Changes in age estimation standards secondary to full fixed edgewise orthodontic treatment

Article · January 2017
DOI: 10.5455/ejfs.225119

7 authors, including:


Talia Marroquin
University of Western Australia


Shalmira Karkhanis
University of Western Australia


Sigrid I Kvaal
University of Oslo


Sivabalan Vasudavan
Harvard University

European Journal of Forensic Sciences
www.ejfs.co.uk
DOI: 10.5455/ejfs.225119

Original Research

Changes in age estimation standards secondary to full fixed edgewise orthodontic treatment

Talia Yolanda Marroquin[1], Shalmira Karkhanis[1], Sigrid Kvaal[2], Sivabalan Vasudavan[1], Edwin Castelblanco[1], Estie Kruger[1], Marc Tennant[1]

[1]School of Anatomy, Physiology and Human Biology, The University of Western Australia, Australia, [2]Department of Oral Pathology and Section of Forensic Odontology, University of Oslo, Norway

Address for correspondence: Estie Kruger, School of Anatomy, Physiology and Human Biology, The University of Western Australia. E-mail: Estie.kruger@uwa.edu.au

Received: April 20, 2016
Accepted: June 15, 2016
Published: March 12, 2017

ABSTRACT

Objective: The aim of this cohort study was to evaluate if the side effects of orthodontic treatment have any significant impact when the Kvaal *et al*., method is used for dental age estimation. The objective of this study was to observe the potential effects of orthodontic treatment on the accuracy of the age estimation, as performed using the Kvaal *et al*. Standards when it was applied on individuals before and after orthodontic treatment. **Materials and Methods:** Following the methodological approach of Kvaal *et al*., odontometric measurements were acquired, and the data were statistically analyzed to develop age estimation regression models. The total number of radiographs analyzed was 182 (644%, $n = 58$) female and 36% ($n = 33$) male. The ages ranged from 12 to 50 years for females (mean age 22 years) and 12-52 years for males (mean age 22 years) before starting the treatment. The average length of the treatment was 2.2 years for both females and males. **Results:** It was observed that the standard error of estimate for the regression models did not change dramatically for the pre- and post-treatment data. **Conclusions:** It is recommended that similar analyses be performed for other methods of dental age estimation, for example, methods based on cone-beam computer tomography or microfocus computer tomography. These novel approaches, though more accurate, are also potentially more sensitive to dental changes caused by orthodontic treatment.

KEY WORDS: Forensic sciences, forensic odontolgy, adults, dental age estimation, orthodontic treatment, root resorption, secondary dentin formation

INTRODUCTION

Kvaal *et al*. [1] developed a non-invasive method for the estimation of age in adults with the measurement of dimensions of the pulp chamber and tooth length to formulate regression models in the estimation of age. Originally, this method was proposed to be used on periapical radiographs. However, more recent work has focused on the use of the Kvaal *et al*. [1] method in panoramic radiographs [2-4]. During tooth development, secondary dentin deposition commences once the root formation is complete, and the tooth erupts to the level of the occlusal plane [5]. Annually, the rate of secondary dentin formation has been documented to be 6.5 μm/year for the crown and 10 μm/year for the root [6]. The rate of secondary dentin formation is influenced by external stimuli such as occlusal forces, trauma, and caries [7]. These external factors also generate the production of tertiary dentin [5], which is indistinguishable to secondary dentin on dental radiographs [8].

The estimation of dental age has been a valid tool in forensic and anthropological research [1,9,10]. For younger persons, including newborns, infants, and adolescents, there are dental age estimation methods, generally based on tooth maturation, which are considered the most accurate to estimate the chronological age in subadults [3,11-13]. In adults, once the root formation is deemed complete, methods for dental age estimation are broadly based on the analysis of secondary dentin deposition and the subsequent narrowing of the pulp chamber [1,6,14]. A potential confounding factor in the estimation of dental age is the high incidence of orthodontic treatment in developed countries [15]. The judicious application of forces is central to successful orthodontic treatment and is well known to induce biological changes in dental hard tissues, including the formation of secondary dentin [7] and root shortening [16]. The corollary being a change in the dental morphological features analyzed in the estimation of dental age in adults [7,17].

Given the potential of the development of tooth structure in adolescents and adult patients to be influenced by the application of orthodontic force, and these structures being the foundation of age estimation methods, and it is important to recognize and quantify the effect. The first aim of this study was to evaluate if the side effects of orthodontic treatment had any significant impact on dental age estimation when using the Kvaal *et al*. [1] method. The objective of this study was to observe the potential effects of orthodontic treatment on the accuracy of the age estimation as performed using the Kvaal *et al*. [1] standards when applied on individuals before and after orthodontic treatment.

MATERIALS AND METHODS

Ethics approval was obtained from the Human Research Ethics Committee of The University of Western Australia (Ref: RA/4/1/6797) before commencement. In the design of the study, data collection and analysis have been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Sample

This cohort study consisted of a series of subjects who consecutively presented for orthodontic treatment at a private specialist orthodontic clinic (SV). All panoramic radiographs were acquired from the same machine and in digital format, with the informed consent of the participants. All of the panoramic radiographs were unidentified, and the only information known was the sex and age of the participants at the starting and finishing time of the orthodontic treatment.

Inclusion Criteria

All subjects who had a recorded panoramic radiograph of high quality with respect to factors of image brightness, contrast, and sharpness were included. In addition, all the analyzed teeth were clinically sound with completed root formation and in functional occlusion.

Exclusion Criteria

Any radiographs that did not meet the inclusion criteria or had observable failings (e.g. image distortion, poor contrast, overlap of tooth structure, or improper positioning) were excluded. Teeth with rotations, incomplete root formation, dilacerations, pulpal pathologies, and endodontic treatment and/or restorations were excluded. Teeth with developmental abnormalities in size, shape, and tooth structure, as well as previous pulpal and periodontal pathologies and endodontic treatment, were excluded. Teeth with large areas of enamel overlap between neighboring teeth were excluded in this study.

Sample Population

This study analyzed a total of 182 pre- and post-orthodontic treatment panoramic radiographs from 91 participants, 64% (n = 58) female and 36% (n = 33) male, from a Western Australian population. All the participants presented for orthodontic treatment that, after diagnosis and treatment planning, was completed with fixed appliances. The ages ranged from 12 to 50 years for females (mean age 22) and 12-52 years for males (mean age 22) before starting the treatment. The average length of treatment was 2.2 years for both females and males. Digital panoramic radiographs were taken as part of routine clinical orthodontic treatment to evaluate the initial condition of the participants and the final treatment results.

Teeth Selection

As established by Kvaal *et al*. [1], three single rooted upper teeth (with Federation Dentaire International [FDI] notation 11/21, 12/22, 15/35) and three single rooted lower teeth (FDI 32/42, 33/43, 34/44) were measured. Kvaal *et al*. [1] reported that there are not significant differences between teeth from the left or the right side of the arch. In accordance with this, if one tooth was absent, the contralateral was used, as long as this was observable in a straight position.

Measurement

The measurements were performed using Image J software (version 1.48 19 April 2014 - National Institute of Health, USA). As proposed by Kvaal et al [1], different odontometric measurements were recorded: tooth length, pulp length and root length as well as pulp width and tooth width at three different levels: A (cemento-enamel junction in the mesial surface of the roots); B (midpoint between the points A and C); C (midpoint between the cemento-enamel junction and root apex). After the collection of the figures in an Excel (2013) spreadsheet, a serial of ratios was calculated: (T) tooth/root length, (R) pulp/tooth length, (P) pulp/root length, and root width/pulp width ratio at levels A, B, and C. The ratio calculation and use were proposed by Kvaal *et al*. [1] with the aim to reduce the effect of magnification and angulation inherent in most radiographs [1,4]. The different mean values calculated with these ratios provided the age estimation predictors (M: Mean value all ratios, W: Mean value width ratios B and C, L: Mean value ratios P and R, W-L: Difference between W-L). The predictors M and W-L were later used to formulate the age estimation models using multiple regression analysis as established by Kvaal *et al*. [1]. The measurements were completed by a single observer (TYM). All data were collected using Excel (Version 2013 Microsoft Redmont, USA), and statistical analysis was completed using the program R Core Team version 3.1.3 (2015) (R: A language and environment for statistical computing and R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/).

Calibration

Intra- and inter-observer calibration was estimated using five randomly selected panoramic radiographs from the final study sample. These panoramic radiographs were measured on five different days with at least 1 day interval. With the aim to avoid the recall of the measurements and landmarks, five new panoramic radiographs were also measured on each occasion. Data were recorded using the software Image J by TYM and SK. To determine intra-observer precision, three estimates of precision were calculated: The technical error of measurement (TEM <1.0), relative TEM (rTEM <5%), and coefficient of reliability were calculated to quantify the inter- and intra-observer measurement error [18].

Statistical Analysis

The strength of linear association between chronological age and the Kvaal *et al*. [1] dental ratios was determined by Pearson correlation coefficient (r). Following this stage, regression analysis was applied to evaluate the relationship between the ratios and the chronological age. The final results were later used to generate the statistical models for age estimation. To quantify the predictive accuracy of the models, the standard error of estimation (SEE) was used in the cross-validation sample. Multivariable linear regression analyses were used to examine the association between the independent and outcome variables. The outcome variables included chronological age (dependent variable) and the predictors M and W-L (independent variables). Different equations were generated to estimate the chronological age, by individual tooth and by group of teeth, as follows: Three maxillary teeth with M and W-L values (6 predictors) individually calculated for each tooth, and the average of M and W-L for the same teeth (2 predictors). Three mandibular teeth with M and W-L values (6 predictors) individually calculated for each tooth, and the average of M and W-L for the same teeth (2 predictors). All six teeth, with M and W-L values (12 predictors) individually calculated for each tooth, and the average of M and W-L for the same teeth (2 predictors). All regression models were built using the ordinary least squares approach. R^2 values were computed to examine the amount of variance explained by the predictor variables. The formula proposed by Preoteasa *et al*. [19] was used to calculate the percentage of teeth with root shortening.

RESULTS

Measurement Precision

After the estimation of intra- and inter-observer error, the obtained values were as follow: Intra-observer error: TEM <1.0 (0.92), rTEM<5% (2.99%), and $R > 0.75$ (0.95). Inter-observer error (between SK and TYM) was: TEM <1.0 (0.80), rTEM <5 (2.37), and $R > 0.75$ (0.98) showing comparable intra- and inter-observer measurement precision.

Age Distribution

The age distribution before orthodontic treatment for females was: 12-19 years (62%, $n = 36$), 20-39 years (28%, $n = 16$), >40 years (10%, $n = 6$), and after treatment, it was: 15-19 years (57%, $n = 33$), 20-39 years (15%, $n = 19$), and >40 years (10%, $n = 6$). For males, before orthodontic treatment was: 12-19 years (52%, $n = 17$), 20-39 years (42%, $n = 14$), and >40 years (6%, $n = 2$), and after orthodontic treatment, it was: 13-19 years (48%, $n = 16$), 20-39 years (45%, $n = 15$), and >40 years (6%, $n = 2$).

The correlation coefficient between chronological age and the dental ratios was calculated for the data before and after orthodontic intervention [Table 1]. In both cases, the correlation coefficient related with the width ratios (A, B, and C) was more significant than those related with length (P, T, R, and L). As established by Kvaal *et al*. [1], the predictors M and W-L are required to be included in the final equation for dental age estimation. Based on the Pearson correlation coefficients, it could be observed that after the orthodontic treatment, the significance of the values for the predictor W-L decreased.

Individual tooth regression models and multiple teeth regression models were proposed for individuals that had not received orthodontic treatment [Tables 2 and 3, respectively] and for individuals after finishing the treatment [Tables 3 and 4]. In regards to the models for age estimation using individual teeth, the SEE tends to increase after orthodontic treatment, especially for the mandibular canine, where the increase was ±2 years. Furthermore, while the results for the SEE provided by the mandibular canine showed a lower SEE (±8.26 years) in the data analysis before treatment, the same tooth showed the greatest value of SEE (±10.23 years) for individual tooth analysis after orthodontic treatment.

When multiple regression models were formulated using different combinations of teeth, it is also noticeable that in a few

Table 1: Correlation coefficients between chronological age before$_{(1)}$ and after$_{(2)}$ starting orthodontic treatment and the Kvaal *et al*.[1] dental ratios

Correlation coefficients before treatment						
	Tooth number (FDI tooth numeration)					
Ratio	11/21	12/22	15/25	32/42	33/43	34/44
P_1	0.156	0.079	−0.080	0.085	−0.083	0.205
P_2	−0.261	−0.137	−0.065	−0.026	−0.220	−0.125
T_1	0.032	0.034	−0.134	−0.186	−0.237	−0.110
T_2	−0.162	−0.127	−0.148	−0.098	−0.085	−0.159
R_1	0.163	0.041	0.076	0.321*	0.174	0.383**
R_2	−0.099	−0.014	0.130	0.070	−0.143	0.037
A_1	−0.442**	−0.419**	−0.422**	−0.418**	−0.325**	−0.168
A_2	−0.306*	−0.388**	−0.475**	−0.172	−0.209	−0.194
B_1	−0.439**	−0.407**	0.026	−0.211*	−0.628**	−0.595**
B_2	−0.440**	−0.494**	−0.449**	−0.221*	−0.488**	−0.522**
C_1	−0.347**	−0.345*	−0.322*	−0.185	−0.517**	−0.459**
C_2	−0.349**	−0.439**	−0.364*	−0.320*	−0.332*	−0.436**
M_1	−0.130	−0.338*	−0.283*	−0.194	−0.566**	−0.378**
M_2	−0.308*	−0.409**	−0.412**	−0.227*	−0.382*	−0.443**
W_1	−0.448**	−0.416**	−0.142	−0.237*	−0.522**	−0.573**
W_2	−0.450**	−0.511**	−0.469**	−0.299*	−0.433**	−0.522**
L_1	0.183	0.074	−0.134	0.193	0.019	0.332
L_2	−0.223*	−0.109	−0.148	0.015	−0.218	−0.076
$W\text{-}L_1$	−0.365	−0.329	0.027	−0.327*	−0.481**	−0.574**
$W\text{-}L_2$	−0.013	−0.234*	−0.058	−0.227*	−0.261*	−0.412**

*$P<0.05$, **$P<0.001$, NS non-significant. P: Pulp length/root length, T: Tooth length/root length, R: Pulp length/tooth length, A: Pulp width/root width at level A, B: Pulp width/root width at level B, C: Pulp width/root width at level C and predictors, M: Mean value all ratios, W: Mean value width ratios B and C, L: Mean value ratios P and R, W-L: Difference between W-L

Table 2: Multiple regression for estimation of chronological age (in years) for individual maxillary and mandibular teeth in subjects before$_{(1)}$ and after$_{(2)}$ orthodontic treatment

Teeth FDI	*n*	*R*	R^2	Equation	SEE±years
11/21$_{(1)}$	83	0.229	0.21	Age=39.87−76.79(M)−51.75(W-L)	8.574
11/21$_{(2)}$	83	0.143	0.122	Age=54.50−73.67(M)−30.64(W-L)	9.064
12/22$_{(1)}$	81	0.186	0.165	Age=68.21−99.54(M)−33.52(W-L)	8.923
12/22$_{(2)}$	81	0.255	0.236	Age=83.07−128.42(M)−42.68(W-L)	8.486
15/25$_{(1)}$	58	0.08	0.046	Age=79.8105−81.5881(M)−0.5444(W-L)	9.993
15/25$_{(2)}$	58	0.213	0.184	Age=90.22−129.66(M)−18.62(W-L)	9.295
32/42$_{(1)}$	87	0.124	0.103	Age=15.40−37.51(M)−43.05(W-L)	9.731
32/42$_{(2)}$	87	0.095	0.74	Age=49.10−77.55(M)−37.65(W-L)	9.893
33/43$_{(1)}$	63	0.476	0.458	Age=111.80−238.35(M)−132.7(W-L)	8.260
33/43 $_{2)}$	63	0.196	0.169	Age=76.60−159.75(M)−105.79(W-L)	10.26
34/44$_{(1)}$	68	0.356	0.336	Age=21.67−69.84(M)−69.59(W-L)	8.404
34/44$_{(2)}$	68	0.312	0.291	73.52−137.96(M)−64.43(W-L)	8.716

R^2: Coefficient of determination. SEE: Standard error of estimation in years. See Table 1 for abbreviations

Table 3: Multiple regression for estimation of chronological age (in years) for the combination of different teeth before orthodontic treatment

Teeth FDI	*n*	*R*	R^2	Equation	SEE±years
3 max 2 pds	50	0.278	0.247	Age=80.40−145.51(M)−47.69(W-L)	7.789
3 max 6 pds	50	0.314	0.219	Age=63.704−6.412(11/21M)−7.216(11/21W-L)−32.812(12/22M) −19.332(12/22W-L)−77.969(15/25M)+10.594(15/25W-L)	7.932
3 mdb 2 pds	46	0.4	0.372	Age=13.11−36.64(M)−19.83(W-L)	9.124
3md 6 pds	46	0.601	0.54	Age=124.528+81.230(32/42M)−7.784(32/42W-L) −328.184(33/43M)−121.021(33/43W-L) −37.503(34/44M)−9.855(34/44W-L)	7.805
6 teeth 2 pds	36	0.45	0.417	Age=133.86−238.98(M)−67.88(W-L)	7.609
6 teeth 12 pds	36	0.729	0.5889	Age=130.727+(15.058(11/21M)+(23.906(11/21W-L)+61.249(12/22M)−29.091(12/22W-L) −100.481(15/25M)−2.441(15/25W-L)+54.517(32/42M)+3.089(32/42W-L)−268.438(33/43M) −89.805(33/43W-L)−41.009(34/44M)-25.32(34/44W-L)	6.392

R^2: Coefficient of determination. SEE: Standard error of estimation in years. See Table 1 for abbreviations

Table 4: Multiple regression for estimation of chronological age (in years) for the combination of different teeth after orthodontic treatment

Teeth	*n*	*R*	R^2	Equation	SEE±years
3 max 2 pds	50	0.389	0.363	Age=102.46−102.16(M)−63.13(W-L)	7.215
3 max 6 pds	50	0.425	0.344	Age=114.631+(−0.876(11/21M))+(2.218(11/21W-L))+(−115.748(12/22M)) +(−38.699(12/22W-L))+(−91.406(15/25M))+(−20.963(15/25W-L))	7.319
3 mdb 2 pds	46	0.337	0.306	Age=98.68−213.10(M)−105.05(W-L)	9.632
3md 6 pds	46	0.447	0.362	Age=42.761(81.109(32/42M))+(1.905(32/42W-L)+(−111.346(33/43M)) +(−173.252(33/43W-L))+(−151.769(34/44M))+(−43.162(34/44W-L))	9.232
6 teeth 2 pds	36	0.490	0.460	Age=174.12−288.42(M)−59.22(W-L)	7.372
6 teeth 12 pds	36	0.602	0.395	Age=154.569+9.383(11/21M)+19.718(11/21W-L)−70.675(12/22M)−39.284(12/22W-L) −39.932(15/25M)−4.881(15/25W-L)+47.114(32/42M)−17.071(32/42W-L)−58.568(33/ 43M)−29.183(33/43W-L)−149.635(34/44M)−0.842(34/44W-L)	7.803

R^2: Coefficient of determination. SEE: Standard error of estimation in years. See Table 1 for abbreviations

cases the SEE decreased after orthodontic treatment: Maxillary lateral incisor (±0.437), maxillary first premolar (±0.698), the multiple tooth regression models using three maxillary teeth with two (±0.574) and six (±0.613) predictors, and in the multiple regression models using six teeth and two predictors (±0.237). In both circumstances, the multiple regression models using the different teeth combinations improved the accuracy of estimation of chronological age, consistent with previous studies [2].

Root shortening was detected in 62% of the upper central incisors, 53% of upper lateral incisors, 48% of upper second premolars, 48% of lower lateral incisors, 50% of lower canine, and 51% of lower second premolars, with a formula previously proposed [19].

DISCUSSION

This is the first study to specifically apply the Kvaal *et al.* method to a group of orthodontically treated subjects, and also the first evaluating the impact of the side effects of orthodontic treatment on one of the proposed methods for dental age estimation in adults based on the formation of secondary dentine and the pulp/tooth dimension ratios. Previous investigations failed to disclose whether subjects had previously received orthodontic treatment. There are well-known biological changes that occur secondary to the application of orthodontic forces including apical root resorption and secondary dentin formation.

External root resorption is one unavoidable, unpredictable, and undesirable sequela [20-22] of orthodontic treatment. The reported frequency of external root resorption is about 100% when it is examined under microscopy. When it is quantified on periapical or panoramic radiographs, the frequency falls to 70%, with a mean reported value of root shortening of 1.42 ± 0.44 mm and 1% to 5% of the cases with a loss of 4mm or one-third of root length [19]. In addition, maxillary teeth are more sensitive than mandibular teeth to root resorption. The most frequently affected teeth, according to severity, are the maxillary laterals, maxillary centrals, mandibular incisors, the distal root of mandibular first molars, second premolars, and maxillary second premolars [21,23], and all these teeth have been used in different methods for dental age estimation in adults [1,2,24]. In this study, a higher percentage of root resorption for upper teeth was also observed.

Confirming the findings of Karkhanis *et al*. [2], the length ratios (P, T, R, and L ratios) in this study have a non-significant correlation coefficient with age ($P > 0.05$), and the percentage of negative correlation coefficients [Table 1], closer to −1, is higher in the observed values after orthodontic treatment (23% before vs. 66% after). As the Kvaal *et al*. method is based on the negative correlation between age and the mentioned ratios, it is possible to observe that after the orthodontic treatment this negative correlation is more evident but not statistically significant. In this study, there was no significant variation in the correlation coefficients of the calculated length ratios with age among the different teeth. Furthermore, as the Kvaal *et al*. method is based on length ratio calculations, not the linear measurements *per se*, it is possible that the effect of root shortening on the estimated ages had been diminished when the ratios are calculated.

In terms of secondary dentin formation owed to orthodontic treatment (a phenomenon that has not been as widely investigated as root resorption), there are reports of complete obliteration of the canals in maxillary incisors [25], and in one study analyzing, the tooth changes in terms of root length and pulp chamber within maxillary central incisors (tooth 11 and 21), statistically significant changes in the width of the pulp chamber at the midpoint of the dental root [26] were found, equivalent to the point C in the Kvaal *et al*. method. [1] Another study using cone-beam computer tomography (CBCT) in maxillary teeth found a statistically significant difference between the volumes before and after orthodontic treatment, with the highest mean volume loss observed in the upper left lateral incisor (3.86 mm^3) and the least for the upper right central incisor (3.04 mm^3) [7].

In this study, the correlation coefficients of the pulp/root width ratios (A, B, C, and W) maintained their negative correlation with age before and after the treatment, without showing the same variation observed for the length ratios. It would still be necessary to assess if the root shortening after orthodontic treatment, displaced the location of the reference points B and C toward the crown (where the pulp chamber is wider), and its relation with the observed variation of the SEE before and after orthodontic treatment, which in both cases is acceptable in forensic terms (SEE = ±10 years).

CONCLUSION

Our investigation demonstrated an alteration in tooth and pulp chamber morphology and dimension following orthodontic treatment. However, these changes did not serve to significantly influence the validity and accuracy (SEE) of the Kvaal *et al*. [1] method when applied in the assessment of panoramic radiographs to estimate chronological age. We recommend further analysis of other methods for dental age estimation in adults based on the formation of secondary dentin, such as Cameriere *et al*. [3], or the more recently proposed methods based on volumetric reconstructions of the tooth and pulp chamber in CBCT [27,28] which could be more susceptible to be affected by orthodontic treatment sequels.

REFERENCES

1. Kvaal SI, Kolltveit KM, Thomsen IO, Solheim T. Age estimation of adults from dental radiographs. Forensic Sci Int 1995;74:175-85.
2. 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.
3. Panchbhai AS. Dental radiographic indicators, a key to age estimation. Dentomaxillofac Radiol 2011;40:199-212.
4. 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;57:277-84.
5. Hargreaves KM. Cohen's Pathways of the Pulp Expert Consult. St. Louis: Mosby; 2010.
6. 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;214:105-12.
7. Venkatesh S, Ajmera S, Ganeshkar SV. Volumetric pulp changes after orthodontic treatment determined by cone-beam computed tomography. J Endod 2014;40:1758-63.
8. Nanci A. Ten Cate's Oral Histology-Pageburst on VitalSource: Development, Structure, and Function. St. Louis, MO: Elsevier Health Sciences; 2007.
9. Sarkar S, Kailasam S, Mahesh Kumar P. Accuracy of estimation of dental age in comparison with chronological age in Indian population – a comparative analysis of two formulas. J Forensic Leg Med 2013;20:230-3.
10. Senn DR, Weems RA, editors. Manual of Forensic Odontology. 5th ed. Boca Raton, FL: CRC Press; 2013.
11. Yusof MY, Thevissen PW, Fieuws S, Willems G. Dental age estimation in Malay children based on all permanent teeth types. Int J Legal Med 2014;128:329-33.
12. Ebrahim E, Rao RK, Chatra L, Shenai P, Veena KM, Prabhu RV, *et al.* Dental age estimation using schour and Massler method in South Indian Children. Sch J Appl Med Sci 2014;2:1669-74.
13. Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Hum Biol 1973;45:211-27.
14. Gustafson G. Age determination on teeth. J Am Dent Assoc 1950;41:45-54.
15. Pretty IA, Sweet D. A look at forensic dentistry – Part 1: The role of teeth in the determination of human identity. Br Dent J 2001;190:359-66.
16. Baumrind S, Korn EL, Boyd RL. Apical root resorption in orthodontically treated adults. Am J Orthod Dentofacial Orthop 1996;110:311-20.
17. Ramazanzadeh BA, Sahhafian AA, Mohtasham N, Hassanzadeh N, Jahanbin A, Shakeri MT. Histological changes in human dental pulp

following application of intrusive and extrusive orthodontic forces. J Oral Sci 2009;51:109-15.
18. Weinberg SM, Scott NM, Neiswanger K, Marazita ML. Intraobserver error associated with measurements of the hand. Am J Hum Biol 2005;17:368-71.
19. Preoteasa CT, Ionescu E, Preoteasa E, Machado JA, Baleanu MC, Baleanu D. Multidimensional scaling for orthodontic root resorption. Math Probl Eng 2013;2013:1-6.
20. Ponder SN, Benavides E, Kapila S, Hatch NE. Quantification of external root resorption by low - Vs high-resolution cone-beam computed tomography and periapical radiography: A volumetric and linear analysis. Am J Orthod Dentofacial Orthop 2013;143:77-91.
21. Campos MJ, Silva KS, Gravina MA, Fraga MR, Vitral RW. Apical root resorption: The dark side of the root. Am J Orthod Dentofacial Orthop 2013;143:492-8.
22. Harris DA, Jones AS, Darendeliler MA. Physical properties of root cementum: Part 8. Volumetric analysis of root resorption craters after application of controlled intrusive light and heavy orthodontic forces: A microcomputed tomography scan study. Am J Orthod Dentofacial Orthop 2006;130:639-47.
23. Brezniak N, Wasserstein A. Root resorption after orthodontic treatment: Part 2. Literature review. Am J Orthod Dentofacial Orthop 1993;103:138-46.
24. Mathew DG, Rajesh S, Koshi E, Priya LE, Nair AS, Mohan A. Adult forensic age estimation using mandibular first molar radiographs: A novel technique. J Forensic Dent Sci 2013;5:56-9.
25. Delivanis HP, Sauer GJ. Incidence of canal calcification in the orthodontic patient. Am J Orthod 1982;82:58-61.
26. Tobón D, Aristizabal D, Álvarez C, Urrea J. Cambios radiculares en pacientes tratados ortodoncicamente (Spanish). Root changes in patients treated orthodontically (English). CES Odontol 2014;27:37-46.
27. Ge ZP, Ma RH, Li G, Zhang JZ, Ma XC. Age estimation based on pulp chamber volume of first molars from cone-beam computed tomography images. Forensic Sci Int 2015;253:133.e1-7.
28. Sakuma A, Saitoh H, Suzuki Y, Makino Y, Inokuchi G, Hayakawa M, *et al*. Age estimation based on pulp cavity to tooth volume ratio using postmortem computed tomography images. J Forensic Sci 2013;58:1531-5.

Source of Support: Nil, Conflict of Interest: None declared.