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ORIGINAL ARTICLE

Postmortem computed tomography age assessment of juvenile dentition: comparison against traditional OPT assessment

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Abstract Age estimation is one of the primary demographic features used in the identification of juvenile remains. Determining the accuracy and repeatability of age estimations based on postmortem computed tomography (PMCT) data compared with those using conventional orthopantomography (OPT) images is important to validate the use of PMCT as a single imaging technique in forensic and disaster victim identification (DVI). In this study, 19 juvenile mandibles and maxilla of known age underwent both OPT and PMCT. Three raters then estimated dental age using the resulting images and 3D reconstructions. This assessment showed excellent agreement between the age estimations using the two techniques for all three observers. PMCT also offers a greater range of measurements for both the dentition and the whole human skeleton using a single image acquisition and therefore has the potential to improve both the speed and accuracy of age estimation.

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Introduction

Under the United Nations Universal Declaration of Human Rights, retaining an identity after death represents a basic human right [1]. When dealing with juvenile remains, age-at-death is an important criterion, and odontological examination is arguably the most rapid and practical method available for this purpose. Dental age markers are reported to correlate more strongly with chronological age than skeletal markers, being less affected by the environment [2]. Dental age estimation techniques are predominantly based on the degree of mineralization and/or eruption of the dentition and involve matching radiographs to atlases of dental development or assigning formative stages of mineralization by scoring individual teeth. Although development of the third molar is regularly used as a quick indication of sub-adult age [3], this tooth displays the highest degree of variation amongst individuals, and therefore a technique using multiple tooth development is preferred, where possible [4, 5]. The most regularly utilised methods for odontological age-at-death estimation in UK forensic practice at present are the 'London Atlas of Human Tooth Development and Eruption (QMUL) [6, 7] and Demirjian's method [8, 9] of formative tooth maturity scores'. The QMUL method is an adaptation of Ubelaker's 1978 atlas [10], using data from modern UK dental collections, illustrating dental structures including tooth roots, with a more comprehensive range of age stages and where eruption refers to emergence from alveolar bone.

An orthopantomogram (OPT) captures a full dental arcade in a single image using a revolving X-ray tube and is traditionally used in forensic practice. However, OPTs may be difficult to obtain in a forensic context, due to a lack of access to equipment or difficulties with the revolving nature of the image acquisition due to severe trauma or rigor mortis [11, 12]. Recently, there has been gradual acceptance that postmortem computed tomography (PMCT) could aid, and potentially replace, this more traditional imaging method by both reproducing and augmenting the information available from an OPT. This has been driven by increasing availability and affordability, and the development of spiral and multiple detector CT (MDCT), which has improved scanning speeds and resolution, allowing high quality image reconstructions in multiple planes and 3D modelling of slices [13]. A single image acquisition using PMCT allows teeth and bones to be assessed in any plane without invasive procedures, offering considerable practical and aesthetic benefits. Used in conjunction with a teleradiology system, such as the FiMag system [14], it would also allow secure global distribution and evaluation of images used for identification purposes. Although the availability of PMCT for forensic examinations is not widely spread, if a 'one stop' protocol could be produced for the examination and identification of the entire human skeleton using PMCT, this could replace all existing image techniques currently used. A particular advantage of PMCT dental evaluation is that it does not need the placement of image receptors into the mouth, required for intra-oral radiography, nor manipulation of the head to align the X-ray beam as required for OPT [15]. However, there are significant disadvantages due to increased sensitivity to metal artefact [16, 17]. CT reconstruction algorithms can now accommodate for metal implants such as titanium, but high-density metals such as gold or mercury in dental restorations are still a problem [18]. Cone beam CT (CBCT) is also being increasingly used in dental practice and gives similar (but not superior) 3D dental assessment. However, CBCT cannot be practically used to image the whole skeleton and so could not provide a 'one stop' protocol.

For PMCT to become routinely implemented in forensic practice, evidence is required that age estimations using this approach have comparable accuracy and repeatability to methods using conventional OPTs. The aims of this investigation were therefore (1) to determine if age estimations based on PMCT data were in agreement with those made on OPTs, using the London Atlas of Human Tooth Development and Eruption (QMUL) and Demirjian's dental age estimation method; (2) to determine whether prior knowledge of software had any effect on precision of measurement; and (3) to asses intra- and inter-rater variability between three observers of varying experience with dental PMCT age estimation.

Materials and methods

Selection of cases

This project utilised human remains from the Scheuer Juvenile Skeletal Collection, believed to be the only active repository exclusively for juvenile skeletal remains. The collection contains the skeletons of over 100 individuals, from archaeological, forensic and historical anatomical sources and is held in the Centre for Anatomy and Human Identification at the University of Dundee. Nineteen mandibles and maxillae from individuals of known age (between 0 and 18 years) were selected randomly from the collection, by an independent practitioner who had no further involvement or knowledge of this investigation and CT scanned by a trained dental radiographer. PMCT dental images were acquired using a truck mounted SOMATOM® Emotion 16-detector CT scanner (Siemens AG Medical Solutions). Scans involved helical acquisition using a 0.75 mm slice thickness, 120 kVp, and 100 mA with bone and soft tissue reconstructions at 1.25 mm. Data were stored on compact disc and transferred to a workstation with image analysis software (OsiriX version 3.7.1; distributed freely as open-source software under the GNU licensing scheme at the following Web site: http://homepage.mac.com/rossetantoine/osirix).

Imaging protocol

Image analysis for the PMCT data was undertaken using software (OsiriX version 3.7.1; distributed freely as open-source software under the GNU licensing scheme at the following Web site: http://homepage.mac.com/rossetantoine/osirix). Curved multi-plane reconstructions (curved MPRs) from the data set were created to allow dental analysis to be undertaken in any plane. Typical OPT and OsiriX curved MPRs are shown in Fig. 1.

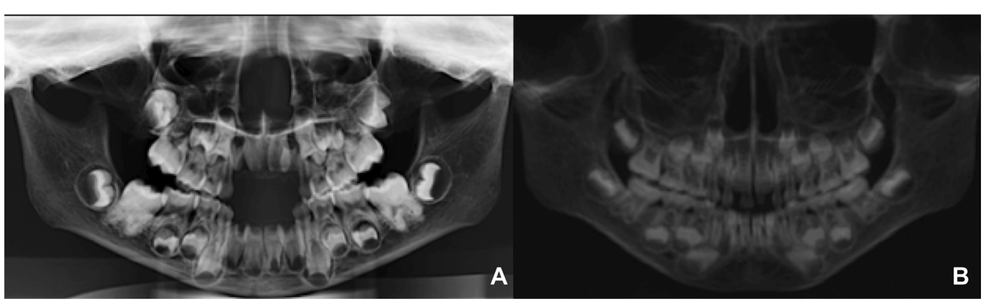

Fig. 1 **a** Conventional orthopantomography (OPT) image and **b** multidetector computed tomography curved MPR image

Table 1 Comparison of predicted age in months obtained using the QMUL method and OPT and PMCT images

Case	Documented age (months)	QMUL method						Average
		Rater 1		Rater 2		Rater 3		
		OPT	PMCT	OPT	PMCT	OPT	PMCT	
1	228	282	270	288	276	282	270	278.0
2	96	114	115.5	114	120	114	102	113.3
3	144	144	150	144	150	150	150	148.0
4	168	174	160	180	160	150	162	164.3
5	228	282	234	288	240	282	234	260.0
6	228	222	246	222	252	234	234	235.0
7	228	186	222	180	186	198	216	198.0
8	Perinate	1.5	2.25	1.5	2.25	1.5	2	1.8
9	2	1.5	3	1.5	3	1.5	2	2.1
10	18	18	18	18	18	18	18	18.0
11	18	24	30	30	30	30	24	28.0
12	96	90	97.2	90	98.4	90	102	94.6
13	144	150	162	150	162	150	162	156.0
14	60	78	78	78	81	78	78	78.5
15	96	168	174	168	174	168	162	169.0
16	216	198	198	204	205.5	210	210	204.3
17	144	96	92.4	90	88.8	114	102	97.2
18	132	66	42	66	42	66	42	54.0
19	216	72	168	72	168	78	168	121.0

Image analysis

The PMCT and OPTs were reviewed independently by three raters: two dental practitioners with experience in dental age estimation and one forensic anthropologist with PMCT data analysis experience. Observers were unaware of the age of each individual. The raters applied the QMUL method to each case, followed 1 week later by the Demirjian method (where possible—see below). The PMCT images were assessed 2 months after the OPTs. The age assigned through both methods and both media were then compared with the original age assigned for each individual. Age was only revealed after all age estimations were completed. If there was any uncertainty over age estimation, the practitioner was asked to comment and provide a reason for this uncertainty.

Statistical analysis

PMCT age estimations are compared to actual age using 95 % confidence interval (CI) and paired Student's t test (statistical

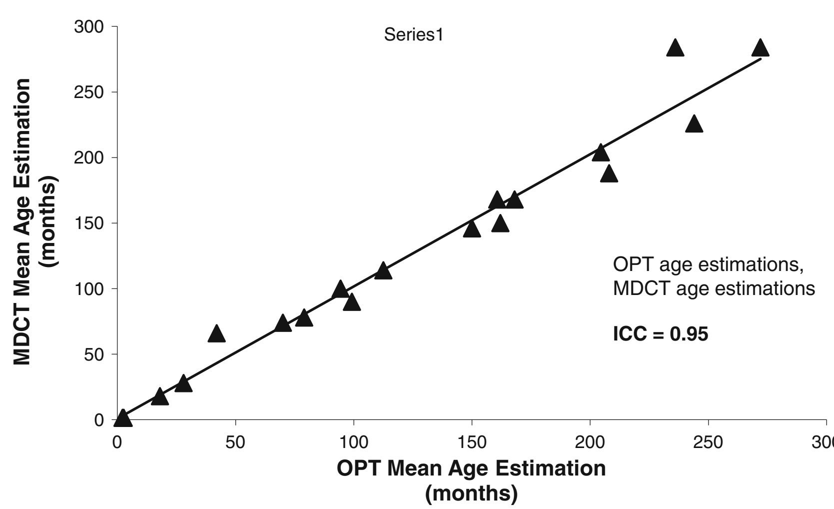

Fig. 2 Mean age estimations using PMCT images versus mean age estimations using conventional OPTs

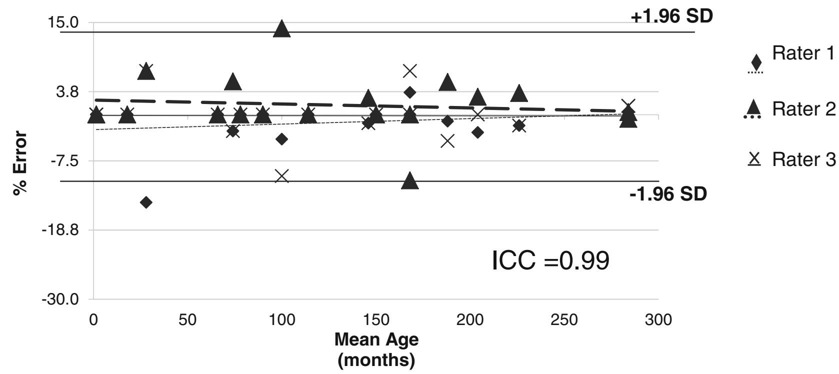

Fig. 3 The *diamond shaped* and *triangular shaped markers* correspond to the two dental practitioner observers. These data points are extremely close for almost every case compared with the inexperienced observers (*cross shaped marker*) that are clearly more scattered, with two points lying outside the confidence intervals

significance was assumed if $p<0.05$), after a Kolmogorov–Smirnov test using SPSS determines the data was normally distributed. Measurement error is calculated and presented using the 'Bland and Altman' plots [16, 19]. Statistical analysis of agreement is performed using interclass correlation (ICC) to measure the level of agreement between observers, methods and data sets. Initially, a two-way analysis of variance was performed, and if the column mean sum of squares (between methods of measurements or raters) is not significantly greater than the residual error, concordance is assumed. The ICC for the relationship provided a scalar measurement of agreement, where a value of 1 represented perfect agreement, and 0 was interpreted as a lack of any agreement. ICC has advantages over correlation coefficient analysis, as it adjusts for the effects of scale magnitude and can represent the agreements for more than two observers.

Results

Comparison of the predicted ages using OPT and PMCT are given in Table 1 and Fig. 2. Using the paired Student's t test method, no significant difference was detected between the predicted ages for OPT and PMCT for each rater (p values of 0.45, 0.56 and 0.83 for raters 1, 2 and 3 respectively). No significant inter- or intra-rater variation was found. Almost perfect agreement was illustrated, both between observers and between repeat estimations by the same raters, for OPT age estimations and PMCT age estimations, using both the QMUL and Demirjian methods with an ICC coefficient of 0.99 calculated for both (Figs. 3 and 4). Applying the QMUL method obtained almost perfect agreement between mean estimated age using PMCT, mean estimated age using OPTs and original age assignment age (Fig. 5). Age estimations using OPTs and age estimations using PMCT were also in almost perfect agreement (Fig. 5).

Unfortunately, since the Demirjian technique is only valid for individuals aged 3–16 years, the sample size was too small for a similar analysis to be performed. However, as the agreement between observers for this technique was almost perfect (ICC 0.98), our results suggest that in cases where this technique is possible, dental age estimations could potentially be improved by PMCT.

Discussion and conclusion

Orthopantomography is the standard imaging method for dental evaluation in forensic investigations. Current standards for dental identification are therefore based on this method, and there are no recognised standards for PMCT dental evaluation. This study has followed the protocols implemented for OPTs as closely as possible with slight modification where PMCT has offered improved measurement opportunities. This

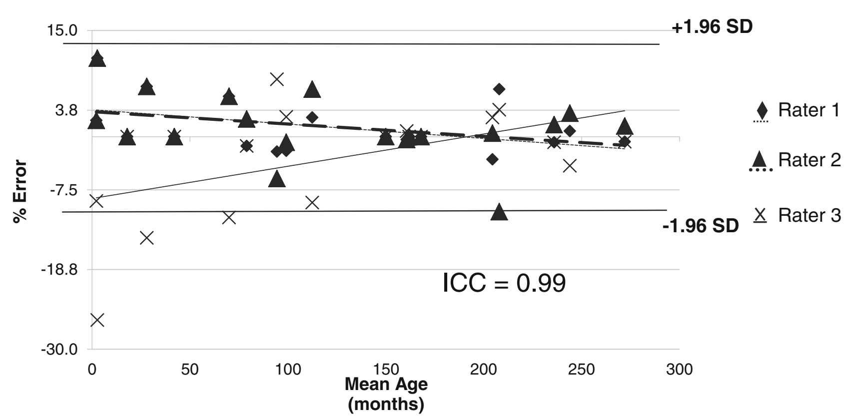

Fig. 4 For PMCT estimations, the results of the inexperienced observer are much less scattered than those using traditional OPT images, suggesting that this technique is more reproducible by individuals with no previous dental experience

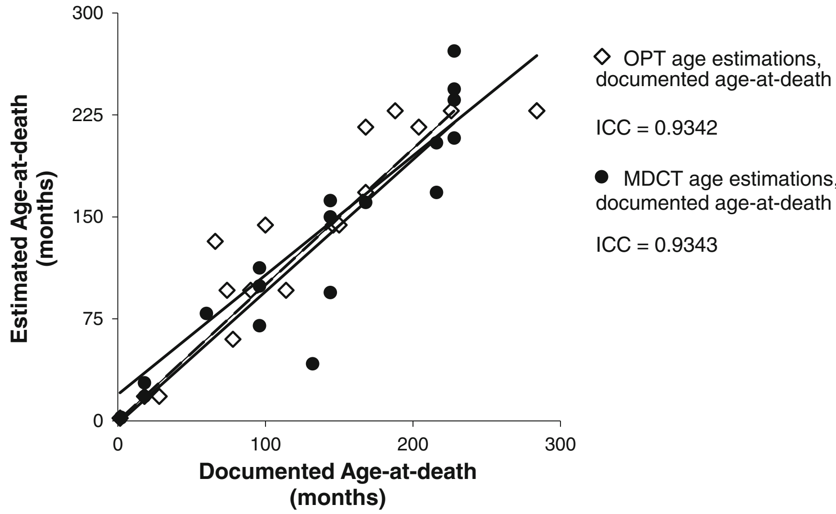

Fig. 5 Age estimations using OPTs versus age estimations using PMCT, in almost perfect agreement

includes the ability to scroll through multiple images to remove superimposition and cross-check results with high quality 3D representations. This image interpretation protocol proved repeatable when used by a variety of practitioners from different professional backgrounds and levels of experience. The figures show that the least experienced rater had greater errors in age prediction, although these were less using PMCT compared with OPT.

The authors were unable to demonstrate the increased measurement opportunities afforded by PMCT-improved age estimation. Difficulties readjusting to the multiple 2D data set and issues relating to resolution and slice thickness highlighted additional training requirements. Feedback from the raters suggested dental practitioners found it difficult to readjust to the multiple 2D data set—numerous still shots of the curved MPRs were provided to each practitioner to ensure all dental features were clearly represented. However, one rater, despite clear instructions, still viewed the images as single 2D MPRs before collating the final estimation, instead of using the multiple views to enhance one single estimation. More experience using multiple MPR data sets and surface rendered images is required so that this technique becomes more familiar to the user, something that can be achieved easily through training and experience. Resolution and slice thickness were also highlighted by all raters as an issue, creating uncertainty in a couple of cases, using the Demirjian method in particular—where the increment between scores is often slight. However, as is well known in clinical practice, PMCT has the advantage over standard radiography, by being able to isolate single thin slices without superimposition of distracting or obscuring structures (Fig. 6). This made several cases easier to assess, where using the OPT image, it was sometimes difficult to tell whether complete closure of root apices had occurred. In OPT, owing to the various positions of teeth within the jaw, roots may not be optimally positioned within the focal trough and therefore their degree of root formation in particular may be adversely interpreted. Jaws can also be digitally reconstructed using PMCT, which means even when severely disrupted, bodies could be scanned in any position, and a comprehensive dental examination could still be

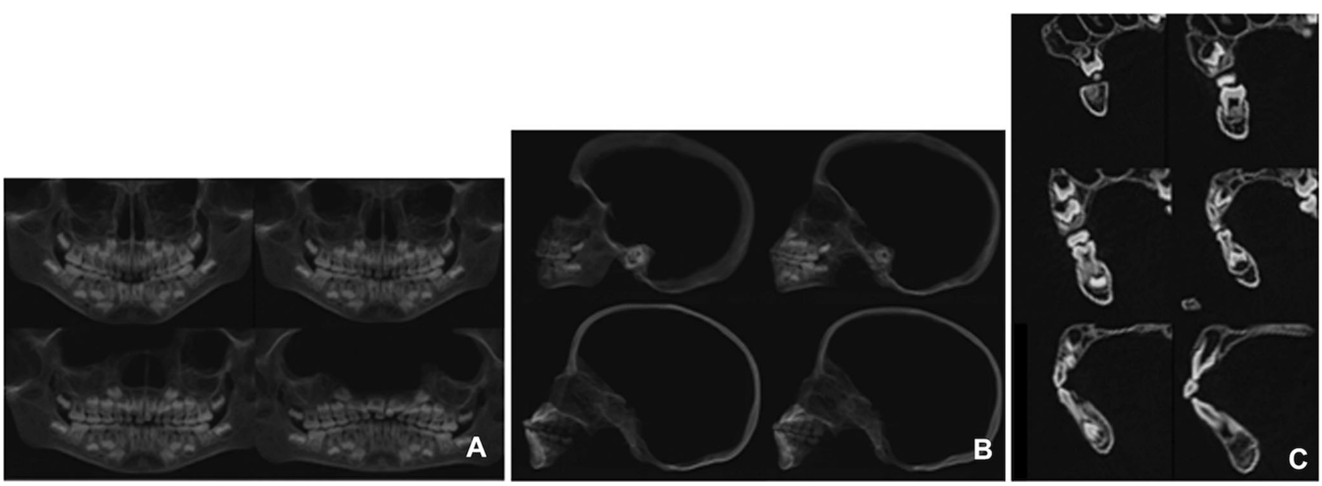

Fig. 6 Series of curved MPR views (**a**) and transverse views (**b** and **c**) of a complete dental arcade using PMCT data. By producing a series of images, problems associated with superimposition are overcome

undertaken. If a full body CT scan is already planned, processing times in forensic investigation could be reduced by negating the necessity to take dental OPTs. Finally, 3D surface rendering has the potential to further increase the accuracy of estimations and future work by the author would include assessing the impact of this.

Although further research is required in this area before a protocol utilising PMCT can be implemented internationally as part of standard forensic examination, this technical report provides evidence that PMCT is a viable imaging technique for the reliable and repeatable assessment of age from juvenile remains. To complete this study and provide further evidence to support this statement in the near future; blind-testing dental PMCT image technique on clinical cases, analysing 3D surface rendered images of each case and exploring the potential application of mandibular measurements, such as maximum ramus height is required.

In conclusion, although this investigation did not prove PMCT to be more accurate at estimating juvenile age at death, it did prove to be equally as accurate as dental age estimations using conventional OPT images. Therefore, the age estimation process performed on victims following a mass disaster may now be complemented with the use of PMCT, where previously any dental ageing analysis was performed using conventional radiographs, either full mouth periapicals or OPTs. Finally, with 3D surface rendered techniques, the authors believe PMCT has the potential to be more accurate than OPTs for juvenile dental age determination. PMCT also has greater flexibility of measurement and is not restricted to a single image, so the potential to develop new techniques exists.

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