motives which are extremely complex. Interestingly, of the many different forms of body decoration and mutilation encountered in the modern world, the basic theme underlying all of them would appear to be communication either at the interpersonal level or at the spiritual level.[1]

Of the various forms of body decorations and mutilation which may be encountered in contemporary societies, mutilation and adornment of the teeth and oral soft tissues comprise a group of practices of obvious significance to students and practitioners of dentistry.[2,3,4,5] Knowledge of these practices is important for the valuable insights they provide into the cultural beliefs and traditions of the people who practice them. By examining the dental traits in the form of these adornments or mutilatory practices, it is possible for the odontologist to provide the corpse with its identity and satisfy a basic societal need. A tooth tattooed with Choumps has extremely low incidence and could be used as an identification trait.[6]

CASE REPORTS
Choumps are a rare type of tooth tattoo made in gold and are placed on the tooth enamel, mainly on the labial surfaces of the maxillary anterior teeth. This unique practice of getting the teeth engraved with these tattoos is prevalent among certain tribes of western Uttar Pradesh and Rajasthan, India, specially the Gujjar Tribes, and also some Jaduvanshi Thakurs & Jaat Tribes. This practice is equally prevalent amongst both the sexes and is mainly carried out after the eruption of maxillary permanent incisors.

The patterns of these tattoos vary among different tribes but one tribe following more than one pattern was also noticed. The patterns included single gold spot tattoos (Fig.1), double gold spot tattoos (Fig.2), triple gold spot tattoos (Fig.3), six gold spot tattoos (Fig.4) on each of the upper central incisors. Other patterns include triple gold spot tattoos on each of the upper central incisors and single gold spot tattoos on each of the upper lateral incisors (Fig.5), triple gold spot tattoos on each of the upper central incisors and single gold spot tattoo on left lateral incisor (Fig.6), and triple colored spot tattoos on each of the upper central incisors and single colored spot tattoos on each of upper lateral incisors (Fig.7).

In this practice tooth enamel of the labial surface of upper central incisors are engraved with circular patterns using a hand drill and are later filled with gold. The instruments used in the technique are known by various local names like plas or a plier, burma or a hand driven drill, cutter, hammer or hathoda, chimti or forceps, drilling burs or ghurni, gold wire and polishing stone (Fig.8).

These tattoos are not made by professionals, but rather by a local tattoo maker, better known as a Ferua. Feruas usually come to the villages during festivities or villagers visiting the local fares (Melas) get them done. The procedure for placement of Choumps, although simple is unhealthy. It is as follows –

I. The tattoo seeker is made to sit on the ground and the Ferua (Tattoo Maker) sits on the raised platform or a chair. A cloth piece is inserted into the mouth to stabilize the jaws and to prevent aspiration of foreign body. (Fig.9)

II. The labial surfaces of the upper teeth are polished using a local polishing stone. (Fig.10) and then using a drilling bur, markings are made on the teeth where gold wire is later placed (Fig.11).

III. Following this, a hand drill is rotated simulating the lock opening movements thus creating tiny holes at the site of interest. The drilled holes are approximately 0.5mm deep. (Fig.12)

IV. The gold wire is then uncoiled using forceps and is then placed against the already drilled holes. (Fig.13 A,B)

V. Excessive wire is cut (Fig.14A) and the rest of the wire is hammered against the tooth surface to ensure proper adaptation. (Fig.14B)

VI. In the end, a pliers is used to smooth the cut ends of the wire (Fig.15) to get a finished tattoo (Fig.16).

ORIGIN AND MYTHS

The origin of this practice is thought to date back thousands of years. The fact that individuals within a single society or tribal group may possess different levels of knowledge regarding the purposes of a particular dental mutilation practiced by them, lead to the advancement of a number of reasons for a single type of mutilation by different members of a single society or tribe. They include:

Mahabharata and Choumps - According to the great Indian epic, The *Mahabharata*, which was written thousands of years ago, Princess Kunti was blessed with a son named Karana and because of his generous nature; he was popularly known as “Danveer Karana”. When Karana was on his death bed, Lord Krishna (Hindu God) came to him in the disguise of a beggar and asked for some donation in kind to judge his generosity. Even though he was penniless, he realized that he had a tooth with a golden choump on it and so he plucked out his tooth and gave it to the beggar. On seeing this act of kindness, Lord Krishna appeared in his real avatar and blessed him. Since then the devotees of Lord Krishna, follow this tradition of tooth Choumps, in the hope that they will be blessed by Lord Krishna.

The Five Tatvas - According to Hindu mythology, a person should carry five basic elements, called tatvas, in his mouth at the time of his death. One of the five tatvas is gold; hence this particular nomadic clan follows this tradition of engraving gold during their lifetime.

Purity of Speech and Mind - Gold being a purest metal symbolizes truth. Hence this tribe has a belief that a person who has gold engraved in his mouth will follow the path of honesty and truthfulness.

Branding - In olden times, members of a particular tribe were recognized on the basis of the specific patterns of the Choumps.

Biological - Some even believed that engraving the Choumps would arrest the growth of tooth, and thus prevent unnecessary lengthening of the crown.

Fashion Statement and Beautification - Younger generations unaware of the mythological significance followed this practice as a fashion statement.

DISCUSSION

Mutilatory practices involving teeth have been present since pre-historic times and many of these practices are still being followed, but adequate data regarding each is lacking. Non-therapeutic tooth extraction or deliberate tooth avulsion of upper incisors is being practiced by Australian Aboriginal tribes[7] and in regions of the African continent including Nigeria, Uganda and Tanzania.[8,9] The custom of chipping the incisal edges of incisors is well known amongst the Bushmen tribes of Africa.[8,9,10] In certain areas of the Philippines, the practice of inlaying small gold discs, often multiple, in the labial surfaces of anterior maxillary teeth, was prevalent. The practice of mounting decorative inlays like pearls and semi-precious stones on anterior crowns, was also carried out in India by the kings and rulers of ancient times. The Dyaks of Borneo were also reported to drill small holes into the labial surface of maxillary teeth and to place pieces of copper in variously shaped defects. Some people of Algeria in North-West Africa are known to insert a small piece of gold between the proximal surfaces of anterior maxillary teeth for adornment purposes.[11] Among Muslims, the presence of a gold crown on a front tooth is used to signify that the wearer has visited Mecca, the spiritual centre of that religion. Also use of gold jacket crowns is favored by some people in the Caribbean and some groups of Urban Blacks in USA as a status symbol.[12]

Not only the hard tissues, but the peri-oral soft tissue, may also be involved in mutilatory practices which can range from lacquering and black staining, dyeing using iron or barks, tattooing of lips and gingiva, piercing of lips and other soft tissues and insertion of materials such as wood, ivory or metal, uvelectomy and facial scarring.[3,4,5,13,14,15]

CONCLUSION

Data with low frequency of occurrence are considered to be important to those seeking to identify the deceased.[16] The practice of enamel tattoos Choumps is unique in itself by the way of its geographical distribution and the nomadic clan following this traditional practice. Hence it is appropriate to include tooth art or modifications in ante-mortem records and to reproduce proper radiographic and photographic records of these modifications, which will enable not only to secure cultural heritage but ease job of forensic specialist. We also emphasize the need for further studies regarding the prevalence of other mutilatory practices involving the oral and peri-oral structures in various tribes of Indian subcontinent.

Fig.1: *Single gold spot tattoos on each of the upper central incisors.*

Fig.2: *Double gold spot tattoos on each of the upper central incisors.*

Fig.3: *Triple gold spot tattoos on each of the upper central incisors.*

Fig. 4: *Six gold spot tattoos on each of the upper central incisors.*

Fig. 5: *Triple gold spot tattoos on each of the upper central incisors and single gold spot tattoos on each of the upper lateral incisors.*

Fig. 6: *Triple gold spot tattoos on each of the upper central incisors and single gold spot tattoo on left lateral incisor.*

Fig. 7: *Triple coloured spot tattoos on each of the upper central incisors and single coloured spot tattoos on each of the upper lateral incisors*

Fig. 8: *Armamentarium used in placing the enamel tattoo.*

Fig. 9: *Positioning of the tattoo seeker and the tattoo maker.*

Fig. 10: *Polishing.*

Fig. 11: *Markings with a bur.*

Fig. 12: *Holes created with the help of a hand drill.*

Fig.13A,B: *Placement of the gold wire.*

Fig. 14: *A – Excessive wire being cut; B – The remainder of the wire being hammered.*

Fig. 15: *Smoothening.*

Fig. 16: *The finished tattoo.*

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