

Dental Age Estimation in Adults: A Review of the Commonly Used Radiological Methods

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This review provides an overview of the most commonly used dental age estimation techniques which focus on radiological methods in Korean adults. The literature from 1995 through July 31, 2014, was searched, using PubMed, for publications in English language. In PubMed, the keywords 'tooth' OR 'dental' AND 'pulp' AND 'age estimation' were searched. Inclusion criteria was comprised of the following: the subjects were living adults and dental radiography (excluded computed tomography [CT] and cone-beam CT) was used to measure the pulpal size. Twenty articles that met the criteria were selected. The method of age estimation using dental radiographs for measuring pulp and tooth size was represented in all studies. The methods were assorted into three categories generally; Kvaal's, Ikeda's and Cameriere's methods. Those methods had certain limitations such as large error range and low correlation coefficient depending on populations, type of employed teeth and particular method. Various techniques and many studies have been published for age estimation from human teeth using dental radiographs, but those techniques showed various predictability and reliability. Therefore, future studies on larger samples with well-distributed age group using not only existing techniques but new techniques are necessary for deriving convincing results.

Key Words: Adult; Age determination by teeth; Radiography; Secondary dentin

INTRODUCTION

The forensic literature has provided several methods for estimating age in adults, both dead and living. Several methods of age estimation are based on the study of teeth, because teeth have the benefit to be preserved long after other tissue, even bone, and dental maturity has low variability.¹⁾ Some dental age estimation methods apply various forms of tooth modification including attrition, root dentin transparency, tooth cementum annulation, racemization of aspartic acid, and apposition of secondary dentin. Among these, analysis of the apposition of secondary dentin is the currently available nondestructive method. With aging the

pulp area gradually becomes smaller because of continuous secondary dentin deposition, so the measurement of this reduction can be used as an indicator of dental age estimation. Secondary dentin has been studied using various methods for age estimation and one method used was by X-rays.²⁾ Dental radiographs have been used relatively recently for age estimation methods in living persons due to convenient, simple, and can be examined directly in living subjects, without tooth extraction and destruction.³⁾ During the last decade, numbers of articles were published examining the various methods applied and comparing the precision and reproducibility of each one of them. The objective of the present study was to systematically review the

pertinent literature to provide an overview of the commonly used dental age estimation techniques in adults by measuring the pulpal size on dental radiographs.

MATERIALS AND METHODS

1. Study Selection

MEDLINE/PubMed was searched from 1995 through July 31, 2014 using the following terms: 'tooth' OR 'dental' AND 'pulp' AND 'age estimation'. The studies were included if 1) the subjects were not children, 2) living individuals, and 3) dental radiography (excluded 3-dimensional dental radiography) was used to measure the pulpal size. Case reports and articles which published not in English language were excluded from the review. Also, reference lists of the relevant publications and review articles were examined to identify additional studies.

2. Search Strategy

Study selection was performed in three sequential stages: 1) study selection in accordance with title relevance; 2) abstracts of studies were screened to find further accordance with inclusion criteria; and 3) full-text analysis of the remaining articles.

The initial search retrieved a total of 51 studies. All the titles and abstracts were read to identify potentially suitable articles for inclusion and 20 articles of these met the inclusion criteria. Since a limited numbers of original articles addressed our focused purpose, the pattern of the present review was customized to mostly summarize the relevant data.

RESULTS

1. Characteristics of the Studies

In total, 20 articles⁴⁻²³⁾ were included and several methods were presented in literature (Table 1). In general the methods were classified into three categories, Kvaal's, Ikeda's, and Cameriere's methods, which were all based on secondary dentin deposition of the tooth. The methods were described below. Eleven studies⁴⁻¹⁴⁾ described Kvaal's method, 3 studies¹⁵⁻¹⁷⁾ Ikeda's method, and 5 studies¹⁸⁻²²⁾ Cameriere's methods. One study²³⁾ used a different method for measuring the

pulpal size, which is the thickness of the pulp chamber ceiling and floor in first and second mandibular molars.

Among the 20 articles, 13 studies^{5-9,12-17,22,23)} were performed on orthopantomograms for measuring of the size of the pulp cavity and 7 studies^{4,10,11,18-21)} were performed on periapical radiographs. Although most studies included range of age, only one study²³⁾ provided insufficient data of age. All studies executed a reproducibility test in order to evaluate the accuracy of the measurements except for one study. Eight studies^{5,8,9,12,13,19,20,23)} carried out measurement of the pulp and tooth size by one observer while 12 studies^{4,6,7,10,11,14-18,21,22)} carried out by two observers and reexamined to test intraobserver or interobserver reproducibility of the measurements.

2. Commonly Used Radiological Methods to Quantify the Secondary Dentin Formation

1) Kvaal's method

In 1994, Kvaal and Solheim²⁴⁾ introduced a method which estimated the age of an adult from measurements of the size of the pulp on dental radiographs, but this method combined radiological and morphological measurements. As a continuation of this method Kvaal et al.⁴⁾ developed a method which based solely on the investigation of periapical radiographs. They examined radiographs of 100 Norwegian with an individual age ranging from 20 to 87 years and analyzed six teeth in each subject: maxillary central incisor, lateral incisor and second premolar, mandibular lateral incisor, canine and first premolar. They measured pulp length and width as well as tooth length and width at three defined levels (Fig. 1). Ratio between the length and width measurements were calculated in order to compensate for differences because of magnification and angulation of the image on the radiograph. Such ratios were: pulp/root length (P), pulp/tooth length (R), tooth/root length (T) and pulp/root width at enamel-cementum junction (A), pulp/root width at the mid-root level (C) and pulp/root width at the midpoint between the enamel-cementum junction and mid-root level (B), mean value of all ratios excluding T (M), mean value of width ratios B and C (W), mean value of length ratios P and R (L). The results showed the strongest correlation with age to be in the ratio between the

Table 1. Characteristics of included studies

Study	Year	Age range (y)	Subject (n)	Country	Measurement tool	Tooth (FDI)	Dental radiography	Observer (n)	Analysis
Kvaal's method									
Kvaal et al. ⁴⁾	1995	20-87	100	Norway	Vernier, callipers	11/21, 12/22, 15/25, 32/42, 33/43, 34/44	Periapical radiograph (paralleling tech.)	2	r ² =0.76 SEE=8.6 y Note a regression analysis for all six teeth combination
Bosmans et al. ⁵⁾	2005	19-75	197	Belgium	Adobe Photoshop 6	11/21, 12/22, 15/25, 32/42, 33/43, 34/44	OPG	1	r ² =0.87 SEE=9.5 y Note the mean value of all ratios from all six teeth combination
Paewinsky et al. ⁶⁾	2005	14-81	168	Germany	Hipax program (ver. 3.01)	11/21, 12/22, 15/25, 32/42, 33/43, 34/44	OPG	2	r ² =0.839 SEE=6.4 y Note a regression analysis for the width ratio at level A of the pulp cavity from upper lateral incisors
Meinl et al. ⁷⁾	2007	13-24	44	Austria	Adobe Photoshop 6	11/21, 12/22, 15/25, 32/42, 33/43, 34/44	OPG	2	Regression formulas reported by Kvaal et al. ⁴⁾ —underestimation of age Regression formulas reported by Paewinsky et al. ⁶⁾ —overestimation of age Note Evaluate the accuracy of regression formulas reported by Kvaal et al. ⁴⁾ & Paewinsky et al. ⁶⁾
Landa et al. ⁸⁾	2009	14-60	100	Spain	Image-J program	32/42, 33/43, 34/44	OPG	1	r ² =0.478 Note a regression analysis for the width ratio at level B of the pulp cavity from the lower first premolars
Saxena ⁹⁾	2011	21-60	120	India	Kvaal's method+Camieriere's method	13	OPG	1	Age=72.48-203.74 (AR)—51.69 (Q) SD= -2.2-1.5 y Note a regression equation for the width ratio at level C of the pulp cavity (c) & pulp/tooth area (AR) from the right upper canine were significant results (p<0.001)
Kanchan-Talreja et al. ¹⁰⁾	2012	25-77	100	India	AutoCAD 2005 Commercially available computer software	11/21, 12/22, 15/25, 32/42, 33/43, 34/44	Periapical radiograph Group A: paralleling tech. Group B: bisecting angle tech.	2	Group A: r ² =0.18-0.34 SEE= ± 18-20 y Group B: r ² =0.11-0.44 SEE= ± 19-21 y Note a regression analysis for all six teeth combination
Agarwal et al. ¹¹⁾	2012	20-70	50	India	Divider (mm)	11	Periapical radiograph (paralleling tech.)	2	r ² =0.77 Note a regression analysis for the ratio pulp and root length from the right upper central incisor
Erbudak et al. ¹²⁾	2012	14-57	123	Turkey	Image-J program (1.43n)	11/21, 12/22, 15/25, 32/42, 33/43, 34/44	OPG	1	r ² =0.345 SE=8.73 y Note a regression analysis for the length ratio of the pulp and root from the mandibular lateral incisors

Table 1. Continued

Study	Year	Age range (y)	Subject (n)	Country	Measurement tool	Tooth (FDI)	Dental radiography	Observer (n)	Analysis
Limdiwala and Shah ¹³	2013	20-55	150	India	Group A: based on Kvaal's criteria Group B: not based on Kvaal's criteria	11/21, 12/22, 15/25, 32/42, 33/43, 34/44	OPG	1	Group A: $r^2=0.29$ SEE=8.3 y Group B: $r^2=0.12$ SEE=9.45 y Note a regression analysis for all six teeth combination
Karkhanis et al. ¹⁴	2014	20-73	279	Australia	Kodak dental imaging software 1) Image-J program 2) CD Viewer	11/21, 12/22, 15/25, 32/42, 33/43, 34/44	OPG	2	$r^2=0.221$ SEE=7.963 y Note a regression analysis for all six teeth combination
Ikeda's method									
Drusini et al. ¹⁵	1997	9-76	433	Italy	Digital caliper	34/44, 35/45, 36/46, 37/47	OPG	2	$r^2=0.85$ SEE=6.23 y Note a regression analysis for male molars
Igbigbi and Nyirenda ¹⁶	2005	20-80	134	Malawi	Digital caliper	35/45, 36/46, 37/47	OPG	2	$r^2=0.799$ SE=-8.62 y Note a regression analysis for male molars
Karkhanis et al. ¹⁷	2013	9-60	450	Australia	1) Image-J program 2) CD Viewer	34, 35, 36, 37, 44, 45, 46, 47	OPG	2	$r^2=0.396$ SEE=6.306 y Note a regression analysis for male molars
Cameriere's method									
Babshet et al. ¹⁸	2010	20-70	178	India	Adobe Photoshop CS2 →AutoCAD	33/43	Periapical radiograph	2	$r^2=0.34$ Note a regression analysis for lower canines
Jeevan et al. ¹⁹	2011	16-72	240	India	Adobe Photoshop CS3	13/23, 33/43	Periapical radiograph	1	$r^2=0.995$ Note a regression analysis for all canines combination
Zaher et al. ²⁰	2011	12-60	144	Egypt	Adobe Photoshop →AutoCAD	11/21, 12/22	Periapical radiograph	1	$r^2=0.1$ SEE=1.36-5.08 y Note a regression analysis for upper central incisors
Babshet et al. ²¹	2011	21-71	61	India	Adobe Photoshop CS2 →AutoCAD	33/43, 34/44, 35/45	Periapical radiograph	2	$r^2=0.438$ SEE=12.22 y Note a regression analysis for three-tooth combination
Cameriere et al. ²²	2012	18-75	606	Spain	Adobe Photoshop CS4	34, 35, 44, 45	OPG	2	$r^2=0.86$ SE=5.31 y Note a regression analysis for all lower premolars combination
Other									
Tsatsoulis et al. ²³	2014	NA	234	Greece	EMAGO/advanced version 5.1 software	36/46, 37/47	OPG	1	No data Note to investigate the effect of age and external irritating stimuli on th pulp chamber ceiling and floor →Age is related to diminished pulp chamber size

OPG, orthopantomograms; r^2 , coefficient of determination; r , correlation coefficient; SEE, standard error of the estimated in years; SE, standard error; tech., technique; NA, not available.

width of the pulp and the root. The coefficient of determination for the regression ($r^2=0.76$) appeared to be the strongest when the ratio for all six type teeth for the age estimation and gender was independent variables.⁴⁾

2) Ikeda’s method

In 1985, Ikeda et al.²⁵⁾ developed a new index, called the tooth-coronal index (TCI). The TCI is based on two linear measurements on dental radiographs of extracted human teeth, crown height (CH) and coronal pulp cavity height

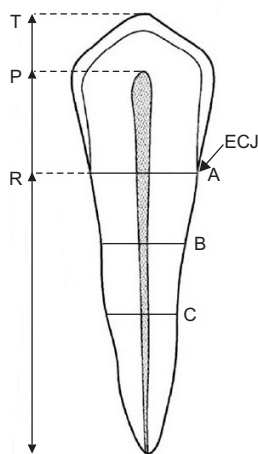


Fig. 1. Diagram showing the measurements according to Kvaal et al.⁴⁾ T, maximum tooth length; R, root length on the mesial surface; P, maximum pulp length; A, root and pulp width at enamel-cementum junction (ECJ); B, root and pulp width midway between measurement levels A and C; C, root and pulp width midway between apex and ECJ. Revised from Kvaal et al. (Forensic Sci Int 1995;74:175-185).⁴⁾

(CPCH). A straight line traced between the cemento-enamel junctions on the mesial and distal aspects is the division between the anatomical crown and root. The CH was measured vertically from the cervical line to the tip of the highest cusp and the CPCH was measured vertically from the cervical line to the tip of the highest pulp horn (Fig. 2). The TCI was then calculated as follows: $TCI=CPCH \times 100/CH$.²⁵⁾

Drusini et al.¹⁵⁾ followed the method developed by Ikeda et al.²⁵⁾ and confirmed the negative correlation between the TCI and age by measuring the lower premolars and molars from panoramic radiographs. The simple linear regression equations were derived, the correlations coefficients ranged from -0.92 (molars, combined sample, right side) to -0.87 (molars, female).

3) Cameriere’s method

In 2004, Cameriere et al.²⁶⁾ introduced a new method of age estimation using pulp/tooth area ratio (PTR) to quantify the apposition of secondary dentin of canine in digitalized periapical radiographs. The sample consisted of 100 Italian white Caucasian patients (46 men, 54 women) with age ranging from 18 to 72 years in skeleton remains. A computer-aided drafting program was used to compute of the pulp/tooth ratio, tooth length, pulp/tooth length ratio, pulp/tooth area, and pulp/tooth width ratios. Statistical analyses indicated that the pulp/tooth ‘area’ ratio correlated best with age, obtained high regression coefficients ($r^2=0.85$). The method was originally to examine the PTR of maxillary canine but subsequently added the another teeth, i.e.,

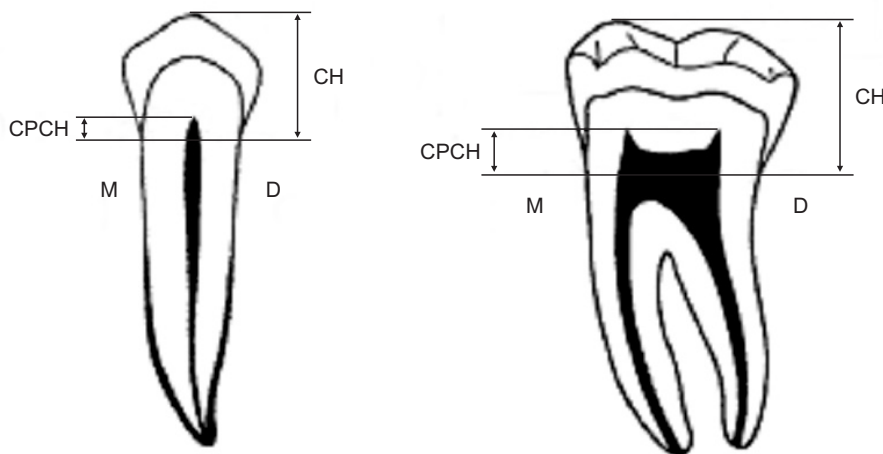


Fig. 2. Schematic representation of tooth measurements taken off a dental radiograph. The straight line traced between the distal (D) and mesial (M) enamel. CH, coronal height; CPCH, coronal pulp cavity height. Tooth-coronal index (TCI)= $CPCH \times 100/CH$. Revised from Drusini et al. (Am J Phys Anthropol 1997;103:353-363).¹⁵⁾

incisors, premolars, molars, using orthopantomographs as well as intra oral periapical radiographs for estimating age and the authors gained high levels of accuracy in age prediction (mean error 2.58-5.4 years).^{22,27-29)}

DISCUSSION

Age estimation in adults is of great important problem in both dead and living persons. Several methods of age estimation have been studied using various parts of the body and some are based on the study of tooth modification. Although there are many dental methods applying different forms of tooth modification, most of them require extraction of tooth, and therefore cannot be used in living individuals. Whereas the apposition of secondary dentin can be analysed by several radiological techniques which are non-invasive, simple and convenient. The secondary dentin is deposited along the wall of the tooth pulp chamber throughout life and this slow process leads to a gradually decrease in the size of the pulp cavity.¹⁾ Therefore, measurements of the pulp cavity on dental radiographs can be used as an age indicator in adults.

Kvaal et al.⁴⁾ introduced a method based on radiographic measurements only. Using the periapical radiographs of six teeth they measured pulp and tooth length as well as width and ratios between the length and width measurements were calculated. According to the result of analysis, width ratios appeared to have a stronger correlation than length ratio and coefficient of determination for regression was found to be the strongest when the ratio for all six teeth from both jaws were used. Bosmans et al.⁵⁾ applied Kvaal's formulae on digital orthopantomographs (OPGs) and compared with the original technique using measurements made on periapical radiographs. They obtained age estimation in adults comparable to those based on the original Kvaal's method, especially when all six types of teeth were employed. Similarly, Paewinsky et al.⁶⁾ verified the applicability of Kvaal's method on digitized panoramic radiographs in a German population and an increased accuracy and higher correlation coefficients were observed. According to the results, the best correlations between the measurements and age were found at level A of upper lateral incisors and a linear correlation coefficient $r=-0.916$ with a standard

deviation of 6.4 years. Meinel et al.⁷⁾ evaluated the use of the regression equation developed by Kvaal et al.⁴⁾ and Paewinsky et al.⁶⁾ to OPGs from an Austrian population and they concluded that direct application of the regression formulae led to an underestimation of actual age ranged from 31.4 to 47.1 years. After that, several studies have been published analyzing Kvaal's and Paewinsky's technique applied using different type of tooth from diverse ethnicities and each one demonstrated various accuracy, precision and reliability.⁸⁻¹⁴⁾ Almost all studies showed that correlations between chronological age and the dental ratios were lower than those reported by Kvaal et al.⁴⁾ and Paewinsky et al.⁶⁾

In 1985, Ikeda et al.²⁵⁾ reported that the length of the pulp cavity shows a significant correlation with chronological age. They measured the length of the coronal pulp cavity and crown of the teeth using dental radiographs of 116 extracted teeth (53 incisors, 63 molars) and calculated the TCI for each tooth. In 1997, Drusini et al.¹⁵⁾ tested the method of Ikeda et al.²⁵⁾ using mandibular posterior teeth in digitalized OPGs and confirmed the stronger correlation between TCI and age. The simple linear regression equations were formulated and correlation were especially significant for male molars ($r=-0.92$). They concluded that the TCI is not only reliable biomarker for age estimation in assessing the chronological age at death in skeletal remains, but in also useful tool in determining the age of living individuals.¹⁵⁾ Since then, some studies^{16,17)} were carried out on different populations applying the method of Ikeda et al.,²⁵⁾ and these studies recommended that age estimations based on the TCI scores of the tooth using dental radiographs.

Cameriere et al.²⁶⁾ have demonstrated a radiographic method of age estimation which measured the tooth in two dimensions, specifically the tooth and pulp 'area' of canines. Having published several articles²⁷⁻²⁹⁾ on this method studied on Italian subjects as well as in skeleton remains, the authors obtained high level of accuracy in age prediction and the median of absolute value of the residual errors between chronological age and estimated age was usually less than 4 years. An advantage of this technique is more representative of the changes within teeth than one dimensional length and width measurements undertaken by Kvaal et al.⁴⁾ as well as Ikeda et al.²⁵⁾ The method of Cameriere et al.²⁶⁾ originally calculated the PTR of upper canine, but

subsequently has been tested on different teeth, large sample sizes, and various populations using periapical radiographs and OPGs. Recent reports advocated that more population-specific equation with well-distributed age group in larger samples must be made to reach maximum accuracy.

We observed that only one study used a new method, not mentioned above. Tsatsoulis et al.²³⁾ investigated the effects of age on the morphology and thickness of the pulp chamber in mandibular molars. They examined 494 mandibular molars (262 first and 232 second molars) and four distances, two angles and two ratios were measured using certain landmarks on OPGs. The authors demonstrated that age is related to diminished pulp chamber size occlusogingivally and the increase rate of the pulp chamber ceiling thickness is similar to that of the pulp chamber floor thickness. Although, these results provided that relation between age and pulp chamber ceiling-floor distance of multi-root teeth, any regression formulas of the estimation of age based on measurements were not derived.

Dental radiographs have been used recently for dental age estimation methods in living individuals. Periapical radiographs and OPGs were mostly used for measuring pulp and tooth size and computed tomography (CT) and cone-beam CT were employed lately. Several studies published using the three-dimensional digital radiographic images of teeth in order to calculate of pulp chamber volumes and the authors obtained the promising results for age estimation based on the pulp-tooth volume ratio.¹⁾ Even though various radiological dental age determination techniques which quantified secondary dentinal deposition indirectly were viable in living adults, numerous studies tested on these techniques showed various accuracy, precision and reliability. In order to obtain more reliable results, forensic odontologist should apply different techniques, perform repetitive measurements and collect additional experimental data from various ethnicities. Also, they should develop the new techniques continually as well as validate the established techniques.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

1. Stavrianos Ch, Mastagas D, Stavrianou I, Karaiskou O. Dental age estimation of adults: a review of methods and principals. *Res J Med Sci* 2008;2:258-268.
2. Cameriere R, Ferrante L, Belcastro MG, Bonfiglioli B, Rastelli E, Cingolani M. Age estimation by pulp/tooth ratio in canines by peri-apical X-rays. *J Forensic Sci* 2007;52:166-170.
3. Willems G. A review of the most commonly used dental age estimation techniques. *J Forensic Odontostomatol* 2001;19:9-17.
4. Kvaal SI, Kolltveit KM, Thomsen IO, Solheim T. Age estimation of adults from dental radiographs. *Forensic Sci Int* 1995;74:175-185.
5. Bosmans N, Ann P, Aly M, Willems G. The application of Kvaal's dental age calculation technique on panoramic dental radiographs. *Forensic Sci Int* 2005;153:208-212.
6. Paewinsky E, Pfeiffer H, Brinkmann B. Quantification of secondary dentine formation from orthopantomograms--a contribution to forensic age estimation methods in adults. *Int J Legal Med* 2005;119:27-30.
7. Meinel A, Tangl S, Pernicka E, Fenes C, Watzek G. On the applicability of secondary dentin formation to radiological age estimation in young adults. *J Forensic Sci* 2007;52:438-441.
8. Landa MI, Garamendi PM, Botella MC, Alemán I. Application of the method of Kvaal et al. to digital orthopantomograms. *Int J Legal Med* 2009;123:123-128.
9. Saxena S. Age estimation of indian adults from orthopantomographs. *Braz Oral Res* 2011;25:225-229.
10. Kanchan-Talreja P, Acharya AB, Naikmasur VG. An assessment of the versatility of Kvaal's method of adult dental age estimation in Indians. *Arch Oral Biol* 2012;57:277-284.
11. Agarwal N, Ahuja P, Sinha A, Singh A. Age estimation using maxillary central incisors: A radiographic study. *J Forensic Dent Sci* 2012;4:97-100.
12. Erbudak HÖ, Ozbek M, Uysal S, Karabulut E. Application of Kvaal et al.'s age estimation method to panoramic radiographs from Turkish individuals. *Forensic Sci Int* 2012;219:141-146.
13. Limdiwala PG, Shah JS. Age estimation by using dental radiographs. *J Forensic Dent Sci* 2013;5:118-122.
14. Karkhanis S, Mack P, Franklin D. Age estimation standards for a Western Australian population using the dental age estimation technique developed by Kvaal et al. *Forensic Sci Int* 2014;235:104.e1-6.
15. Drusini AG, Toso O, Ranzato C. The coronal pulp cavity index: a biomarker for age determination in human adults. *Am J Phys Anthropol* 1997;103:353-363.
16. Igbigbi PS, Nyirenda SK. Age estimation of Malawian adults from dental radiographs. *West Afr J Med* 2005;24:329-333.
17. Karkhanis S, Mack P, Franklin D. Age estimation standards for a Western Australian population using the coronal pulp cavity index. *Forensic Sci Int* 2013;231:412.e1-6.
18. Babshet M, Acharya AB, Naikmasur VG. Age estimation in Indians from pulp/tooth area ratio of mandibular canines. *Forensic Sci Int* 2010;197:125.e1-4.
19. Jeevan MB, Kale AD, Angadi PV, Hallikerimath S. Age estimation

- by pulp/tooth area ratio in canines: Cameriere's method assessed in an Indian sample using radiovisiography. *Forensic Sci Int* 2011; 204:209.e1-5.
20. Zaher JF, Fawzy IA, Habib SR, Ali MM. Age estimation from pulp/tooth area ratio in maxillary incisors among Egyptians using dental radiographic images. *J Forensic Leg Med* 2011;18:62-65.
 21. Babshet M, Acharya AB, Naikmasur VG. Age estimation from pulp/tooth area ratio (PTR) in an Indian sample: a preliminary comparison of three mandibular teeth used alone and in combination. *J Forensic Leg Med* 2011;18:350-354.
 22. Cameriere R, De Luca S, Alemán I, Ferrante L, Cingolani M. Age estimation by pulp/tooth ratio in lower premolars by orthopantomography. *Forensic Sci Int* 2012;214:105-112.
 23. Tsatsoulis IN, Filippatos CG, Floratos SG, Kontakiotis EG. Estimation of radiographic angles and distances in coronal part of mandibular molars: A study of panoramic radiographs using EMAGO software. *Eur J Dent* 2014;8:90-94.
 24. Kvaal S, Solheim T. A non-destructive dental method for age estimation. *J Forensic Odontostomatol* 1994;12:6-11.
 25. Ikeda N, Umetsu K, Kashimura S, Suzuki T, Oumi M. Estimation of age from teeth with their soft X-ray findings. *Nihon Hoigaku Zasshi* 1985;39:244-250.
 26. Cameriere R, Ferrante L, Cingolani M. Variations in pulp/tooth area ratio as an indicator of age: a preliminary study. *J Forensic Sci* 2004;49:317-319.
 27. Cameriere R, Brogi G, Ferrante L, et al. Reliability in age determination by pulp/tooth ratio in upper canines in skeletal remains. *J Forensic Sci* 2006;51:861-864.
 28. Cameriere R, Cunha E, Sassaroli E, Nuzzolese E, Ferrante L. Age estimation by pulp/tooth area ratio in canines: study of a Portuguese sample to test Cameriere's method. *Forensic Sci Int* 2009; 193:128.e1-6.
 29. Cameriere R, Cunha E, Wasterlain SN, et al. Age estimation by pulp/tooth ratio in lateral and central incisors by peri-apical X-ray. *J Forensic Leg Med* 2013;20:530-536.