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The application of computerized tomography (CT) to the dental ageing of children and adolescents

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ABSTRACT

Introduction: Following a mass disaster, the aim of the Disaster Victim Identification process is to establish the identity of the victims. The ageing screening process on victims in Victoria may now be complemented with the use of computerized tomography (CT), where previously any dental ageing analysis was performed using conventional radiographs.

The aim of this study was to assess the accuracy of age estimation using the dental ageing method proposed by Moorrees, Fanning and Hunt (MFH) using CT images. Intra- and inter-rater variability between two raters, one experienced and one inexperienced, was also assessed.

Materials and methods: The two raters were blinded to the ages of 96 deceased Australian children aged up to 15 years. Using three-dimensional (3D) shaded surface displays (SSD) and reformatted CT images, the age was first estimated based on prior experience alone, followed at a later date by the age estimation utilizing the MFH method. These estimates were then compared to the known chronological age. The results were statistically analyzed in a one-sample *t*-test, using the mean log-ratio of the estimated age to the chronological age.

Results: Our findings show that the experienced rater was more accurate in age estimation than the less experienced when using prior experience ($p < 0.0001$). The use of reformatted CT images to perform an ageing estimate using the MFH method was found to systematically underestimate the chronological age by 10% by both raters ($p = 0.784$). There was no significant difference between the two raters. Intra-rater reliability was high ($p = 0.135$).

Conclusions: CT can provide accurate estimates of dental ages. Prior experience with dental ageing and/or CT improves the accuracy. However, with the use of validated ageing charts, inexperienced raters can also achieve accurate age estimates using CT images.

1. Introduction

The identification of deceased persons by dental means is one of the most rapid and useful methods utilized by the investigating authorities following mass disasters [1]. The estimation of the chronological age of a deceased child, even when given as a range of ages, can be an essential factor in the subsequent identification of that child, enabling the investigating authorities to reduce the range of possible matches prior to the implementation of more expensive and time-consuming identification techniques.

Age estimation requires a thorough understanding of the chronological development of the dentition and research into it has undergone some modification over time. Different manners of showing the dental development have been utilized: diagrams [2], charts [3] and the assignation of formative stages [4]. Moorrees, Fanning and Hunt (MFH) divided the formation of teeth into 14 stages. They produced charts showing the mean age of attainment of each of the stages for each of the prescribed teeth, permanent and deciduous, from which the age is estimated using whatever teeth are visible [5,6].

The abovementioned method relied on the use of intra-oral and panoramic radiographs which can be difficult to take in the

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deceased for a variety of reasons—rigor mortis, trauma to the head and lack of access to equipment.

The recent introduction of computerized tomography (CT) among a few forensic institutes around the world has facilitated obtaining images of deceased persons for post-mortem examinations. At the Victorian Institute of Forensic Medicine (VIFM) in Melbourne, Australia, CT imaging is routinely used as part of every post-mortem examination, including the dental examination where CT has a number of advantages over intra-oral radiography. It does not require placing image receptors into the mouth, nor does it require manipulation of the head in order to align the X-ray beam in the appropriate direction, even after severe head trauma.

CT also has the capability of producing cross-sectional and images in three-dimensions (3D) of an individual in a variety of ways. In the mortuary setting, it enables the emerged teeth and the skeletal system of the deceased to be viewed through shaded surface display (SSD) reconstruction of the original axial datasets. Axial CT images may also be reformatted using a curved multiplanar reconstruction (MPR) to produce images that resemble conventional panoramic dental radiographs.

The use of CT has not yet been tested in the estimation of children's ages.

The aims of this study were threefold: (1) to determine if the use of reformatted CT images was clinically useful for the estimation of chronological age in a cohort of deceased Australian children and adolescents using the dental ageing method of MFH; (2) to determine if prior dental experience affects the accuracy of age estimation using the above method; and (3) to determine the intra- and inter-rater variability in our setting.

2. Materials and methods

2.1. Selection of cases

Ethical approval for the conduct of this study was obtained from the Ethics Committee of the VIFM and the Standing Committee on Ethical Research in Humans at Monash University, Melbourne.

A list of 173 deceased children admitted to the VIFM from April 2005 to 31st July 2006, all aged up to 15 years, was obtained from the Information Technology Section of the VIFM. The researchers were blinded to all personal information, except the gender. An individual research number was allocated to each of these in reverse chronological order by an independent investigator.

The upper limit of age for the cases in our study was set at 15 years of age, as the formation of the last permanent lower tooth to have emerged by that age (the second permanent molar) is almost complete, and hence the last stages of its root development can be used for ageing. There was no lower limit set, as children of very young ages are admitted to the VIFM.

Of the 173 cases identified, the CT images of 96 cases were available for viewing on the server.

2.2. Imaging protocol

The CT scanner at the VIFM used in this study is a Toshiba Aquilion® 16 slice multidetector CT (Toshiba Medical Systems Corporation, Tochigi, Japan). Upon admission to the VIFM, each deceased person undergoes a full body scan. Scans of the deceased's chest, abdomen and pelvis are reconstructed into 2.0 mm overlapping slices and the head into 1.0 mm overlapping slices.

The images obtained from the scan were viewed on a Vitrea® 2 workstation (Vital Images Inc., MN, USA). Using the MPR facility of the software, orthogonal views of the head were obtained, as well as 3D SSD images. Curved reformats of the axial slices were then constructed through the forming dental tissues of the mandible and/or the maxilla, producing an image resembling an orthopantomograph (OPG). Oblique sagittal reformats on each side produced a lateral image of the mandible. The dataset of the sharpest images of the algorithms provided was used. 'Snapshots' (digital copies) of relevant reformatted MPRs were then taken and converted to Portable Network Graphics (PNG) image format for digital storage at the VIFM. These images constituted the dataset for analysis of the developing dental tissues.

The 3D SSD images and the reformatted CT images of all the cases were copied onto a compact disc (CD) by the same independent investigator. This CD was later used by both raters to estimate dental ages.

2.3. Estimation of ages

Rater 1 was a general dentist of 31 years' experience; Rater 2 was an English fourth year dental student, who was visiting Melbourne, Australia, for two and a half weeks in 2008 on the elective study component of her course. This rater had no experience using CT images nor the MFH method.

The 3D SSD images and the reformatted CT images of the developing dentitions of the cases on the CD were viewed by both raters independently from each other.

2.3.1. Estimate using dental experience

This age estimation was based solely on the rater's prior experience. Neither rater had documentation of any kind on hand. Both raters gave an estimate of each deceased child's age in whole months based solely on the 3D SSDs and the reformatted CT images, blinded to the other rater.

2.3.2. MFH method

MFH was selected as the method of choice, because of the ability to use any number and any kind of developing teeth visible (permanent or deciduous), with separate charts for boys and girls. This renders this method more adaptable and practical for use in children of all ages.

Both raters were provided with identical reference diagrams and documentation for the MFH method. The pertinent 'Male' or 'Female' versions for each of the charts developed by MFH were provided for each case: that with the mandibular permanent canines and posterior teeth ('permanent'), that with the maxillary and mandibular permanent incisors ('incisors') and lastly, that with the mandibular deciduous canines and molars ('deciduous'). The gender of each case was known, imitating a real-life scenario.

The ages of the children were estimated in months to two decimal points using the pertinent MFH charts mentioned above. If only one chart was used, the age estimate was rounded up or down to the nearest whole month. If more than one MFH chart was used, the arithmetic mean of the estimated ages was obtained and rounded up or down to the nearest whole month.

2.4. Intra-rater reliability

In order to assess intra-rater reliability, Rater 1 analyzed a randomly selected subset of 10 cases on three separate occasions. On each occasion, the cases were shuffled randomly to change the sequence of the cases. Further, each analysis was carried out several weeks after the previous analysis, in order to avoid remembering individual cases.

2.5. Inter-rater reliability

Inter-rater reliability was assessed for the two raters using two different ageing methods. The first method was based solely on prior experience, while the second used the validated method developed by MFH [5,6].

Raters 1 and 2 each worked alone and were blinded to the results of the other throughout the entire study. Rater 1 performed the estimate using prior experience at the time of the reformatting of the images on the Vitrea workstation; Rater 2 performed that estimate 18 months later, viewing the images of the cases on the CD in the same order as Rater 1 had in 2006 and using a similar Vitrea workstation at the VIFM.

For the MFH analysis, the reformatted CT images of the developing dentitions of the cases on the CD were viewed by both raters separately on the same laptop computer using Windows Pictures and Fax Viewer (Microsoft® Corporation, Redmond, USA), in the same order and each working alone under the same lighting conditions. Rater 1 performed the MFH analysis 3 months after the estimate using experience; Rater 2 performed the MFH analysis one week after the estimate using experience due to time constraints.

Both raters were unblinded upon completion of the respective studies and an independent investigator (SRG) carried out the statistical analyses comparing estimated ages obtained by both raters and methods to the chronological ages of the cases. The distribution of ages of the deceased children is shown in Table 1.

2.6. Statistical analysis

As it is the relative error, rather than the absolute error, in the estimated age that is of interest, the analysis was performed using the ratio of estimated age to chronological age. This was converted to a logarithmic scale, yielding log(estimated age/chronological age) or 'log-ratio' as the variable of interest.

A one-sample t-test was performed using Stata (version 8.2, StataCorp Inc., College Station, TX, USA) for the statistical analysis and a p-value of <0.05 was considered statistically significant. The mean log-ratio and the 95% Confidence

Table 1
Cases of deceased children grouped according to ages (total $N = 96$).

Age (months)	n/N	(%)
1–12	47	(49.0)
13–60	15	(15.6)
61–120	13	(13.5)
121–180	21	(21.9)

Table 2
Age estimation (mean ratios of estimated to chronological age) of two raters based on two ageing methods using CT images.

	Mean ratio	95% CI	*p*-value[a]
Experience-based estimation			
Experienced rater	1.017	0.925–1.120	0.719
Inexperienced rater	1.525	1.333–1.761	<0.0001
MFH-based estimation[b]			
Experienced rater	0.908	0.839–0.984	0.019
Inexperienced rater	0.901	0.829–0.978	0.014

[a] One-sample *t*-test.
[b] Moorrees, Fanning and Hunt.

Interval (CI) were converted to ratios for the purpose of this study. A ratio of 1.0 indicated that the estimate was identical to the chronological age of each case.

3. Results

The accuracy of CT-based age estimation compared to chronological ages is shown in Table 2.

Overall, CT-based age estimation was feasible and achieved clinically useful outcomes. When using the MFH method on reformatted CT images, ages were underestimated by 10%. Overall, when compared to chronological ages, accuracy rates of estimated ages based on CT was high.

The age estimation by an experienced dentist using prior dental experience was found to be more accurate than that by that rater using the MFH method.

3.1. Intra-rater reliability

The findings showed that there was high intra-rater reliability when performed by an experienced rater using the MFH method ($p = 0.135$).

3.1.1. Inter-rater reliability—age estimation using prior experience

There was a significant difference between the two raters when using age estimation based solely on prior experience ($p < 0.0001$). The mean age estimation by Rater 2 was significantly higher than that by Rater 1 (Table 2).

3.1.2. Inter-rater reliability—MFH method

Our results showed that the use of the MFH method by both raters systematically underestimated the age of the deceased children by approximately 10% when using CT (Table 2). However, there was no significant difference between the two raters when using the MFH method ($p = 0.784$). This result highlights that the use of a systematic dental ageing method, such as MFH, can significantly improve the age estimation by an inexperienced rater.

Table 3
Age estimation by an experienced rater according to ages and method.

	Mean ratio	95% CI	*p*-value[a]
Ages (months)			
1–60	0.880	0.771–1.004	0.056
61–120	0.928	0.882–0.977	0.008
121–180	0.900	0.855–0.948	0.0004
MFH chart used[b]			
Incisors	1.107	1.055–1.159	0.0014
Deciduous	1.108	0.920–1.115	0.72
Permanent	0.882	0.813–0.955	0.0026

[a] One-sample *t*-test.
[b] Charts produced by Moorrees, Fanning and Hunt.

3.2. Further results

The results of Rater 1 were further analyzed comparing the accuracy of the age estimation with the individual MFH charts used and within prescribed age cohorts (Table 3).

They show that age estimation is more accurate in young children, with the use of the 'deciduous' MFH chart ($p = 0.72$) and in the youngest cohort of the cases i.e. those aged less than 60 months ($p = 0.0564$).

4. Discussion

This was the first study to use CT to estimate the age of deceased children. The findings have demonstrated the versatility of CT in image manipulation, not only using its 3D capability, but also its ability to produce radiograph-like images. CT-based age estimation could be reliably performed within 10% of chronological ages by both experienced and inexperienced raters when utilizing the MFH method.

In only 7 of the 96 cases was no MFH analysis possible. In 2 of these, there was not enough calcified dental tissue visible to perform the ageing estimate. In the other 5, there was dental calcified tissue visible, but the stage attained was too early to allow the MFH method to be used. The earliest stage in the formation of deciduous mandibular first molars at which the mean age is shown is $C_{1/2}$ (crown half formed) and that of deciduous mandibular second molars is C_{OC} (occlusal surface complete). In the 5 latter cases, neither of these first stages was reached. All 7 children were assigned the age of 1 month as their estimated age for the initial statistical analysis. It should be noted that the chronological ages of all these 7 cases were less than 1 month, with 5 being less than 12 days.

In order to obtain a more true idea of the accuracy of the MFH method in young children, another statistical analysis of the youngest age group without these 7 cases was performed. In this analysis, the mean ratio was 0.866 (CI: 0.746–1.004) ($p = 0.0563$), compared to a mean of 0.880 when they were included (Table 3). This highlights the consistent underestimation with the use of the MFH method in very young children when using reformatted CT images.

The reformatting most often used for viewing the dentition was the oblique sagittal reformat, which showed the deciduous and permanent mandibular teeth as anteriorly as the canine, as shown in Fig. 1. This rendered these images particularly suitable for use

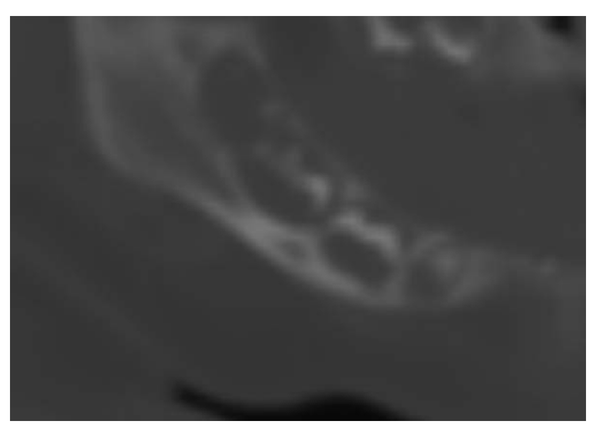

Fig. 1. An oblique sagittal reformatted CT image of the lower right quadrant of a 3-month-old child. Note the appearance of the deciduous molars, indicating the occlusal surface is complete. The notation of this stage of attainment compared to that visible in the periapical radiograph (Fig. 3) has possibly corrected the underestimation found in other studies. The notation of the stage of attainment for the permanent molar remains unchanged at C_i.

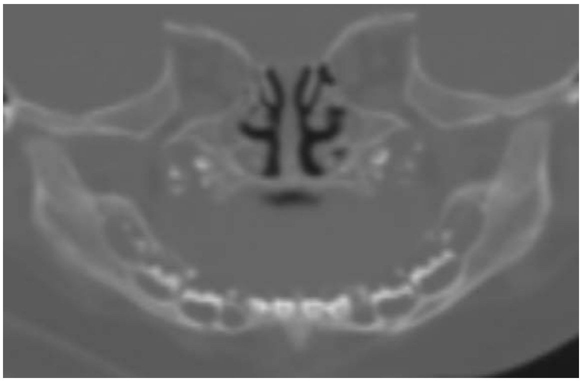

Fig. 2. A curved MPR CT image resembling an OPG. Note the indistinct appearance of the lower deciduous incisors. The occlusal surfaces of the deciduous mandibular molars appear complete and some calcification is visible in the developing mandibular permanent molar sites. Chronological age is 3 months.

Fig. 3. A periapical radiograph of the same quadrant of the same child as Fig. 1. Note the definition of the cusps' outline and that the occlusal surface is not complete.

with the 'deciduous' and 'permanent' MFH charts. The use of the 'deciduous' chart showed a minimal overestimation, while the use of the 'permanent' chart underestimated chronological age and was less accurate (Table 3). However Liversidge noted an underestimation with both charts of 0.52 (±0.62) years and 0.57 (±0.42) years, respectively in a London archaeological population, aged from 0 to 5.4 years of age [7].

In addition, the inability to view the lower incisors well is a common problem with conventional OPGs and curved MPRs, as demonstrated in Fig. 2. The MFH method uses the maxillary and mandibular permanent incisors as one of its ageing features, so an inability to view them reduces the number of teeth available for ageing. In only 9 cases of this study were the images of the anterior teeth able to be used for ageing. The ages of the individuals in which these images were used ranged from 65 to 112 months, which fell in the middle group of the prescribed age cohorts.

However, no child's age was estimated using the 'incisors' chart alone—for all 9 cases above, it was used in conjunction with the 'permanent' chart. The remaining 4 cases of the middle group used the 'permanent' chart only. The slight overestimation by the 'incisors' chart was affected by the 'permanent' underestimation, to produce an overall mean ratio of 0.928 in the middle group.

In the 21 cases comprising the oldest group, the age estimates were calculated solely by using the 'permanent' chart, with a similar degree of underestimation.

In the analysis of the youngest group, either the 'deciduous' nor 'permanent' charts were utilized together (37 cases), or just the 'deciduous' chart (20 cases) or just the 'permanent' chart (5 cases), combining to give an overall mean ratio of 0.866. With the slight overestimation by the use of the 'deciduous' chart, the subsequent underestimation found in this group was again introduced by the underestimation using the 'permanent' chart.

This study agreed with Liversidge in finding that the age prediction in young children is more accurate than in older children and adolescents [7]. However in the very young age group, it is sometimes difficult to differentiate the individual tooth tissues on the reformatted CT images, as the crowns of the smaller deciduous canines and molars are only beginning to calcify. Figs. 1 and 3 demonstrate the differences in appearance of the same dental structures using two imaging modalities. The accuracy obtained using the 'deciduous' chart in this study seems inconsistent with the features visible in Fig. 1.

The appearance of the deciduous molars as seen in Fig. 1 may be due to the different manner in which deciduous teeth form [8]. The more radiolucent dental pulp is in closer proximity to the highly mineralized enamel crown form with less dentine between; in developing permanent teeth, there is a thicker intervening layer of dentine. Thus, the improved contrast resolution of CT (i.e. that showing the different electron density of the varying hard tissues) seems to have overwhelmed the reduced spatial resolution (i.e. that which demonstrates fine structures, for example the individual cusp tips and cuspal planes), producing a more complete crown form.

The versatility of CT was demonstrated in the estimation using prior dental experience. The 3D SSDs only enabled the number of emerged teeth to be viewed, whereas the reformatted CT images showed the dental developmental stage reached radiographically. In addition, the 3D SSD of the skull can be rotated on any of its axes, making all aspects of the skull visible. They include all the fontanelles in very young children. For example, the frontal fontanelle closes at approximately 12 months of age, with the other 5 closing at different ages within the first 12 months [9]. Fig. 4 shows a lateral view of a 3D SSD of a 3-month-old child.

The use of the age of closure of all the fontanelles using SSDs may add another parameter to age estimation in very young children. It may also be used in tandem with the 'deciduous' charts

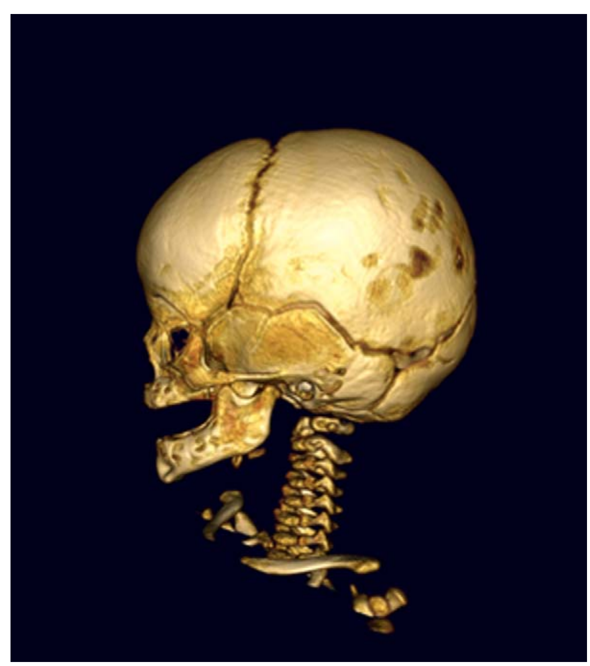

Fig. 4. The lateral view of a 3D SSD reconstruction showing no emerged teeth and the incomplete closure of the fontanelles, both indicating an age of less than 12 months. Chronological age is 2 months.

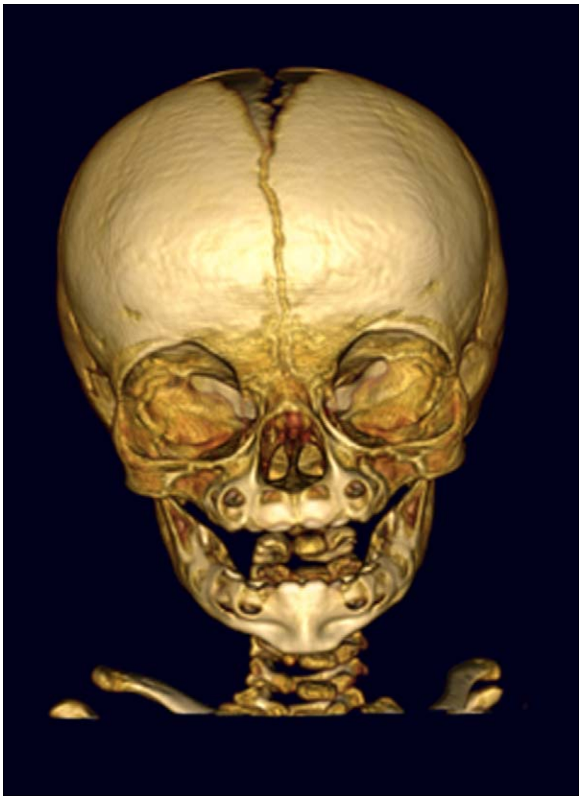

Fig. 5. The frontal view of the 3D SSD of the same child as Fig. 4. The patent frontal fontanelle is visible. Note the appearance of the incisal edges of the emerging deciduous anterior teeth and that no gingival tissue is visible.

of the MFH method. However it should also be noted that the reformatted CT images of the developing dentitions can be quite unclear in some very young children, as noted above.

The SSDs also showed which teeth had emerged. However, they showed when a part of the crown had pierced the bony alveolar crest, rather than the gingiva. Fig. 5 shows the frontal view of the same child as Fig. 4—note the appearance of the incisal edges of the emerging mandibular and maxillary deciduous incisors. With this unique view of the emerging teeth, especially in the very young children, an overestimation of age would be expected. These children would be perceived to have more teeth than what would be clinically visible as no gingival tissue was visible on these particular SSDs. Both raters overestimated the chronological age in these cases using their experience, though to different degrees.

Overall, both raters underestimated the chronological age by 10% when using the MFH method on reformatted CT images. However, without the dental charts developed by MFH nor any other documentation, the estimates were significantly less reliable by the inexperienced rater. This outcome may have been due to the inability of Rater 2 to view the cases on the CD in 3D at the workstation, and also in the limited dental experience of Rater 2 in her career to date. This study using prior experience was more subjective in nature, with no diagrams nor documentation able to be referred to for comparison. Previous studies analyzing experience were more objective in nature, in the matching of radiographs by a dental student and other dental practitioners [10–12].

We also found that experience with CT may be beneficial in the estimation of age. Rater 1 had received tuition in CT image manipulation, had viewed all the images of the cases, manipulated them and had taken the 'snapshots' of the cases. Rater 2 did not have this experience. It is however, possible that having viewed the cases in the component using experience first, Rater 2 gained some proficiency in viewing and analyzing the reformatted CT images for the later MFH analysis. This was manifested by the insignificant difference between the mean ratios for Raters 1 and 2 in the MFH analysis. Further studies are needed to establish how much training is necessary to obtain reliable age estimates among staff with varying levels of experience.

5. Conclusion

CT can provide clinically useful images for the accurate and reliable estimation of dental ages of children after a mass disaster. Prior experience in dental ageing and the use of CT imaging improves the overall accuracy, especially when used in conjunction with a validated dental ageing method.

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