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ORIGINAL ARTICLE

Comparison of Accuracy Between Pulp/Tooth Ratio and Tooth Coronal Index Methods for Dental Age Estimation Using Digital Panoramic Radiographs

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ABSTRACT

Objective: To evaluate the reliability and the accuracy of Tooth Coronal Index (TCI) and Pulp/Tooth Ratio (PTR) methods in dental age estimation using digital panoramic radiography. **Material and Methods:** In this cross-sectional study, 237 dental panoramic images were collected. The two methods (TCI and PTR) were applied to all left mandibular first and second molars based on inclusion and exclusion criteria. In order to analyze the acquired data, statistical methods were used. The estimated ages derived by exclusive formula were compared to the chronological age, and the error ranges for each indicator were measured to determine their accuracy. **Results:** There were negative correlations between PTR in the first molar (r=-0.89) and in the second molar (r=-0.788), as well as TCI in the first molar (r=-0.587) and in the second molar (r=-.242). In this study, we found that the Pulp/Tooth Ratio (PTR) accuracy rate for mandibular first and second molar teeth was 79.21% and 62.09 %, respectively, although the Tooth Coronal Index (TCI) value for these teeth was 34.45% and 5.85%. **Conclusion:** Pulp/Tooth Ratio and Tooth Coronal Index are potential age estimation indices. Although PTR was the more accurate one in our study. The results also demonstrated that indices related to the first molar tooth could be used to estimate age with greater accuracy and validity.

Keywords: Age Determination by Teeth; Radiography, Panoramic; Dental Pulp Cavity.

Introduction

Nowadays, accurate estimation of age by teeth has gained a lot of attention due to high usage in forensic odontology, for example, determining the chronological age of individuals without legal documentation of birth, estimating the chronological age of immigrants without a legal record of their birth date, suspects of crimes with unknown exact age, children without a valid birth certificate, and other court-related cases. Also, it can be used in pediatric and orthodontic dentistry, where accurate age estimating provides a reliable treatment plan. This practical method can be applied to dead bodies as well as living individuals [1-4].

The tooth is the hardest structure in the human body that resists to external stimuli, including chemical, mechanical, and thermal stimuli. It has been found that its maturation is much less affected by diseases, drugs, malnutrition, endocrine and other pathological problems than other body tissues and is more dependent on genetic factors. These factors make tooth a useful tool for the age estimation of different individuals [5,6].

Evaluation of the tooth developmental stage is a key factor for children's age estimation, whereas secondary dentin production and reduction of dental pulp cavity happen in adults and are directly related to their increasing chronological age and also has little impact from environmental factors [7-10]. Dental radiography is a usual approach in dental treatment that is not commonly used for age estimation. Secondary dentin measurements in dental radiographs can be used to estimate age is a non-invasive and applicable method for living individuals unlike other methods that are time-consuming, costly, and destructive, for example, morphological, biochemical and histological methods that are invasive and require tooth extraction which are not possible for living bodies [7,11-15].

A modern digital panoramic radiograph is an accessible and widely usable method, which makes it possible to have non-destructive measurements of some morphological parameters of the tooth. Also, exist some measurement methods that are easy to implement and have a relatively high accuracy using this type of radiograph that can be used in forensic dentistry [16,17].

Numerous different statistical methods have been proposed for age estimation; most of them are based on the correlation between the age of individuals (dependent variable) and some of the clear dental parameters obtained from digital radiographs (predictors) [18]. This study aimed to evaluate the accuracy and reliability of dental age estimation in adults through two different methods, tooth coronal index (TCI) and pulp tooth ratio (PTR), using digital panoramic radiographs.

Material and Methods

Study Design and Sample

In this cross-sectional study, an oral and maxillofacial radiologist, based on the inclusion and exclusion criteria, selected 237 digital panoramic radiographs of 17-60 years old patients from the archives of the Oral and Maxillofacial Radiology Department (between April 2018 to March 2019), Dentistry Faculty, Isfahan University of Medical Sciences.

We excluded radiographs displaying blurred images, open roots, root canal treatment, impacted teeth, developmental problems, specific dental diseases, root resorption, visible peri-apical lesions, caries, restorations, abrasions, crown and root fractures, trauma, rotation, or crowding of left mandibular first and second molars. To avoid distortion and other biases, we also discarded radiographs that belonged to individuals with systemic diseases, genetic anomalies, or any other condition that might affect the accuracy of the results.

Radiographic images acquired by Planmeca Promax panoramic machines (Planmeca Oy, Helsinki, Finland) were saved on the computer as high-resolution JPEG files and then imported into Planmeca Romexis

software (Planmeca Oy, Helsinki, Finland) for measurement and analysis. The panoramic radiographs were saved in an encoded format, and information regarding the subject's gender and age was concealed during the statistical analysis of the metric measurements. All measurements were carried out in millimeters (mm) and were performed as follows:

Tooth Coronal Index (TCI) Measurement

As determined By Ikeda et al. [19] method, the Crown Height (CH) was calculated by measuring the vertical distance between the Cemento Enamel Junction (CEJ) line (intersection of the mesial and distal CEJ points of a tooth) and the tip of the highest cusp. The Coronal Pulp Chamber Height (CPCH) was measured at a straight distance from the CEJ line to the tip of the highest pulp horn. These measurements were then used in the following formula to calculate the Tooth Coronal Index (TCI) for each of the left mandibular first and second molars (Figure 1): TCI=CPCH×100/CH.

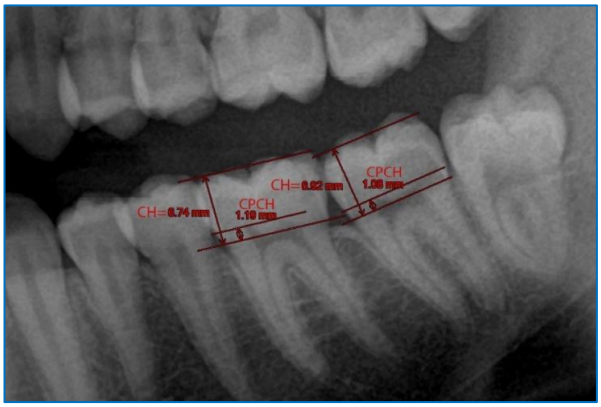

Figure 1. Measurement of tooth coronal index (TCI) in the left mandibular first and second molars.

Pulp/Tooth Ratio (PTR) Measurement

As well, in the selected teeth, the Crown Root Trunk Height (CRTH) was calculated by measuring the vertical distance between the highest point near the root bifurcation and the central fossa in accordance with the method described by Dehghani et al. [6]. The Pulp Chamber Height (PCH) was also recorded as a vertical line between the roof and floor of the pulp chamber on the same axis. These measurements are used in the following formula to calculate Pulp/Tooth Ratio (PTR) for each left mandibular first and second molars (Figure 2): PTR=PCH/CRTH.

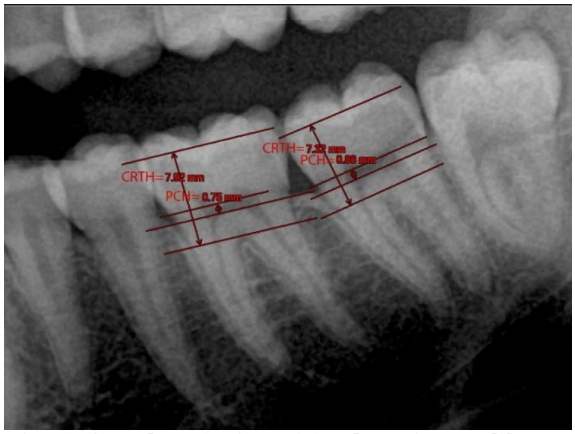

Figure 2. Measurement of pulp/tooth ratio (PTR) in the left mandibular first and second molars.

A calibrated observer (trained by an oral and maxillofacial radiologist) conducted these measurements. Furthermore, to reduce the impact of one indicator measurement result on the other, one of them (TCI or PTR indicator) was measured after another with a two-week interval without knowing the previous measurement results. Additionally, a random samples of 35 digital panoramic radiographs were reexamined after an interval of six weeks to ascertain intra-observer variation and there was no statistically significant difference. Lastly, a randomly selected 25 digital panoramic radiographs were examined by another observer to determine the inter-observer errors that were acceptable.

Data Analysis

Another author entered the collected data into IBM SPSS Statistics Version 22.0 (IBM Co., Armonk, NY, USA) without any knowledge of the gender or chronological age of the participants. The data were then divided into four groups (two groups for the first molars and two groups for the second molars) and analyzed using descriptive statistics such as mean and standard deviation, Pearson's coefficient test, and linear and non-linear regressions. Based on Pearson correlation coefficients, a relationship was found between the chronological age and these methods (TCI and PTR) for left mandibular first and second and a p-value <0.05 was considered statistically significant. As the data were normal but not linear and heteroscedastic, a curve estimation model was used to derive a regression equation; the patient's dental age (Estimated age) was then calculated using these respective equations and entered into a Microsoft Excel spreadsheet. To determine the accuracy of each indicator, the Mean Absolute Error (MAE) was obtained by calculating the average of the absolute value by subtracting the chronological age (CA) from the Estimated age (EA) in the first and second molars as per following formula:

$$Mean\ Absolute\ Error\ (MAE) = \frac{\sum_{i=1}^{n}|CAn - EAn|}{n} = \frac{|\mathrm{CA1} - EA1| + \cdots + |CAn - EAn|}{n}$$

CA= Chronological age; EA= Estimated age; n= number of participants = 237.

Ethical Clearance

The study has been approved by the ethics committee and was conducted in cooperation with the dental implant research center of the Isfahan dental faculty in July 2019. Throughout all procedures involved in the study, human participants were treated in accordance with the ethical standards of the institutional ethics committee, vide no. IR.MUI.REASEARCH.REC.1397.484, As well as the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Prior to including a panoramic radiograph in the current study, informed written consent was obtained from all individual participants.

Results

In this study, 57.4% (136 participants) and 42.6% (101 participants) of the patients were females and males, respectively. According to the data in Table 1, the exact chronological age of the participants was between 17 and 60 years, with an average age of 29.03 years.

The results of the Pearson correlation test between the chronological age and pulp/tooth ratio (PTR) variables of mandibular first molars indicated a higher statistically significant negative linear correlation (r = -0.890) between them than other indices (p<0.05); thus the results showed pulp/tooth ratio decreases with increasing chronological age (p<0.05). A negative and statistically significant correlation with a p-value < 0.05

between all indices and chronological age shows that the numerical value of TCI and PTR indices decreases with increasing chronological age (Table 2).

Table 1. Age, gender distribution and estimated age average.

Gender	N	Age	Age	Estimated Age			
			Mean±SD	PTR 1 Mean±SD	PTR 2 Mean±SD	TCI 1 Mean±SD	TCI 2 Mean±SD
Female	136	17-60	30.10±10.08	30.05±10.07	29.96±7.97	29.49±5.38	28.99±1.98
Male	101	17-57	27.58±9.21	27.65±8.75	27.77±6.89	28.40±5.05	29.07±2.10
Total	237	17-60	29.030±9.78	29.029±9.58	29.029±7.59	29.029±5.26	29.029±2.03

SD = Standard Deviation; PTR = Pulp Tooth Ratio; TCI = Tooth Coronal Index.

Table 2. Results of Pearson correlation test between chronological age and pulp/tooth ratio (PTR) in first and second molar and tooth coronal index (TCI) in the first and second molar.

	Mandibular First Molar PTR	Mandibular Second Molar PTR	Mandibular First Molar TCI	Mandibular Second Molar TCI
Correlation Coefficient	- 0.890	- 0.788	- 0.587	- 0.242
p-value	0.000	0.000	0.000	0.000

The results of the regression test for each of the indices showed that all of them were negatively correlated with chronological age. The accuracy of the mandibular first molar PTR due to variance changes in age estimation was about 80% (correlation coefficient (R^2) = 0.792), and in the second molar PTR was about 62%(correlation coefficient (R^2) = 0.62), also the accuracy of mandibular first molar TCI due to variance changes in prediction age was about 34%(correlation coefficient (R^2) = 0.344) and TCI in the second molar was about 6%(correlation coefficient (R^2) = 0.058) (Tables 3 and 4).

Table 3. Pulp Tooth Ratio (PTR) and gender distribution.

	R_1	R_2	% of Accuracy Level (R_1^2)	% of Accuracy Level (R_2^2)
Female	-0.900	-0.736	81	54.16
Male	-0.884	-0.855	78.14	73.10
Total	- 0.890	- 0.788	79.21	62.09

R_1 = PTR Coefficient correlation of first molars; R_2 = PTR Coefficient correlation of second molars.

Table 4. Tooth Coronal Index (TCI) and gender distribution.

	R_1	R_2	% of Accuracy Level (R_1^2)	% of Accuracy Level (R_2^2)
Female	-0.586	-0.302	34.33	9.12
Male	-0.589	-0.185	34.69	3.42
Total	- 0.587	- 0.242	34.45	5.85

R_1 = TCI Coefficient correlation of first molars; R_2 = TCI Coefficient correlation of second molars.

After the data was normal in a linear regression formula (negative correlation), by using non-linear regression analysis (curve model) estimated ages were calculated for each indicator in mandibular first and second molars. The mean absolute error (MAE) showed us the average error range for each indicator's estimated age against chronological age, which for PTR of the mandibular first molars was equal to 1.0 year while it was equal to 3.2 years for the mandibular second molar. The mean absolute error (MAE) for TCI of the mandibular

first molar was equal to 6.1 years, while it was equal to 7.4 years for the mandibular second molar (Tables 5 and 6). The diagrams of these regressions for indices are presented in Figures 3, 4, 5 and 6, respectively.

Table 5. Equation estimated age (Y) from PTR method and percentage of accuracy levels in first and second molars.

	Age (Mean±SD)	Estimated Age (Mean±SD)	Prediction Equation	% of Accuracy Level (R^2)	Mean Absolute Error (Year)
First molars	29.030±9.78	29.029±9.58	Y=7.30+2.68/X	79.21	1
Second molars	29.030±9.78	29.029±7.59	Y=12.07+2.35/X	62.09	3.2

X represents the value for PTR both for first and second molars, respectively; R = PTR Coefficient correlation.

Table 6. Equation estimated age (Y) from TCI method and percentage of accuracy levels in first and second molars.

	Age (Mean±SD)	Estimated Age (Mean±SD)	Prediction Equation	% of Accuracy Level (R^2)	Mean Absolute Error (Year)
First molars	29.030±9.78	29.029±5.26	Y=10.62+334.38/X	34.45	6.1
Second molars	29.030±9.78	29.029±2.03	Y=21.91+106.80/X	5.85	7.4

X represents value for TCI both for first and second molars, respectively; R = TCI Coefficient correlation.

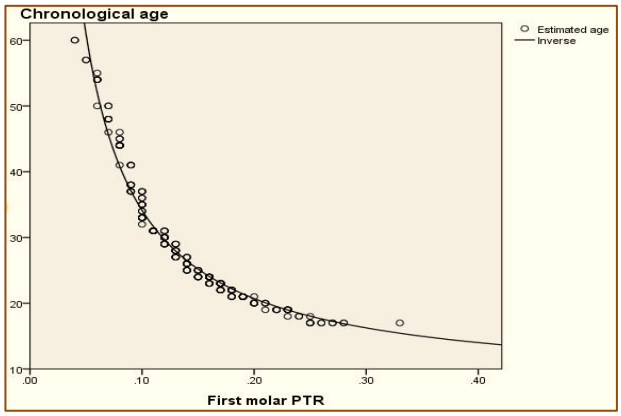

Figure 3. Nonlinear regression diagram of mandibular first molar pulp/tooth ratio (PTR).

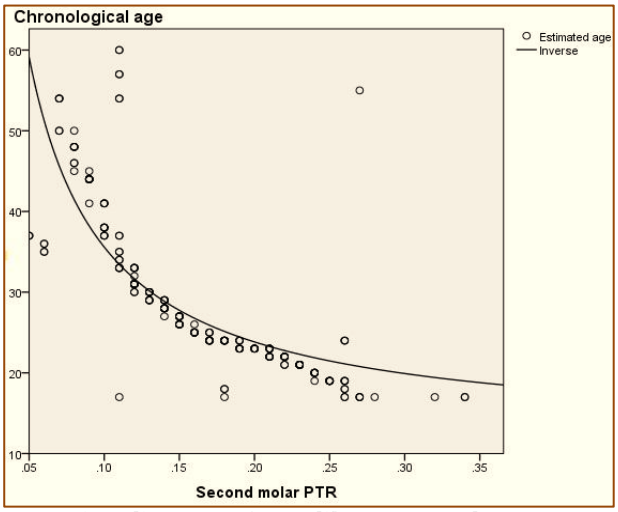

Figure 4. Nonlinear regression diagram of mandibular second molar pulp/tooth ratio (PTR).

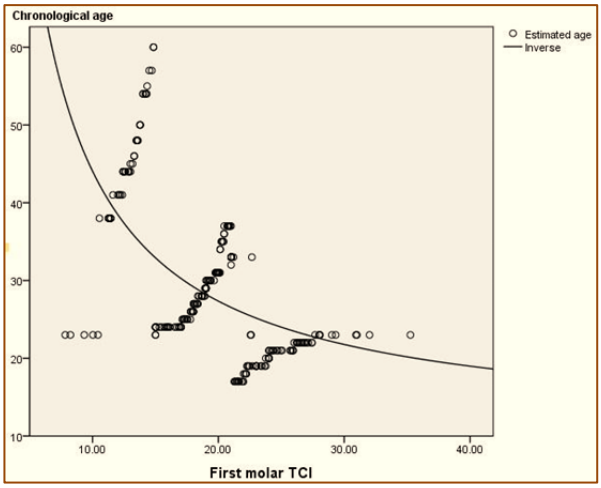

Figure 5. Nonlinear regression diagram of mandibular first molar Tooth Coronal Index (TCI).

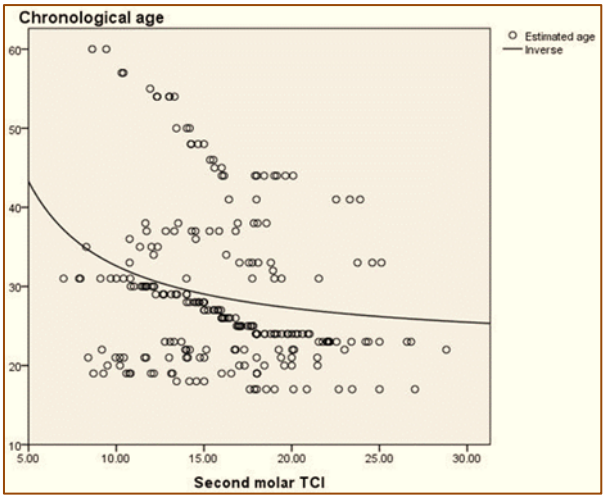

Figure 6. Nonlinear regression diagram of mandibular second molar Tooth Coronal Index (TCI).

Discussion

Age estimation with legal and ethical purposes is one of the most important aspects of forensic dentistry. It has an increasing application of inaccurate registration of legal documents of living individuals, especially related to immigration issues. Legal document registration is nowadays highly prevalent in developed countries. Thus, accurate and scientifically reliable age estimation methods related to a particular group of individuals, especially adults, have gained significant attention in resolving court cases [2,20].

Numerous studies in forensic dentistry have shown that pulp space reduction has a direct relationship with aging as a result of secondary dentin production, which has made this phenomenon the best tool for age estimation, even for ages over 25 years [21,22]. In 1925, Bodecker [23] discovered the correlation between chronological age and secondary dentin production. Subsequently, In 1950, Gustafson [24] introduced a systematic method based on the measurement of secondary dentin for age estimation for the first time.

Following the Bodecker [23] and Gustafson [24] studies, many researches were performed using TCI and PTR in peri-apical and panoramic radiographs, and most of their results, the same as this study, showed that

there exists a correlation between chronological age and these indices. Also, there have been several studies examining peri-apical radiographs and age, such as Kvaal et al. [11], Zaher et al. [25], and Cameriere et al. [26], all of them examined peri-apical radiographs of anterior and premolar teeth and patient age. The results showed a correlation and linear relationship between chronological age and PTR, which were in agreement with the findings of the current study. Subsequently, various studies have been conducted considering panoramic radiographs, different indices, markers, and age-determining abilities, most of them confirming the potential ability of these indices for age estimation.

In the present study, TCI showed a lower accuracy in age estimation and a relatively low correlation coefficient (0.587 in the first molar and 0.242 in the second molar) in this index and exact chronological age for both mandibular first and second molar teeth. However, this index was statistically acceptable (p-value < 0.05), indicating an inverse correlation with age and height of the pulp horns, which are related to physiological or pathological secondary dentin production due to increasing age.

The following studies have been carried out in this field, which are similar to the present study and represents the significant correlation between TCI and PTR indices and the exact chronological age. By evaluation of TCI in premolar and molar teeth of 433 patients, Drusini et al. [27] found the potential capability of this index for age prediction. Also, by investigation of TCI and the chronological age considering the relationship between them, Igbigbi and Nyirenda [12] concluded that TCI could be effectively used for age estimation and proposed a simple and non-invasive method for that. By examination of TCI in premolar, first, and second mandibular molar teeth in the Western Australian population, Karkhanis et al. [28] also confirmed the usage of this index for age estimation.

Veera et al. [22] concluded the high capability of TCI for age estimation, especially for under 50 years old patients, in a study of 100 patients. But they did not find any significant difference in the results of premolar and molar teeth. Shrestha [29] found that TCI was a more accurate index than others indices by evaluation of the results of several radiological age estimation indices. Also, El Morsi et al. [30] concluded that TCI is the most accurate, fastest, and most non-invasive radiographic method for age estimation by calculating and analyzing TCI of premolars and mandibular molars. Talabani et al. [31] also examined TCI of 92 patients and concluded that this index had a good ability in age prediction. By assessing the accuracy of age estimation methods using TCI, Nagi et al. [32] also concluded the high capability of this index for age estimation.

The results of this study showed the superiority of PTR in age estimation against other indices in this study (with a correlation coefficient equal to 0.890 in the first molar and 0.788 in the second molar). The index was able to estimate the age of the individuals with a difference of 1 year for the first molar and 3.2 years for the second molar on average.

The size of the pulp chamber space can be measured by different methods, such as longitudinal incision, direct observation, or radiology. According to previous studies, secondary dentin is not uniformly produced. Reduction of pulp space and production of secondary dentin between the roof and floor of the pulp chamber occurs in molar teeth when the age is increasing, which ultimately reduces the height of the pulp chamber without changing its width [31]. The results of this study and the other studies in this field indicate the superiority of PTR accuracy as an age estimation method compared to other indices in this study.

Cameriere et al. [33] investigated the age estimation capability of different indices such as pulp/root ratio, tooth length, pulp/tooth length ratio, pulp/tooth area, and pulp/root width ratio in maxillary canine teeth. They also analyzed the impact of these indices on each other. The authors derived a correlation between age and these indices similar to the results of the current study and also concluded PTR was the best index among the

studied cases [33]. Paewinsky et al. [34] conducted a study to evaluate dental pulp space measurement ability in adult age estimation, which confirmed a significant correlation between age and pulpal space size reduction. They also introduced the maxillary lateral tooth as the most reliable tooth with the highest correlation [34]. In the study of Zaher et al. [25], the authors evaluated the age estimation capability of the pulp chamber/tooth ratio in maxillary incisor teeth and showed the high reliability of the index. Cameriere et al. [35] investigated age estimation using PTR, which showed the high capability of the index for age estimation. The authors also proposed PTR as a beneficial age estimation index [35].

Mathew et al. also published an article indicating the validity of PTR [7]. Sakhdari et al. [36] concluded that TCI is not capable of age estimation when no other indices are considered by statistical analysis of data related to PTR in canine teeth. They concluded that the index could be a helpful index with high potential capability in age estimation [36]. Shah et al. conducted a study for age estimation and investigated the accuracy of PTR in first and second molar teeth of an [21]. Dehghani et al. [6], using pulp/tooth ratio in canine teeth of an Iranian population, found this method reliable in predicting age. Mehta et al. [37] concluded that PTR can be applied correctly to assess the age of Indian individuals in 2017.

Few studies have examined Pulp/Tooth Ratio and Tooth Coronal Index at the same time. Jain et al. examined the accuracy of these two indices in mandibular second premolars and molars and found that both indices were suitable for age estimation, while PTR had relatively higher accuracy in predicting [38].

Conclusion

Pulp/Tooth Ratio and Tooth Coronal Index have a negative correlation with the chronological age of individuals and can be used as potential indices with relatively good accuracy in chronological age estimation. Pulp/Tooth Ratio had higher accuracy in age estimation than Tooth Coronal Index, and the results showed that the mandibular first molar has higher accuracy and validity for age estimation. Such studies should be performed on a larger sample size from all races to achieve a universal formula.

Authors' Contributions

MA	https://orcid.org/0000-0001-8619-9337	Conceptualization, Methodology, Software, Validation, Investigation, Resources, Visualization, Supervision, Project Administration and Funding Acquisition.
HE	https://orcid.org/0000-0002-6246-0315	Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review and Editing, Visualization, Supervision, Project Administration and Funding Acquisition.
MA	https://orcid.org/0000-0003-1087-5209	Conceptualization, Methodology, Investigation, Data Curation, Writing - Review and Editing, Visualization and Supervision.

All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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References

[1] Shrestha A, Yadav R, Shrtestha S, Majarjan I, Camelio S. Measurement of open apices in teeth for estimation of age in children. Health Renaissance 2015; 12(1):33-7. https://doi.org/10.3126/hren.v12i1.11983

[2] Cameriere R, Ferrante L, Cingolani M. Precision and reliability of pulp/tooth area ratio (RA) of second molar as indicator of adult age. J Forensic Sci 2004; 49(6):1319-23.

[3] Marroquin T, Karkhanis S, Kvaal S, Vasudavan S, Kruger E, Tennant M. Age estimation in adults by dental imaging assessment systematic review. Forensic Sci Int 2017; 275:203-11. https://doi.org/10.1016/j.forsciint.2017.03.007

[4] Jeon H-M, Kim J-H, Heo J-Y, Ok S-M, Jeong S-H, Ahn Y-W. Age estimation by radiological measuring pulp chamber of mandibular first molar in Korean adults. J Oral Med Pain 2015; 40(4):146-54. https://doi.org/10.14476/jomp.2015.40.4.146

[5] Jeevan M, 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(1-3):209.e1-5. https://doi.org/10.1016/j.forsciint.2010.08.017

[6] Dehghani M, Shadkam E, Ahrari F, Dehghani M. Age estimation by canines' pulp/tooth ratio in an Iranian population using digital panoramic radiography. Forensic Sci Int 2018; 285:44-9. https://doi.org/10.1016/j.forsciint.2018.01.016

[7] 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(1):56-59. https://doi.org/10.4103/0975-1475.114552

[8] Murray PE, Stanley HR, Matthews JB, Sloan AJ, Smith AJ. Age-related odontometric changes of human teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2002; 93(4):474-82. https://doi.org/10.1067/moe.2002.120974

[9] Godge P, Sharma S, Vibhakar P, Kulkarni S, Shroff J. Age estimation using orthopantomographs-a forensic study. IJOCR 2014; 2(4):26-30.

[10] Moorrees CF, Fanning EA, Hunt Jr EE. Age variation of formation stages for ten permanent teeth. J Dent Res 1963; 42(6):1490-502. https://doi.org/10.1177/00220345630420062701

[11] Kvaal SI, Kolltveit KM, Thomsen IO, Solheim T. Age estimation of adults from dental radiographs. Forensic Sci Int 1995; 74(3):175-85. https://doi.org/10.1016/0379-0738(95)01760-g

[12] Igbigbi P, Nyirenda SK. Age estimation of Malawian adults from dental radiographs. West Afr J Med 2005; 24(4):329-33. https://doi.org/10.4314/wajm.v24i4.28227

[13] Saxena S. Age estimation of Indian adults from orthopantomographs. Braz Oral Res 2011; 25(3):225-9. https://doi.org/10.1590/S1806-83242011005000009

[14] Afify MM, Zayet MK, Mahmoud NF, Ragab AR. Age estimation from pulp/tooth area ratio in three mandibular teeth by panoramic radiographs: study of an Egyptian sample. J Forensic Res 2014; 5(3):1-5. https://doi.org/10.4172/2157-7145.1000231

[15] 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(8):350-4. https://doi.org/10.1016/j.jflm.2011.07.003

[16] Willems G. A review of the most commonly used dental age estimation techniques. J Forensic Odontostomatol 2001; 19(1):9-17.

[17] Singaraju S, Sharada P. Age estimation using pulp/tooth area ratio: A digital image analysis. J Forensic Dent Sci 2009; 1(1):37-41. https://doi.org/10.4103/0974-2948.50888

[18] Kvaal S, Solheim T. A non-destructive dental method for age estimation. J Forensic Odontostomatol 1994; 12(1):6-11.

[19] Ikeda N, Umetsu, K, Kashimura, S, Suzuki, T, Oumi, M. Estimation of age from teeth with their soft X-ray findings. Japanese Journal of Legal Medicine 1985; 39(3):244-50.

[20] Mittal S, Nagendrareddy SG, Sharma ML, Agnihotri P, Chaudhary S, Dhillon M. Age estimation based on Kvaal's technique using digital panoramic radiographs. J Forensic Dent Sci 2016; 8(2):115. https://doi.org/10.4103/0975-1475.186378

[21] Shah PH, Venkatesh R. Pulp/tooth ratio of mandibular first and second molars on panoramic radiographs: An aid for forensic age estimation. J Forensic Dent Sci 2016; 8(2):112. https://doi.org/10.4103/0975-1475.186374

[22] Veera SD, Kannabiran J, Suratkal N, Chidananada DB, Gujjar KR, Goli S. Coronal pulp biomarker: A lesser known age estimation modality. J Indian Acad Oral Med Radiol 2014; 26(4):398-404. https://doi.org/10.4103/0972-1363.155684

[23] Bodecker CF. A consideration of some of the changes in the teeth from young to old age. Dental Cosmos 1925; 67(6):543-9.

[24] Gustafson G. Age determinations on teeth. J Am Dent Assoc 1950; 41(1):45-54. https://doi.org/10.14219/jada.archive.1950.0132

[25] 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(2):62-5. https://doi.org/10.1016/j.jflm.2010.12.004

[26] 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(1):166-70. https://doi.org/10.1111/j.1556-4029.2006.00336.x

[27] 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(3):353-63.

[28] 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(1-3):412.e1-6. https://doi.org/10.1016/j.forsciint.2013.04.004

[29] Shrestha M. Comparative evaluation of two established age estimation techniques (two histological and radiological) by image analysis software using single tooth. J Forensic Res 2014; 5(4):1-6. https://doi.org/10.4172/2157-7145.1000237

[30] El Morsi D, Rezk H, Aziza A, El-Sherbiny M. Tooth coronal pulp index as a tool for age estimation in Egyptian population. J Forensic Sci Criminol 2015; 3(2):201. https://doi.org/10.15744/2348-9804.2.501

[31] Talabani RM, Baban MT, Mahmood MA. Age estimation using lower permanent first molars on a panoramic radiograph: A digital image analysis. J Forensic Dent Sci 2015; 7(2):158-162. https://doi.org/10.4103/0975-1475.154597

[32] Nagi R, Jain S, Agrawal P, Prasad S, Tiwari S, Naidu GS. Tooth coronal index: Key for age estimation on digital panoramic radiographs. J Indian Acad Oral Med Radiol 2018; 30(1):64-67. https://doi.org/10.4103/jiaomr.jiaomr_139_17

[33] 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(2):317-9.

[34] 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(1):27-30. https://doi.org/10.1007/s00414-004-0492-x

[35] 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(1-3):105-12. https://doi.org/10.1016/j.forsciint.2011.07.028

[36] Sakhdari S, Mehralizadeh S, Zolfaghari M, Madadi M. Age estimation by using pulp/tooth ratio in digital panoramic radiographs. JIDAI 2015; 27(1):19-23.

[37] Mehta S, Urala AS, Vineetha R, Mehta A, Lodha S. Ocena wieku na podstawie obrazu na zdjęciu pantomograficznym pierwszego dolnego zęba trzonowego. Dent Med Probl. 2017; 54(2):179-82. https://doi.org/10.17219/dmp/73836 [In Polish].

[38] Jain S, Nagi R, Daga M, Shandilya A, Shukla A, Parakh A, et al. Tooth coronal index and pulp/tooth ratio in dental age estimation on digital panoramic radiographs — a comparative study. Forensic Sci Int 2017; 277:115-21. https://doi.org/10.1016/j.forsciint.2017.05.006