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Original Article

Age Estimation Based on Tooth Morphometric Parameters From Cone-Beam Computed Tomography Scans in an Iranian Population

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Abstract
Background: Age determination plays an important role in forensic medicine. This study aimed to evaluate the precision of age estimation based on pulp chamber dimensions using cone-beam computed tomography (CBCT) scans in an Iranian population.
Methods: In this diagnostic study, CBCT scans of 85 males and 95 females, all over 12 years of age, were retrieved from the archives of a radiology clinic in Ardabil, Iran. The study included a total of 180 teeth. All CBCT scans were obtained using the ProMax 3D scanner. The Kvaal's parameters were measured on CBCT scans for maxillary central and lateral incisors, second premolars, and mandibular lateral incisors, canines, and first premolars. The Kvaal's regression formula was then applied for age estimation. Next, a new regression model was developed for the study population, and its accuracy in estimating age underwent evaluation.
Results: No significant correlation was found between the estimated age for males using Kvaal's method and their chronological age ($P>0.05$). Multiple regression analysis revealed that tooth length, radicular pulp length, and root width at the mid-root were good predictors for age estimation in males. In females, tooth length, root width at the cementoenamel junction (CEJ), and root width at the mid-root were good predictors for age estimation.
Conclusion: The regression formula proposed by Kvaal was found to be unsuitable for estimating age in males within our study population. The dimensions of the mean pulp chamber, except for tooth length, on CBCT scans were only suitable for age estimation in females; thus, a new regression model was developed for the study population.
Keywords: Age determination by teeth, Cone-beam computed tomography, Forensic medicine

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Background

Age estimation has an essential role in orthodontic treatment, orthognathic surgery, pediatric endocrinology, and clinical dentistry (1-3), where it informs diagnosis and treatment planning. Crucially, age estimation has long been a cornerstone of forensic medicine, providing vital information for identification purposes in the cases of unknown individuals or mass disasters (1, 4). Thus, ongoing attempts are being made to find accurate non-invasive methods for age estimation. In 1925, Bodeckar was the first to report that aging causes significant changes in the tooth structure, which can be utilized for age estimation. Gustafson (1950) was the first to suggest an efficient method for estimating the age of a corpse using teeth (5). The determination of dental age by radiography has gained increasing popularity since it appears to be more reliable than other methods (2,6-9). Radiographic methods for dental age estimation are generally considered to have high reliability and low variability and are less influenced by environmental factors compared to some other biological indicators (6,8,10).

There are two main approaches for dental age estimation, including (I) the age of tooth eruption and (II) the pattern of tooth calcification. Age of tooth eruption is no longer considered an accurate method for age estimation because tooth eruption can be influenced by various local factors, such as early loss of primary teeth or crowding of permanent teeth (2,3,9,11). Tooth formation and calcification follow a lengthy process with specific criteria for each stage (2,11-14). Several methods have been proposed for dental age estimation based on the developmental stage of permanent teeth on radiographs. The Demirjian method is most commonly used worldwide for age estimation and is based on tooth calcification. In this method, the level of calcification of seven mandibular left teeth is assessed on panoramic radiographs (15,16). Cameriere et al (17) developed a method based on measuring the ratio of pulp volume to tooth volume (reflecting secondary dentin deposition) in canine teeth using digital panoramic and periapical radiographs. However, this method has shortcomings, such as the inherent distortion of panoramic radiographs (18).

In 1995, Kvaal et al (19) proposed a method for estimating dental age based on the presence of secondary dentin visible on radiographs and the radiolucency of the pulp (19). Since then, radiographic age estimation and its accuracy have been the subject of numerous investigations (20).

The use of radiography for this purpose is simple and practical in living individuals; however, it has some limitations as well (21,22). Of the various dimensions of the pulp, tooth crown, and tooth root, the only parameter that was found to have a significant correlation with age was the ratio of pulp space to the entire tooth. Thus, the correlation between this ratio in different teeth and age, as well as the effectiveness of this method for age estimation in different populations, has undergone investigation (20). Evidence shows that the volume of pulp decreases with age due to the deposition of secondary dentin. Therefore, it has a high potential for age estimation, especially because it is protected by primary dentin and is not easily affected by environmental factors (23). Thus, measuring the reduction in the size of the pulp chamber can serve as an important criterion for age estimation (10,19,24). The majority of the relevant studies used the pulp/tooth area ratio for age estimation in different populations (20,25-27). Nonetheless, the direct application of generalized formulae across diverse populations is a significant challenge. Population-specific variations in dental maturation rates and secondary dentin deposition patterns imply that a single formula may not be applicable universally, potentially limiting accuracy in both clinical decision-making (e.g., tailoring orthodontic treatment or assessing developmental milestones in diverse patient groups) and in forensic contexts where precise age-at-death profiles are critical for identification, particularly within specific regional or ethnic populations (28). Therefore, this study, by focusing on an Iranian population, aims to assess the accuracy of age estimation by applying Kvaal's morphometric parameters to cone-beam computed tomography (CBCT) scans and to develop new, population-specific regression formulae. This will address the need for more accurate and relevant tools for both forensic and clinical applications within this demographic.

Methods

This diagnostic study utilized CBCT scans from 180 individuals (85 males and 95 females) retrieved from the archives of an oral and maxillofacial radiology clinic in Ardabil, Iran. Informed consent was obtained from patients prior to acquiring the CBCT images, specifying that their images could be used for research purposes.

All CBCT scans were obtained using the ProMax 3D MID CBCT scanner (Planmeca, Helsinki, Finland; FOV: 5 x 5.8 cm, 5.6 mA, 96 kVp, and voxel size: 0.2 mm) for diagnostic purposes unrelated to this study. The inclusion criteria were CBCT scans of patients over 12 years of age, with the visualization of fully erupted teeth and completely formed roots. Impacted teeth, rotated teeth, endodontically treated teeth, restored teeth, and those with prosthodontic treatment, as well as teeth with pathological lesions, such as dental caries, periodontitis, and periapical lesions, were excluded from the study.

The age of patients at the time of radiography was recorded, followed by measuring the dimensions of the pulp chamber of maxillary central and lateral incisors, second premolars, and mandibular lateral incisors, canines, and first premolars on CBCT scans using Romexis Viewer software, version 3.1.1 (Planmeca, Helsinki, Finland) and inputting them into Kvaal's formula for age estimation by a board certified oral and maxillofacial radiologist. To assess intra-examiner reliability, all CBCT scans were evaluated by the same oral and maxillofacial radiologist three months after their primary assessment, and the agreement between the findings in the first and second observations was calculated using Cohen's Kappa, yielding almost perfect agreement (Kappa = 0.85). Following Kvaal and Solheim (29), the following parameters were measured to account for magnification and/or angulation of teeth: radicular pulp length (R), pulp length (P), tooth length (T), root width at the cementoenamel junction (CEJ) (A), root width at the mid-root (C), and root width at the midpoint between A and C (B) (Figures 1-3). Finally, the mean of all values except for T (indicated as M in the formula), the mean of B and C (indicated as W in the formula), and the mean of P and R (indicated as L in the formula) were calculated:

$AGE = 129.8 - 316.4\ (M) - 66.8\ (W - L)$ $M = (P + R + A + B + C) / 5$

$W = (B + C) / 2$

$L = (P + R) / 2$

Figure 1. Measuring the Maximum Tooth Length

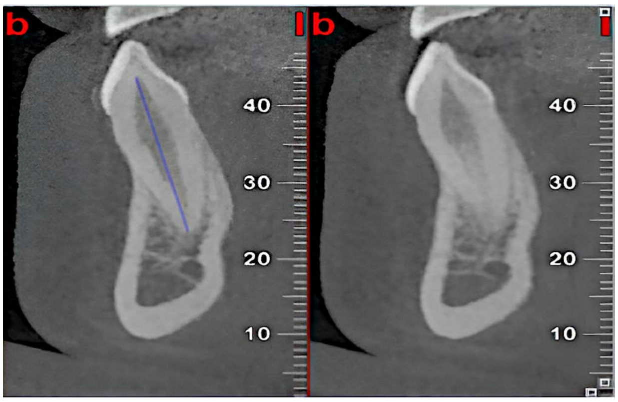

Figure 2. Measuring the Maximum Pulp Length

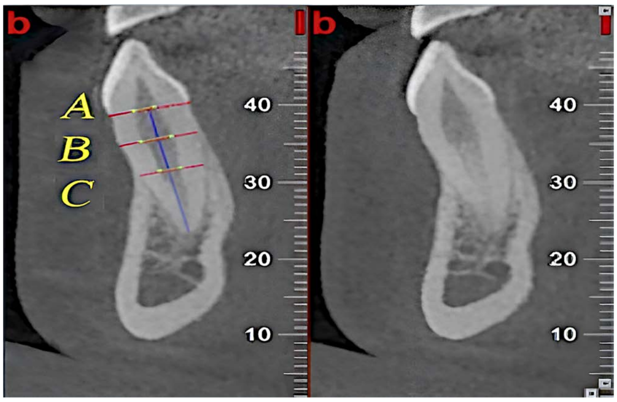

Figure 3. Measurement of the Root Length From the CEJ to the Apex (Blue): (A) Root Width at the CEJ, (C) Root Width at the Mid-Root, and (B) Root Width at the Midpoint Between A and C. *Note*. CEJ: Cementoenamel junction

Age was estimated using Kvaal's regression formula and compared to the patients' chronological age. The role of gender in age estimation was also analyzed.

The Kolmogorov-Smirnov test was used to analyze the normality of the data distribution. Statistical analyses were conducted using simple and multiple linear regression tests. Pearson's correlation test was applied to analyze the correlation between estimated age and chronological age. All statistical analyses were conducted using SPSS (version 24) at a significance level of $P > 0.05$.

Results

The CBCT scans of 85 males (47.2%) and 95 females (52.8%) were evaluated in this study. The mean chronological age was 30.84 ± 12.5 years (range: 14–62 years) in males and 30.55 ± 9.83 years (range: 13–51 years) in females. The intra-examiner reliability was found to be Kappa = 0.85, indicating almost perfect agreement.

Table 1 presents descriptive statistics (measures of central tendency and dispersion) for tooth length (T), pulp length (P), radicular pulp length (R), root width at the CEJ (A), root width at the mid-root (C), root width at the midpoint between A and C (B), and mean pulp chamber dimensions except T (M) in males and females. All variables had a normal distribution ($P > 0.05$).

Age Estimation According to Pulp Chamber Dimensions on CBCT Scans

Simple linear regression showed that age estimation was impossible according to pulp chamber dimensions measured on CBCT scans (Table 2).

Age Estimation According to Pulp Chamber Dimensions on CBCT Scans in Males

Based on simple linear regression, age estimation was not possible according to pulp chamber dimensions measured on CBCT scans in males (Table 2).

Age Estimation According to Pulp Chamber Dimensions on CBCT Scans in Females

Simple linear regression demonstrated that age estimation was possible according to pulp chamber dimensions measured on CBCT scans in females (Table 2). Accordingly, the following regression formula was designed for age estimation according to pulp chamber dimensions in females:

$$\text{Estimated age in females} = (55.826 - 225.527) \times (M)$$

Correlation of Estimated Age With Chronological Age

Pearson's correlation test revealed no significant correlation between the estimated age of males by Kvaal's method and their chronological age ($r = -0.089$, $P = 0.420$). However, the correlation between the estimated age of females according to Kvaal's method and their chronological age was statistically significant ($r = 0.296$,

Table 1. Measures of Central Dispersion for Tooth Length (T), Pulp Length (P), Radicular Pulp Length (R), Root Width at the CEJ (A), Root Width at the Mid-Root (C), Root Width at the Midpoint Between A and C (B), and Mean Pulp Chamber Dimensions Except T (M) in Males and Females

Variable	Gender	Number	Mean	Std. Deviation	Skewness	Kurtosis	Minimum	Maximum
Tooth length (T)	Males	85	26.27	2.92	0.301	0.747-	21	33
	Females	95	26.79	3.23	0.164-	0.918-	19.60	33
Pulp length (P)	Males	85	21.36	2.65	0.192	0.885-	16.4	26.8
	Females	95	21.94	3.12	0.167-	1.072-	14.3	26.9
Radicular pulp length (R)	Males	85	16.20	2.41	0.570	0.422-	12	22
	Females	95	16.84	2.66	0.186	0.810-	11.1	22.1
Root width at the CEJ (A)	Males	85	7.41	0.608	0.089-	0.122-	5.7	8.9
	Females	95	7.60	0.640	1.303-	1.885	5.2	8.5
Root width at the mid-root (C)	Males	85	5.77	0.73	0.282	1.211	4	8
	Females	95	5.99	0.59	0.810-	0.861	4.10	7
Root width at the midpoint between A and C (B)	Males	85	6.98	625	0.218-	0.466-	5.40	8.4
	Females	95	7.09	616	1.310-	2.203	4.90	7.9
Mean pulp chamber dimensions except T (M)	Males	85	11.54	1.15	0.206	0.814-	9.10	13.96
	Females	95	11.89	1.35	0.428-	0.324-	8	14.08

Note. CEJ: Cementoenamel junction; Std. deviation: Standard deviation.

Table 2. Results of Simple Regression Analysis for Age Estimation

Age Estimation	Model	Non-Standard Coefficients		Standard Coefficients	T	*P* Value
		B	Standard Error	B		
Total	Constant	36.571	7.703		4.474	0.000
	(M)	50.108-	65.297	-0.057	-0.767	0.444
	Correlation coefficient: 0.057, determination coefficient: 0.003, and adjusted determination coefficient: 0.002					
Males	Constant	7.452	16.210		0.460	0.647
	(M)	189.968	131.171	0.157	1.448	0.151
	Correlation coefficient: 0.157, determination coefficient: 0.025, and adjusted determination coefficient: 0.013					
Females	Constant	55.826	8.815		6.333	0.000
	(M)	225.527-	78.202	-0.287	-2.884	0.005
	Correlation coefficient: 0.287, determination coefficient: 0.082, and adjusted determination coefficient: 0.072					

$P = 0.004$).

Age Estimation According to Tooth Length (T), Pulp Length (P), Radicular Pulp Length (R), Root Width at the Cementoenamel Junction (A), Root Width at the Mid-Root (C), and Root Width at the Midpoint Between A and C (B)

Multiple regression analysis (Table 3) confirmed that tooth length, radicular pulp length, root width at the CEJ, and root width at the mid-root were good predictors for age estimation ($P < 0.05$). Conversely, pulp length and root width at the midpoint between A and C could not estimate age. Thus, the following regression formula was developed for age estimation:

Age = 24.829 - 436.572 (T) + 163.293 (R) + 540.981 (A) + 680.224 (C)

In males, radicular pulp length and root width at the mid-root were acceptable predictors for age estimation ($P < 0.05$, Table 4). Hence, the following regression formula was established for age estimation in males:

Age = -13.293 + 322.966 (R) + 868.303 (C)

In females, tooth length, root width at the CEJ, root width at the midpoint between A and C, and root width at the mid-root were found to be good predictors for age estimation ($P < 0.05$, Table 5). As a result, the following regression formula was developed for age estimation in females:

Age = 45.441 - 365.852 (T) + 551.965 (A) - 758.6 (B) + 557.201 (C)

Discussion

This study assessed the accuracy of age estimation based on pulp chamber dimensions on CBCT scans in an Iranian population. Cameriere et al (17) reported that both maxillary and mandibular teeth can be reliably used for age estimation. Consistent with this, both maxillary and mandibular teeth were included in our analysis. In addition, the maxillary central and lateral incisors and second premolars, as well as the mandibular lateral incisors, canines, and first premolars, are considered among the

Table 3. Multiple Regression Analysis for Age Estimation According to Tooth Length (T), Pulp Length (P), Radicular Pulp Length (R), Root Width at the CEJ (A), Root Width at the Mid-Root (C), and Root Width at the Midpoint Between A and C (B)

Model	Non-Standard Coefficients		Standard Coefficient	t	*P* Value
	B	Standard Error	Beta		
Constant	24.829	10.112		2.455	0.015
Tooth length	-436.572	113.801	-1.211	3.836-	0.000
Pulp length	193.328	116.873	0.506	1.654	0.100
Radicular pulp length	163.293	79.439	0.376	2.056	0.041
Root width at the CEJ	540.981	214.201	0.306	2.526	0.012
Root width at the midpoint between A and C	-395.725	231.600	-0.225	-1.709	0.089
Root width at the mid-root	680.224	180.482	0.408	3.769	0.000

Note. CEJ: Cementoenamel junction. Multiple correlation coefficient: 0.439, determination coefficient: 0.193, adjusted determination coefficient: 0.165, and Durbin-Watson statistic: 1.60.

Table 4. Multiple Regression Analysis for Age Estimation in Males

Model	Non-Standard Coefficients		Standard Coefficient	t	*P* Value
	B	Standard error	B		
Constant	-13.293	20.211		-0.654	0.515
Tooth length	-221.955	215.593	-0.412	-1.030	0.306
Pulp length	-216.096	230.154	-0.386	-0.939	0.351
Radicular pulp length	322.966	133.098	0.550	2.427	0.018
Root width at the CEJ	509.351	463.781	0.224	1.098	0.275
Root width at the midpoint between A and C	102.239	474.777	0.049	0.215	0.830
Root width at the mid-root	868.303	376.770	0.411	2.305	0.024

Note. CEJ: Cementoenamel junction. Multiple correlation coefficient: 0.534, determination coefficient: 0.286, adjusted determination coefficient: 0.231, and Durbin-Watson statistic: 1.67.

Table 5. Multiple Regression Analysis for Age Estimation in Females

Model	Non-Standard Coefficients		Standard Coefficient	t	*P* Value
	B	Standard Error	B		
Constant	54.441	12.477		3.642	0.000
Tooth length	-365.852	129.162	-1.164	-2.833	0.006
Pulp length	255.452	135.904	0.764	1.880	0.063
Radicular pulp length	36.905	102.475	0.101	0.360	0.720
Root width at the CEJ	551.965	233.908	0.332	2.360	0.020
Root width at the midpoint between A and C	-758.600	265.537	-0.484	-2.857	0.005
Root width at the mid-root	557.201	195.430	0.384	2.851	0.005

Note. CEJ: Cementoenamel junction. Multiple correlation coefficient: 0.503, determination coefficient: 0.253, adjusted determination coefficient: 0.202, and Durbin-Watson statistic: 1.53.

most suitable teeth for measuring pulp dimensions. This is because they have large pulp chambers and a high likelihood of having a single canal (30). Therefore, the aforementioned teeth were selected for the measurements in the present study. CBCT was used in the current study due to its high accuracy and absence of magnification error caused by geometric distortion (31,32). Moreover, CBCT is ideal for volumetric measurements (7). The calculation of pulp chamber dimensions on CBCT scans is more reliable than that of the surface area on two-dimensional radiographs because the formation of secondary dentin occurs three-dimensionally and does not often take place homogeneously on the pulp chamber walls (33).

In brief, the present results revealed no significant correlation between the estimated age for males by using Kvaal's method and their chronological age ($P > 0.05$). Multiple regression analysis showed that the radicular pulp length and root width at the mid-root were acceptable predictors for age estimation in males, while tooth length, root width at the CEJ, root width at the midpoint between A and C, and root width at the mid-root were good predictors for age estimation in females.

Sakhdari et al (34) proposed a regression formula for estimating age based on the pulp/tooth area ratio, which was measured using digital panoramic radiographs of 120 patients older than 12 years. The correlation between age and pulp/tooth area ratio was insignificant in males but significant in females. They concluded that the pulp/tooth area ratio cannot be used alone for age estimation; instead, it can only be applied in conjunction with other methods for this purpose.

In the present study, the estimated age according to Kvaal's method was not correlated with the chronological age in males. However, this correlation was significant in females, which is consistent with the findings of Sakhdari et al (34). Moshfeghi et al (35) evaluated the accuracy of age estimation based on the pulp/tooth area ratio in an Iranian population aged 20–70 years, using panoramic radiographs. They found Kvaal's parameters to be applicable for age estimation in mandibular canine teeth. Moreover, they reported that the measurement of pulp width was more accurate than that of pulp length for this purpose. They utilized measurements such as pulp/tooth length and ratios of pulp/root width at the CEJ, mid-root, and the midpoint between CEJ and mid-root to assess pulp surface area in canine teeth for age estimation. In first premolars, the width of the pulp/root at the CEJ, the width of the pulp/root at the mid-root, and the width of the pulp/root at the midpoint between the CEJ and mid-root were applicable for age estimation. In contrast to the findings of Moshfeghi et al on specific parameter applicability, our CBCT-based study revealed that radicular pulp length and root width at the mid-root are good predictors for age estimation in males. Consequently, a regression formula is suggested for this purpose. In females, tooth length, root width at the CEJ, root width at the midpoint between A and C, and root width at the mid-root were reliable indicators for age estimation. A regression formula was developed based on these findings. The difference between the results of the two studies may be attributed to the use of CBCT in the present study, which has higher accuracy compared to panoramic radiography. The present results demonstrated that pulp chamber dimensions can only be utilized for age estimation in females, considering the appropriate formula.

Xu et al (5) assessed the accuracy of Kvaal's method for age estimation in an Indian population using periapical radiographs (both parallel and bisecting angle methods). They observed a significant difference between the actual age and the estimated age using this method. They explained that this difference may be due to different patterns of deposition of secondary dentin as a result of both genetic and environmental factors in the Indian population.

In line with the present findings, Babshet et al (26) demonstrated a weak correlation between pulp dimensions in mandibular canine teeth and age in an Indian population. The reason they explained is the deposition of secondary dentin in canine teeth, which does not continuously increase with age. In other words, the deposition of secondary dentin could have been slow and irregular in their study population.

Zaher et al (20) estimated the age based on the pulp/tooth area ratio of maxillary incisors in an Egyptian population. They used periapical radiographs of 144 patients aged between 12 years and 60 years. They found a significant correlation between the estimated and chronological age. Haghanifar et al (36) also reported the same result in an Iranian population, indicating that maxillary central incisors were more reliable for age estimation compared with the other anterior teeth. Jeevan et al (27) estimated age using the pulp/tooth area ratio of 456 maxillary and mandibular canine teeth in an Indian population through digital radiography. They confirmed the reliability of dental methods for estimating biological age in forensic dentistry for both living and deceased individuals. They also concluded that this method was more accurate for estimating age in individuals younger than 45 years. Gender had no significant effect on age estimation in their study.

Cameriere et al (23) estimated age according to the pulp/tooth area ratio of canine teeth on periapical radiographs in a Portuguese population between 20 years and 84 years and observed that this method had an error of approximately 2.5 years. Landa et al (37) utilized Kvaal's method to estimate age by examining three single-rooted mandibular teeth on digital orthopantomography of 100 patients ranging in age from 14 years to 60 years. They found that Kvaal's regression formula was unsuitable for their study population. In addition, the estimated age by their developed regression formula was far from the chronological age of patients. Their results corroborate the present findings.

Kvaal et al (19) suggested that regression-specific formulas should be designed for each population. Considering that the Kvaal's formula was not suitable for our study population, further investigations are required to identify the possible confounders that need to be considered in the regression formula. Kvaal et al (19) used periapical radiographs in their study, while we employed CBCT scans to address the limitations of conventional two-dimensional radiography. According to Cameriere et al (7), certain external factors, such as mastication, type of food, and chewing time, can influence the formation of secondary dentin. Furthermore, gender and tooth type may affect age estimation (38). Moreover, morphological assessments based on dental and skeletal developments observed on radiographs are often more accurate during childhood and adolescence. However, their accuracy tends to decrease in adulthood (39). Further studies are required on other factors that may be involved in age estimation.

This study, while providing valuable insights into age estimation using CBCT-derived tooth morphometrics in an Iranian population, had several limitations. Firstly, the findings are specific to the population sample from Ardabil, Iran. Due to ethnic and regional variations in dental development and aging patterns, the derived regression formulae may not be directly generalizable to other Iranian populations or different ethnic groups worldwide without further validation. Secondly, while our sample size of 180 individuals provided sufficient data for initial formula development, larger and more diverse cohorts could enhance the statistical power and precision of the age estimation models.

Thirdly, this was a cross-sectional study, capturing dental parameters at a single point in time. Longitudinal studies, tracking changes within the same individuals over several years, would offer more definitive insights into the rate and pattern of secondary dentin deposition. Fourthly, the study focused on specific maxillary and mandibular teeth chosen for their suitability (e.g., single canals and large pulp chambers). The applicability of these findings or developed formulae to other tooth types requires further investigation. Finally, while CBCT offers high accuracy, variations in imaging parameters, scanner types, and measurement software across different centers could potentially influence the results, highlighting the need for standardized protocols. Although intra-examiner reliability was excellent, the assessment of inter-examiner reliability for the primary measurement protocol could further strengthen the methodology.

Building upon the findings and limitations of this research, several avenues are recommended for future investigation. There is a clear need to validate the newly developed regression formulae in larger, more diverse Iranian populations and to test their applicability across different ethnic groups. Such studies would help establish the robustness and broader utility of these CBCT-based morphometric parameters.

Future research could also explore the inclusion of other tooth types, particularly those more resistant to post-mortem changes or commonly available in forensic examinations.

Longitudinal studies, though challenging, would be invaluable for understanding individual variations in the rate of secondary dentin apposition and its correlation with chronological age. Moreover, the integration of advanced image analysis techniques, such as machine learning or artificial intelligence algorithms, could potentially identify more subtle or complex morphometric patterns from CBCT data, possibly leading to even more accurate age estimation models.

Finally, exploring the combined utility of these dental parameters with other skeletal or biochemical age indicators could lead to a multi-factorial approach, improving the overall accuracy and reliability of age estimation in living individuals and for identification purposes.

Conclusion

The regression formula proposed by Kvaal was found to be unsuitable for estimating age in males within our study population. The dimensions of the mean pulp chamber, except for tooth length, on CBCT scans were only suitable for age estimation in females. Thus, new population-specific regression formulae developed using individual CBCT-derived tooth morphometric parameters demonstrated potential for age estimation in both males and females, utilizing different sets of variables for each gender.

Authors' Contribution

Conceptualization: Ahmad Nouroloyouni, Hesam Mikaieli Xiavi, Saeed Ahmadvand.
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Writing–review & editing: Ahmad Nouroloyouni, Hesam Mikaieli Xiavi, Sara Noorolouny, Saeed Ahmadvand, Sepehr Nouroloyouni, Rashin Alyali.

Competing Interests

The authors declared that there is no conflict of interests regarding the publication of this paper.

Data Availability Statement

The data used to support the findings of this study were supplied by the corresponding author under license, and the data will be available upon request. Requests for access to this data should be made to the corresponding author within 12 months of publication.

Ethical Approval

The study was approved by the Ethics Committee of Ardabil University of Medical Sciences (IR.ARUMS.REC.1398.108).

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References

1. Molina A, Bravo M, Fonseca GM, Márquez-Grant N, Martín-de-Las-Heras S. Dental age estimation based on pulp chamber/crown volume ratio measured on CBCT images in a Spanish population. Int J Legal Med. 2021;135(1):359-64. doi: 10.1007/s00414-020-02377-y.
2. Mani SA, Naing L, John J, Samsudin AR. Comparison of two methods of dental age estimation in 7-15-year-old Malays. Int J Paediatr Dent. 2008;18(5):380-8. doi: 10.1111/j.1365-263X.2007.00890.x.
3. El-Bakary AA, Hammad SM, Mohammed F. Dental age estimation in Egyptian children, comparison between two methods. J Forensic Leg Med. 2010;17(7):363-7. doi: 10.1016/j.jflm.2010.05.008.
4. Du H, Li G, Zheng Q, Yang J. Population-specific age estimation in Black Americans and Chinese people based on pulp chamber volume of first molars from cone beam computed tomography. Int J Legal Med. 2022;136(3):811-9. doi: 10.1007/s00414-022-02776-3.
5. Xu X, Philipsen HP, Jablonski NG, Pang KM, Zhu J. Age estimation from the structure of adult human teeth: review of the literature. Forensic Sci Int. 1992;54(1):23-8. doi:

10.1016/0379-0738(92)90077-a.
6. Lee SS, Kim D, Lee S, Lee UY, Seo JS, Ahn YW, et al. Validity of Demirjian's and modified Demirjian's methods in age estimation for Korean juveniles and adolescents. Forensic Sci Int. 2011;211(1-3):41-6. doi: 10.1016/j.forsciint.2011.04.011.
7. 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. doi: 10.1111/j.1556-4029.2006.00336.x.
8. Ardakani F, Bashardoust N, Sheikhha M. The accuracy of dental panoramic radiography as an indicator of chronological age in Iranian individuals. J Forensic Odontostomatol. 2007;25(2):30-5.
9. Rai B, Anand SC. Tooth developments: an accuracy of age estimation of radiographic methods. World J Med Sci. 2006;1(2):130-2.
10. Saxena S, Sharma P, Gupta N. Experimental studies of forensic odontology to aid in the identification process. J Forensic Dent Sci. 2010;2(2):69-76. doi: 10.4103/0975-1475.81285.
11. Bolanos MV, Manrique MC, Bolanos MJ, Briones MT. Approaches to chronological age assessment based on dental calcification. Forensic Sci Int. 2000;110(2):97-106. doi: 10.1016/s0379-0738(00)00154-7.
12. Galić I, Vodanović M, Cameriere R, Nakaš E, Galić E, Selimović E, et al. Accuracy of Cameriere, Haavikko, and Willems radiographic methods on age estimation on Bosnian-Herzegovian children age groups 6-13. Int J Legal Med. 2011;125(2):315-21. doi: 10.1007/s00414-010-0515-8.
13. Kurita LM, Menezes AV, Casanova MS, Haiter-Neto F. Dental maturity as an indicator of chronological age: radiographic assessment of dental age in a Brazilian population. J Appl Oral Sci. 2007;15(2):99-104. doi: 10.1590/s1678-77572007000200005.
14. Darji JA, Govekar G, Kalele SD, Hariyani H. Age estimation from third molar development a radiological study. J Indian Acad Forensic Med. 2011;33(2):36-40. doi: 10.1177/0971097320110209.
15. Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Hum Biol. 1973;45(2):211-27.
16. Demirjian A, Goldstein H. New systems for dental maturity based on seven and four teeth. Ann Hum Biol. 1976;3(5):411-21. doi: 10.1080/03014467600001671.
17. 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.
18. Saxena S. Age estimation of Indian adults from orthopantomographs. Braz Oral Res. 2011;25(3):225-9. doi: 10.1590/s1806-83242011005000009.
19. Kvaal SI, Kolltveit KM, Thomsen IO, Solheim T. Age estimation of adults from dental radiographs. Forensic Sci Int. 1995;74(3):175-85. doi: 10.1016/0379-0738(95)01760-g.
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(2):62-5. doi: 10.1016/j.jflm.2010.12.004.
21. 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. doi: 10.1007/s00414-004-0492-x.
22. 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(2-3):208-12. doi: 10.1016/j.forsciint.2004.08.017.
23. 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(1-3):128.e1-6. doi: 10.1016/j.forsciint.2009.09.011.
24. 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. doi: 10.1016/j.forsciint.2011.07.028.
25. Dawson B, Trapp RG. Basic & Clinical Biostatistics. 4th ed. New York: Lange Medical Books, McGraw-Hill; 2004.
26. Babshet M, Acharya AB, Naikmasur VG. Age estimation in Indians from pulp/tooth area ratio of mandibular canines. Forensic Sci Int. 2010;197(1-3):125.e1-4. doi: 10.1016/j.forsciint.2009.12.065.
27. 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(1-3):209.e1-5. doi: 10.1016/j.forsciint.2010.08.017.
28. Jagannathan N, Neelakantan P, Thiruvengadam C, Ramani P, Premkumar P, Natesan A, et al. Age estimation in an Indian population using pulp/tooth volume ratio of mandibular canines obtained from cone beam computed tomography. J Forensic Odontostomatol. 2011;29(1):1-6.
29. Kvaal S, Solheim T. A non-destructive dental method for age estimation. J Forensic Odontostomatol. 1994;12(1):6-11.
30. Stavrianos C, Mastagas D, Stavrianou I, Karaiskou O. Dental age estimation of adults: a review of methods and principals. Res J Med Sci. 2008;2(5):258-68.
31. Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. J Can Dent Assoc. 2006;72(1):75-80.
32. Dawood A, Patel S, Brown J. Cone beam CT in dental practice. Br Dent J. 2009;207(1):23-8. doi: 10.1038/sj.bdj.2009.560.
33. Neelakantan P, Subbarao C, Subbarao CV. Comparative evaluation of modified canal staining and clearing technique, cone-beam computed tomography, peripheral quantitative computed tomography, spiral computed tomography, and plain and contrast medium-enhanced digital radiography in studying root canal morphology. J Endod. 2010;36(9):1547-51. doi: 10.1016/j.joen.2010.05.008.
34. Sakhdari S, Mehralizadeh S, Zolfaghari M, Madadi M. Age estimation from pulp/tooth area ratio using digital panoramic radiography. J Islam Dent Assoc Iran. 2015;27(1):19-23.
35. Moshfeghi M, Ghojazadeh M, Khalili Sadrabad Z, Shadkar MM, Shadkar Z. Age estimation in an Iranian population based on pulp/tooth area ratio (PTR). Res J Med Sci. 2014;8(3):116-20.
36. Haghanifar S, Ghobadi F, Vahdani N, Bijani A. Age estimation by pulp/tooth area ratio in anterior teeth using cone-beam computed tomography: comparison of four teeth. J Appl Oral Sci. 2019;27:e20180722. doi: 10.1590/1678-7757-2018-0722.
37. 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(2):123-8. doi: 10.1007/s00414-008-0268-9.
38. Mandojana JM, Martin-de las Heras S, Valenzuela A, Valenzuela M, Luna JD. Differences in morphological age-related dental changes depending on postmortem interval. J Forensic Sci. 2001;46(4):889-92. doi: 10.1520/jfs15063j.
39. Ritz-Timme S, Cattaneo C, Collins MJ, Waite ER, Schütz HW, Kaatsch HJ, et al. Age estimation: the state of the art in relation to the specific demands of forensic practise. Int J Legal Med. 2000;113(3):129-36. doi: 10.1007/s004140050283.