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Age estimation from morphometric features of maxillary central incisors using CBCT images

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Abstract

Background Forensic dentistry is crucial in human identification, with dental age estimation being a key component of this process. The deposition of secondary dentin over an individual's lifetime, along with the resulting changes in tooth anatomy, serves as an important factor in age estimation. The objective of this study was to develop regression equations for estimating age in adults based on linear measurements and ratios obtained from axial, sagittal, and coronal planes of the maxillary central incisors in the Iraqi subpopulation using cone beam computed tomography (CBCT).

Methods In this retrospective cross-sectional study, Multiplanar measurements of 400 maxillary central incisors from subjects ranging in age from 18 to 84 years were taken for a sample of 200 CBCTs. The data were analyzed using independent Student's t-test, Mann-Whitney test, and Spearman's and Pearson's correlation coefficients to determine the strength of correlations. Multiple regression analysis was performed to predict age, and a p-value of ≤ 0.05 was considered statistically significant.

Results The age range of the participants was 18–84 years. The results revealed a statistically significant difference in age between male and female samples ($p = 0.018$). Consequently, separate age estimation equations were developed for each sex. In males, the equation derived from multiplanar linear measurements demonstrated a standard error of estimate (SEE) of ± 10.84 years, with a coefficient of determination (R^2) of 0.49. In contrast, the equation for females, based on multiplanar measurements, yielded a SEE of ± 11.11 years and an R^2 value of 0.393.

Conclusions Based on the findings of this study, dental morphometric measurement of maxillary central incisors using CBCT was found to be an acceptable method for age estimation especially for identification of unknow human remains. Horizontal measurements improve the accuracy of age estimate equations.

Keywords Age estimation, Cone beam computed tomography, Dental morphometry, Forensic dentistry

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Background

Determining age is a critical aspect in the field of forensics and anthropology. It holds particular significance in reconstructing the biological profile of unidentified human remains by narrowing the search for identity. Furthermore, this procedure is routinely employed in situations such as estimating the age of offenders, terrorists, and refugees with missing or outdated birth records. Among various methods, dental age estimation offers a notable advantage compared with other parts of the skeletal structures, as teeth are far less influenced by genetics, nutritional, and hormonal factors [1].

In the field of forensic science, teeth play a crucial role in the identification of unknown human remains because their high mineral content enables them to withstand extreme conditions, and they are not affected by external factors, making them commonly found in almost all forensic investigations involving human remains. Additionally, the literature indicates that teeth provide reliable indicators, contributing to accurate age estimation. As a result, teeth are regarded as a valuable resource for determining age [2].

As individuals age, the pulp chamber reduces in size due to the continuous deposition of secondary dentin, making it a key indicator of aging. Research suggests that dental dimensions for age estimation can be determined using two-dimensional (2D) images based on linear measurements of the pulp-to-tooth ratio [3]. While 2D images provide precise measurements of tooth morphometry in various directions, they cannot accurately reflect the true morphology of a tooth. To address this limitation, three-dimensional (3D) radiographs have proven effective, offering comprehensive information about teeth, including complete measurements such as the shape of the pulp chamber and its age-related changes [4].

The 3D radiographic technique involves segmenting part of an object into very thin slices, typically ranging from 0.13 to 1 mm in thickness. This high-resolution method provides highly accurate measurements of the tooth and pulp's dimensions and shape. These morphometric measurements enable scholars to evaluate the changes in the size of the pulp caused by the deposition of secondary dentin as a person ages. This age-related phenomenon of the dental pulp can be used to establish a relationship with the chronological age [5].

Although researchers have widely used various methods to evaluate changes in tooth structure for estimating age, such as histological, biochemical, and molecular techniques, most of these methods are invasive, as they require tooth extraction. In contrast, radiographic assessment is a non-invasive technique that has become a widely accepted and preferred method for age estimation [6].

The radiographical method entails a process that goes through multiple phases to gain a proper result. These phases include the processing of the image by segmentation, feature extraction, and classification, either categorical or numerical. In the case of categorical classification, the procedures include determining individuals' age within a range, whereas the numerical include providing the exact ages. The success of each method depends on the compatibility of the tooth dimension [7].

Numerous studies have employed the pulp-to-tooth ratio obtained from CBCT radiographs for age estimation [8–11]. However, to the best of our knowledge, this methodology has not yet been applied to estimate age in the subpopulation of Iraq. Accordingly, this study utilized multiplanar CBCT images to develop regression equations based on linear measurements and proportional ratios of the tooth and pulp to estimate age in a sample from this population. The null hypothesis of this study posits that there is no statistically significant correlation between morphometric linear measurements derived from CBCT images of maxillary central incisors and the chronological age of individuals in the sample of the Iraqi subpopulation.

Materials and methods

Study design

The Ethics Committee of the College of Dentistry at the University of Sulaimani granted ethical approval for this study (Approval No. 144/23; issued on 14 February 2023), informed consent was waived by the committee mentioned above, and all radiographic data were fully anonymized before the analysis was conducted. This retrospective cross-sectional study was conducted from April 2023 to August 2024, during which a total of 381 CBCTs were scanned from the archive of the FOTON Maxillofacial Imaging Center in Sulaimaniyah City, Kurdistan Region, Iraq, covering the period from 2020 to 2022; the radiographs were originally performed for treatment planning of various dental procedures.

Two hundred radiographs were included in this study according to the following criteria: radiographs belonging to subjects over the age of 18 years with both maxillary central incisors present in the CBCT without caries, fracture, and free from dental restoration, while exclusion criteria were blurred radiographs or central incisors that were malposed, showed signs of root canal treatment, apical periodontitis, other bone lesions, root resorption, calcified roots, or evidence of prior orthodontic treatment.

Sample size calculation.

In this study, the sample size was calculated using G*Power version 3.1.9.4 developed by Heinrich-Heine-Universität Düsseldorf, Germany with the following parameters:

- Statistical Test: Means: Difference from constant (one sample case).
- Effect Size (d): 0.2 (small effect size).
- Significance Level (α): 0.05 (two-tailed).
- Power (1 – β): 0.8 (80%).

The resulting total sample size:

- The critical t-value was determined to be 1.97202.
- The noncentrality parameter (δ) was 2.8213.
- The degrees of freedom (df) were 198.
- The total sample size required for this analysis was calculated as 199 participants.
- The actual power achieved with these parameters was 0.8017.

Image analysis and measurements

CBCT scans were obtained using the Carestream CS9600 manufactured by Carestream Dental, Atlanta, GA, USA, with the following parameters: a 10 × 10 cm field of view, 120 kVp exposure, and a 6.3 mA over a duration of 20 s. DICOM data were accessed, and linear measurements were performed using the CS3D Imaging viewer software developed by Carestream Dental, Atlanta, GA, USA, on a Lenovo Legion 5 laptop manufactured by Quarry Bay, Hong Kong.

Linear measurements of 400 maxillary central incisors (200 left and 200 right) were acquired in multiplanar views (axial, sagittal, and coronal planes). For the sagittal plane, the slice displaying the maximum palato-labial distance at the CEJ level of each maxillary central incisor (left and right) was selected, and the following measurements were taken at the CEJ level:

1. Palato-labial distance of the tooth on the sagittal plane (PLTS), the distance between the most palatine point of the tooth and the most labial point of the tooth.
2. Palato-labial distance of the pulp on the sagittal plane (PLPS), the distance from the most palatine point of the pulp to the most labial point of the pulp.

The following vertical measurements on the sagittal plane were obtained:

1. Crown length (CL), the linear distance from the incisal edge measured perpendicularly to the PLTS line.
2. The height of the pulp chamber (HPC): the perpendicular linear distance between the highest point of the pulp horn (PH) and of PLTS line.

For the analysis of pulp and tooth morphometry in the coronal plane, the axis was aligned with the long axis of the tooth on the sagittal plane. Subsequently, the coronal slice displaying the maximum mesiodistal width of the crowns of the central incisor was selected, and all measurements of the coronal plane were recorded based on this reference.

1. Coronal pulp width at the level of the PH (CPWPH), the distance between the most mesial and the most distal end of the pulp at the incisor end of the PH.
2. Coronal tooth width at level PH (CTWPH), the distance between the most mesial and the most distal point of the tooth at the incisor end of the pulp cavity.
3. Coronal tooth width at level CEJ (CTWCEJ) is the distance between the most mesial and distal points of the central incisor.
4. Coronal pulp width at level CEJ (CPWCEJ) is the extent between the most mesial and the most distal end of the pulp.

On the axial plane, the final slice displaying enamel was selected, and the following measurements were taken at the level of the CEJ:

1. Pulp width on the axial plane (PWA), the linear distance extending between the most mesial point and the distal end of the pulp cavity.
2. Palato-labial distance of the pulp on the axial plane (PLPA), the measurement between the most labial and palatine end of the pulp.
3. Palato-labial distance of the tooth on the axial plane (PLTA), the distance from the most labial point of the tooth to the most palatal point of the incisor crossing the pulp chamber.
4. Tooth width on the axial plane (TWA), the linear distance from the most mesial to the distal end of the tooth by crossing the pulp chamber. Figure 1 shows all linear measurements obtained from the sagittal, axial, and coronal planes.

Additionally, pulp to tooth width ratio at the level of CEJ on the coronal plane (CPTRCEJ), pulp to tooth width ratio at the level of PH on the coronal plane (CPTRPH), palato-labial distance of the pulp to palato-labial distance of the tooth ratio on the sagittal plane (PLPTRS), and pulp to crown length ratio on the sagittal plane (PCLRS) were calculated by using Microsoft Excel 2021, developed by Microsoft Corporation, Redmond, WA, USA.

Reliability test

All measurements were conducted twice by a single examiner with over 10 years of experience in analyzing digital radiographs. The intraclass correlation coefficient (ICC) ranges from 0 to 1. Values below 0.5 suggest poor

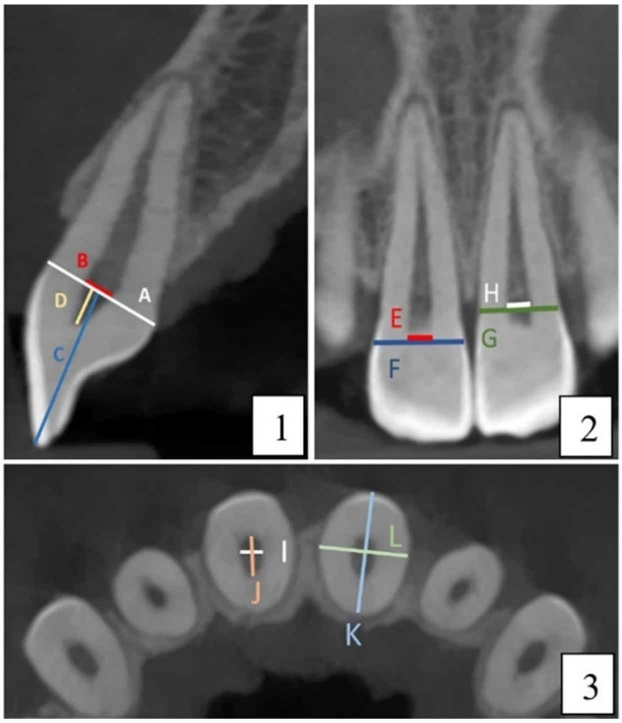

Fig. 1 Linear measurements were used in this study. 1. On the sagittal plane **A**. Palato-labial distance of the tooth at level CEJ, **B**. Palato-labial distance of the pulp at level CEJ, **C**. Crown length, and **D**. The height of the pulp chamber. 2. The linear measurements of the coronal plane, **E**. Coronal pulp width at the level of the PH, **F**. Coronal tooth width at level PH, **G**. Coronal tooth width at level CEJ, **H**. Coronal pulp width at level CEJ. 3. The measurements of the axial plane, at the CEJ level: **I**. Pulp width, **J**. Palato-labial distance of the pulp, **K**. Palato-labial distance of the tooth, **L**. Tooth width

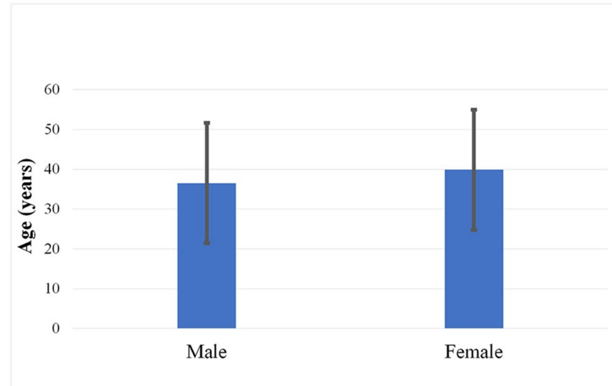

Fig. 2 Mean ± SD age of male and female samples

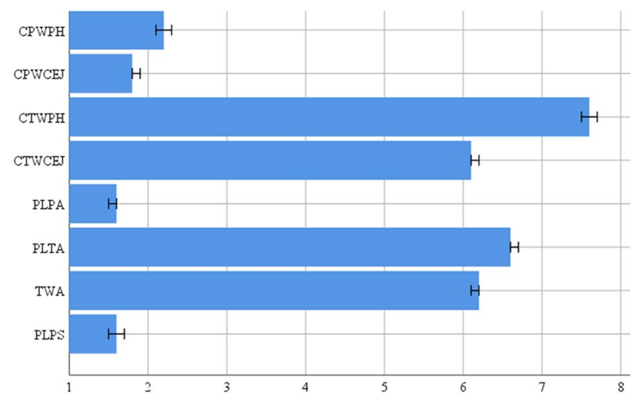

Fig. 3 The mean ± SD of normally distributed variables

reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 reflect good reliability, and values above 0.9 signify excellent reliability [12].

Statistical analysis

All variables obtained from 400 maxillary central incisors on both the right and left sides were subjected to statistical analysis using the Statistical Package for Social Sciences (SPSS), version 26, developed by IBM Corporation, Armonk, NY, USA. Data normality was evaluated with the Kolmogorov-Smirnov test. Based on the results, an independent Student's t-test was used to compare the means of parametric data, while the Mann-Whitney test was applied to compare the mean ranks of nonparametric data. The Spearman's and the Pearson correlation coefficients were calculated to determine the strength of correlations. Multiple regression analysis was performed to predict age, with age serving as the dependent variable. A p-value of ≤ 0.05 was considered statistically significant. Additionally, the intraclass correlation coefficient was used to evaluate the reliability of the measurements.

Results

Two hundred out of 381 CBCTs were included in this study according to the inclusion and exclusion criteria; the age range of the samples was 18–84 years. The average age of all samples was 38.18 years with a standard deviation (SD) of 14.7 and 36.5 ± 15.1 years for the male samples, while that of female samples was 39.9 ± 14.1 years. The result of the independent Student's t-test revealed a statistically significant difference between males and females ($p = 0.018$). The mean ± SD ages of both sexes are illustrated in Fig. 2.

The intraclass correlation coefficient results demonstrated excellent intra-observer reliability, with all parameters showing reliability scores above 0.95, except for PLTA, which scored 0.80. The Kolmogorov-Smirnov test revealed that the variables PLTS, HPC, CL, PWA, PTWRA, PLPTRA, CPTRCEJ, CPTRPH, PLPTRS, and PCLRS followed a normal distribution. In contrast, the variables PLPS, TWA, PLTA, PLPA, CTWCEJ, CTWPH, CPWCEJ, and CPWPH followed non-parametric distribution. As a result, both parametric and non-parametric tests were applied to analyze the study variables. The mean ± SD of parametric data is shown in Fig. 3, while

Fig. 4 illustrates the median and interquartile range (IQR) of non-parametric data.

The results of the independent Student's t-test indicated no significant differences between the right and left sides for the normally distributed data, with the exception of PLPTRA ($p = 0.004$), which was the only parametric variable that demonstrated a statistically significant difference between the two sides. Similarly, the results of the Mann–Whitney U test showed no significant differences for any of the non-parametric variables between the right and left sides, except for PLPA, which exhibited a statistically significant difference ($p = 0.01$). The mean ± SD for all parametric data, along with the independent Student's t-test results, are presented in Table 1, while Table 2 displays the median (IQR) and the results of the Mann–Whitney U test.

The Pearson correlation coefficient test results indicated that all normally distributed variables exhibited a strong, statistically significant inverse correlation with age in both sexes ($P = 0.001$), with the exception of PLTS, which showed no significant correlation ($P = 0.22$). The Pearson correlation coefficient (R) values and P values for all normally distributed variables in both sexes are displayed in Table 3.

The Spearman correlation coefficient test results indicated that all non-parametric variables exhibited a strong, statistically significant inverse correlation with age in both sexes, with the exception of TWA and CTW-CEJ, which showed no significant correlation (P value of 0.842, 0.219 respectively). The Spearman correlation coefficient (rho) values and P values for all non-parametric variables in both sexes are presented in Table 4.

All the variables significantly correlated with the age of the male samples were entered into a multiple regression model. The males' multiple regression model results showed that PCLRS, CPWPH, and PLPA were the best age-estimated predictors for the male samples. The models of age estimation, predictors, R, adjusted R2, and SEE for the male samples are presented in Table 5.

The predictions from the models are outlined in the following equations:

In the first model, the equation to estimate age is:

Age = 68.043 – (73.665 * PCLRS)

Where 68.043 represents the intercept, and – 73.665 is the coefficient for PCLRS. For the second model, the equation for predicting age is:

Age = 71.207 – (51.299 * PCLRS) – (5.176 * CPWPH)

Where 71.207 is the intercept, -51.299 is the coefficient for PCLRS, and – 5.176 is the coefficient for CPWPH.

The equation for predicting age in the third model is:

Age = 76.395 –(43.881 * PCLRS) – (4.658 * CPWPH) – (5.844 * PLPA)

Where 76.395 is the intercept, -43.881 is the coefficient for PCLRS, -4.658 is the coefficient for CPWPH, and – 5.844 is the coefficient for PLPA. Figure 5 illustrates the correlation between the real and the predicted age of the male samples.

For the female samples all statistically significant variables correlated with age were analyzed by multiple regression model and the results indicated that PLPA and PCLRS were the best predictors. The results of the multiple regression analysis for the female samples are presented in Table 6.

For model 1, the equation is based only on PLPA:

Age = 72.628 – (20.708 * PLPA)

Where the intercept is 72.628, and the coefficient of PLPA is – 20.708.

For the second model, the equation includes both PLPA and PCLRS:

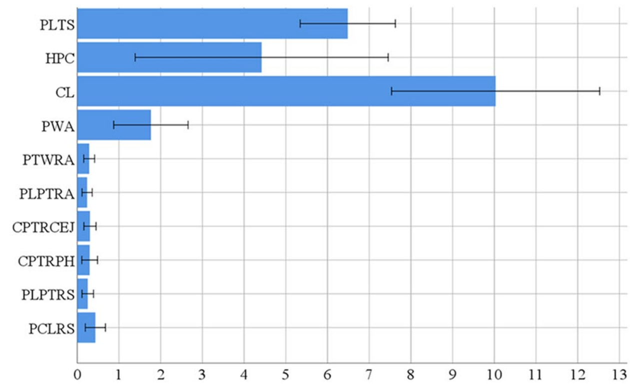

Fig. 4 The median ± IQR of non-parametric variables

Table 1 Means ± SD of normally distributed studied variables by tooth side and independent student's t-test results

Variable	Tooth side	Mean ± SD	*P* value*
PLTS (mm)	Left	6.48 ± 0.57	0.88
	Right	6.49 ± 0.57	
HPC (mm)	Left	4.43 ± 1.54	0.73
	Right	4.37 ± 1.56	
CL (mm)	Left	10.09 ± 1.27	0.36
	Right	9.97 ± 1.22	
PWA (mm)	Left	1.74 ± 0.45	0.3
	Right	1.78 ± 0.45	
PTWRA	Left	0.2817 ± 0.066	0.24
	Right	0.2894 ± 0.065	
PLPTRA	Left	0.2266 ± 0.06	0.004
	Right	0.2444 ± 0.061	
CPTRCEJ	Left	0.3018 ± 0.076	0.64
	Right	0.3053 ± 0.07	
CPTRPH	Left	0.2944 ± 0.093	0.66
	Right	0.2986 ± 0.096	
PLPTRS	Left	0.245 ± 0.068	0.1
	Right	0.2564 ± 0.069	
PCLRS	Left	0.4328 ± 0.125	0.88
	Right	0.431 ± 0.123	

* Calculated by independent Student's t-test

Table 2 Median and IQR of non-parametric variables by tooth side and the results of Mann-Whitney U test

Variable	Tooth side	Median (IQR)	*P* value*
PLPS (mm)	Left	1.6 (0.7)	0.62
	Right	1.6 (0.7)	
TWA (mm)	Left	6.2 (0.7)	0.36
	Right	6.15 (0.7)	
PLTA (mm)	Left	6.6 (0.9)	0.48
	Right	6.7 (0.9)	
PLPA (mm)	Left	1.5 (0.6)	0.01
	Right	1.6 (0.6)	
CTWCEJ (mm)	Left	6.1 (0.7)	0.92
	Right	6.1 (0.77)	
CTWPH (mm)	Left	7.6 (1.07)	0.69
	Right	7.6 (1.15)	
CPWCEJ (mm)	Left	1.9 (0.7)	0.76
	Right	1.8 (0.68)	
CPWPH (mm)	Left	2.2 (1.3)	0.69
	Right	2.2 (1.2)	

* Calculated by Mann-Whitney U test

Table 3 Correlation between age and the normally distributed studied variables among males and females

Variables	Male		Female	
	R	*P* value*	*R*	*P* value*
PLTS	-0.132	0.192	-0.229	0.22
HPC	-0.645	0.001	-0.56	0.001
CL	-0.432	0.001	-0.389	0.001
PWA	-0.317	0.001	-0.38	0.001
PTWRA	-0.34	0.001	-0.38	0.001
PLPTRA	-0.443	0.001	-0.42	0.001
CPTRCEJ	-0.343	0.001	-0.412	0.001
CPTRPH	-0.55	0.001	-0.394	0.001
PLPTRS	-0.3	0.002	-0.405	0.001
PCLRS	-0.647	0.001	-0.529	0.001

* Calculated by Pearson correlation coefficient

Table 4 Correlation between age and the non-parametric studied variables among males and females

Variables	Male		Female	
	rho	*P* value*	rho	*P* value*
PLPS	-0.337	0.001	-0.466	0.001
TWA	0.083	0.412	-0.02	0.842
PLTA	-0.216	0.031	-0.298	0.003
PLPA	-0.529	0.001	-0.583	0.001
CTWCEJ	0.055	0.589	-0.124	0.219
CTWPH	-0.62	0.001	-0.361	0.001
CPWCEJ	-0.378	0.001	-0.441	0.001
CPWPH	-0.633	0.001	-0.5	0.001

* Calculated by Spearman correlation coefficient

Table 5 The output of multivariant linear regression analysis of predictors of age in male samples

Model	Predictor(s)	*R*	Adjusted R2	SEE (± Years)	*P* value*
1	PCLRS	0.651	0.418	11.56	0.001
2	PCLRS, CPWPH	0.694	0.47	11.03	0.001
3	PCLRS, CPWPH, PLPA	0.71	0.488	10.84	0.001

* Multivariant linear regression analysis

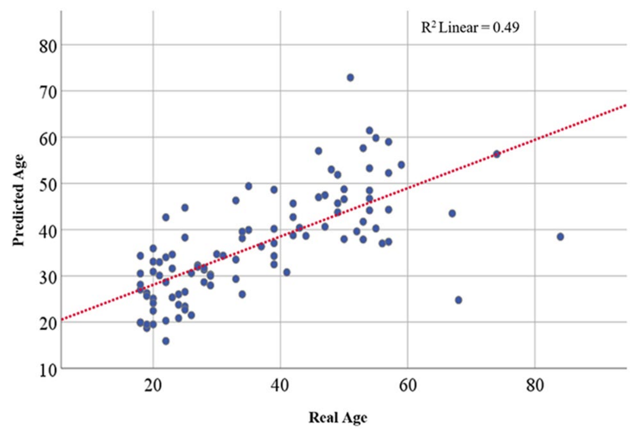

Fig. 5 Correlation between the predicted and the real age of the male samples

Table 6 The results of multivariate linear regression analysis for predicting age in female samples

Model	Predictor(s)	*R*	Adjusted R2	SEE (± Years)	*P* value*
1	PLPA	0.548	0.294	11.86	0.001
2	PLPA, PCLRS	0.627	0.38	11.11	0.001

* Multivariant linear regression analysis

$$Age = 82.908 - (14.435 * PLPA) - (46.34 * PCLRS)$$

Where the intercept is 82.908, the coefficient of is PLPA −14.435, and the coefficient of PCLRS is −46.34. The correlation between real and estimated age is presented in Fig. 6.

Discussion

Dental age estimation is considered the most reliable method for determining age in the absence of a formal birth record [13]. Methods for estimating age include an overall physical examination, hand-wrist skeletal development viewed on radiographs, cervical vertebral maturation, and sternoclavicular joint development [14]. However, among all body parts used for age estimation, teeth are the least impacted by taphonomic processes. This exceptional durability often makes them the only remains available for analysis in certain cases [15].

Radiography plays a significant role in forensic dentistry, primarily in establishing identification. It is also valuable for determining the age of a minor victim and assessing attributes such as sex and ethnicity [16]. Several

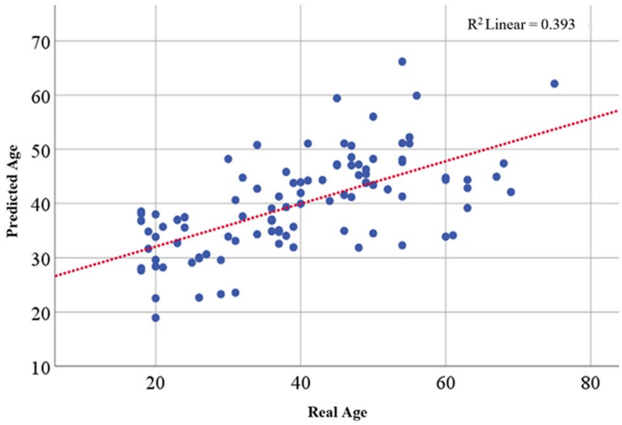

Fig. 6 Correlation between the predicted and the real age of the female samples

types of radiographic images can aid in age determination, including intraoral periapical radiographs, lateral oblique radiographs, cephalometric radiographs, panoramic radiographs, digital imaging, and advanced imaging technologies [17]. The introduction of CBCT offers new possibilities for obtaining 3D views of teeth, providing high-quality images with a low radiation dose. CBCT has several advantages over conventional radiographic techniques, such as controlled magnification, the absence of superimposition and geometric distortion, and the ability to display multiplanar and 3D images, enhancing structure visualization and diagnostic accuracy [18, 19]. Various studies have utilized CBCT for age estimation, reporting a wide range of accuracy [11, 20].

In this study, we have chosen the maxillary central incisor to estimate the age because it is one of the most commonly preserved teeth in older individuals. Additionally, its pulp has a simple structure, considerable size, and few anatomical variations, making it easier to measure compared to other teeth [2, 21]. This study aimed to develop a formula for estimating age in male and female adults of the Iraqi subpopulation by using linear measurements of the right and left maxillary central incisors in the axial, sagittal, and coronal planes.

The results of this study indicate that there is no significant difference in the mean values of morphometric measurements between the right and left sides within the sample of this study, except for PLPTRA and PLPA measurements, which are in line with these studies [22, 23], while this result disagreed with the results of other studies [24, 25]. Such variation could be due to environmental influences on the tooth size. Variations in food resources exploited by different populations have been explained as one such environmental cause. Other scholars have suggested the interference of cultural factors with biological forces [26, 27].

In addition to linear measurements, CBCT allows for the extraction of volumetric and surface area data. These parameters have been employed by researchers to estimate chronological age. For instance, Abdinian et al. [28] used volumetric measurements of the maxillary central incisors and reported a SEE of ± 11.98 years. Bhogte et al. [29] used another methodology to estimate age from CBCT images of maxillary central incisors by analyzing the pulp-to-tooth area ratio and achieved SEEs of ± 9.6, ± 13.3, and ± 12.6 years in the axial, sagittal, and coronal planes, respectively. Although these approaches yield SEEs comparable to those obtained in the present study, linear measurements offer a more practical alternative, as they eliminate the need for segmentation and reduce processing time, and have a high level of accuracy and reproducibility [30].

In the current study, the null hypothesis was rejected because our findings showed that all linear measurements across all planes, in both sexes, were significantly correlated with chronological age of the samples, especially PCLRS, CPWPH, and PLPA in males and PLPA and PCLRS in females, which were the best indicators to estimate age. Our findings align with previous studies that effectively used root canal diameter as an indirect method for quantifying secondary dentin deposition [2, 31]. Several researchers have noted that dentinal thickness increases with age more prominently along the pulp walls than along the pulp roof, and our results agree with this observation [32, 33]. In addition, the results of this study indicated that horizontal measurements provided better R2 and SEE values compared to vertical measurements. These results were consistent with most studies that employed CBCT for age estimation [34–36], with the exception of Lee et al. [37]. Consequently, we concluded that horizontal dimensions are more reliable for age estimation.

However, the fact that vertical measurements are rarely useful for age estimation might be due to the confounding effect of external factors such as attrition, occlusion type, or behavioral habits, and teeth attrition bears a stronger relation to diet and habits [2, 38].

Based on our population, the final formula for estimating age showed a strong positive correlation between chronological and estimated age. However, this formula may vary across populations, as factors such as nutritional and hormonal changes, and certain systemic diseases can influence pulp dimensions [2]. As a result of those factors, several other studies have proposed different formulas for estimating age in their specific populations [2, 39–41]. Additionally, secondary dentin deposition is considered to vary by tooth type, sex, and population [42]. Apart from secondary dentin deposition, pulp cavity dimensions may also be modified by local factors, such as tertiary dentin deposition at the chamber roof due to decay or restorations. To avoid this problem, we have used only sound teeth, following Kvaal's instructions [43, 44].

A study conducted by Trottier et al. [45], which evaluated a total of 227 teeth (including the upper and lower canines, central, and lateral incisors on both sides) from 66 individuals in a Northeastern Ontario population using CBCT, reported results consistent with those of the current study, with a SEE ranging from ± 10.11 to ± 14.98 years. Similarly, findings from a study by Patel et al. [46], who analyzed 185 CBCT images of Indian individuals aged 14–64 years by evaluating the maxillary central incisors, showed that age could be estimated with an SEE of ± 11.36 years in the sagittal plane and ± 11.23 years in the coronal plane. The SEE values reported in these studies align with those of the current study, indicating the potential for cross-population applicability.

In this study, the SEE for the male samples was ± 10.84 years and ± 11.11 years for the female samples. These values are relatively high and are not reliable for age estimation in living individuals who lack a birth certificate. However, this age estimation method could be useful in creating a biological profile of unknown human remains and assisting in the identification process by narrowing the search for identity, especially in cases where only small amounts of human remains are found. This is due to the fact that teeth are the hardest tissues in the body that can withstand harsh environmental conditions such as fire, airplane crashes, and other extreme forensic scenarios.

The primary limitation of this study lies in its retrospective nature, as the teeth could not be evaluated clinically, and obtaining patient history was not possible, as pulp calcification may be influenced by various factors such as lifestyle, periodontal disease, and systemic disorders, which affect morphometry of the pulp [47–49]. Moreover, this study focused exclusively on morphometric measurements of the maxillary central incisors, while other teeth were not evaluated.

Conclusion

The findings demonstrate a significant correlation between the linear morphometric measurements of the maxillary central incisors, obtained from CBCT images, and chronological age. This suggests that such measurements may serve as a useful method for age estimation, aiding in the identification of unknown human remains through the development of a biological profile. Among the parameters analyzed, PLPA, PCLRS, and CPWPH were identified as the most accurate indicators for this purpose.

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Author contributions
SHK and TMF did the investigation, resources collection, data curation, and project administration, as well as composed the original draft. MSA did the supervision and methodology verification, as well as supported the reviewing and editing process of manuscript. MTAB formal analysis, reviewing and editing process of manuscript. All authors have read and approved the manuscript. RMT did the conceptualization, supervision, validation, and visualization, as well as managed the reviewing and editing process of manuscript. KOA supported the reviewing and editing process of manuscript.

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Data availability
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The Ethics Committee of the College of Dentistry at the University of Sulaimani granted ethical approval for this study (Approval No. 144/23; issued on 14 February 2023), informed consent was waived by the committee mentioned above, and all radiographic data were fully anonymized before the analysis was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki for medical research involving human participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Zahid H, Nausheen N, Nisar P, Salam S, Ali A, Siddique AB, et al. The relationship between age and pulp cavity size using Cone-Beam computed tomography. Ibnosina J Med Biomedical Sci. 2023;15:037–41.
2. Santos MA, Muinelo-Lorenzo J, Fernández-Alonso A, Cruz-Landeira A, Aroso C, Suárez-Cunqueiro MM. Age Estimation using maxillary central incisor analysis on cone beam computed tomography human images. Int J Environ Res Public Health. 2022;19.
3. 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;7:158–62.
4. Kazmi S, Shepherd S, Revie G, Hector M, Mânica S. Exploring the relationship between age and the pulp and tooth size in canines. A CBCT analysis. Australian J Forensic Sci. 2022;54:808–19.
5. Merdietio Boedi R, Shepherd S, Oscandar F, Mânica S, Franco A. Regressive changes of crown-root morphology and their volumetric segmentation for adult dental age Estimation. J Forensic Sci. 2022;67:1890–8.
6. Bansal V, Konidena A, Nagi R, Kataria APS, Yumnam N, Farooq F. Correlation of pulp-to-tooth area ratio with age and gender using CBCT of maxillary central incisor and canine: A comparative study. J Indian Acad Oral Med Radiol. 2022;34:87–94.
7. Ataş İ, Özdemir C, Ataş M, Doğan Y. Forensic dental age Estimation using modified deep learning neural network. Balkan J Electr Comput Eng. 2023;11:298–305.
8. Gulsahi A, Kulah CK, Bakirarar B, Gulen O, Kamburoglu K. Age Estimation based on pulp/tooth volume ratio measured on cone-beam CT images. Dentomaxillofacial Radiol. 2018;47:20170239.
9. Kazmi S, Mânica S, Revie G, Shepherd S, Hector M. Age Estimation using canine pulp volumes in adults: a CBCT image analysis. Int J Legal Med. 2019;133:1967–76.
10. Song Y, Yang H, Ge Z, Du H, Li G. Age Estimation based on 3D pulp segmentation of first molars from CBCT images using U-Net. Dentomaxillofacial Radiol. 2023;52:20230177.

11. 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;135:359–64.
12. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med. 2016;15:155–63.
13. Roberts G, Lucas V, McDonald F. Age Estimation in the living: dental age Estimation-theory and practice. Encyclopedia of forensic and legal medicine: second edition. Elsevier Inc.; 2015. pp. 41–69.
14. Alkandiri F, Karimi A, Draft D, Lucas VS, Roberts G. Dental age estimation: A comparison of three methods of estimating dental age in a population of Kuwaiti children and adolescents. Forensic Sci International: Rep. 2021;3:100214.
15. Limdiwala PG, Shah JS. Age Estimation by using dental radiographs. J Forensic Dent Sci. 2013;5:118–22.
16. Singhal I, Dave A, Arora M, Rai R, Saluja P. A review on dental age Estimation in children and adolescents. J Forensic Sci Med. 2024;10:220–33.
17. Vyas T. Radiographic determination: an upcoming aid in forensic radiology. J Int Clin Dent Res Organ. 2019;11:71–5.
18. Rai A, Acharya AB, Naikmasur VG. Age Estimation by pulp-to-tooth area ratio using cone-beam computed tomography: A preliminary analysis. J Forensic Dent Sci. 2016;8:150–4.
19. Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. Oral Surgery, Medicine O. Oral Pathology, Oral Radiology, and Endodontology. 2008;106:106–14.
20. Merdietio Boedi R, Shepherd S, Manica S, Franco A. CBCT in dental age estimation: A systematic review and meta analysis. Dentomaxillofacial Radiol. 2022;51:20210335.
21. Tan C, Ekambaram M, Yiu CKY. Prevalence, characteristic features, and complications associated with the occurrence of unerupted permanent incisors. PLoS ONE. 2018;13:e0199501.
22. Al-Gunaid T, Yamaki M, Saito I. Mesiodistal tooth width and tooth size discrepancies of Yemeni Arabians: A pilot study. J Orthod Sci. 2012;1:40–5.
23. Otuyemi OD, Noar JH. A comparison of crown size dimensions of the permanent teeth in a Nigerian and a British population. Eur J Orthod. 1996;18:623–8.
24. Khangura RK, Sircar K, Singh S, Rastogi V. Sex determination using mesiodistal dimension of permanent maxillary incisors and canines. J Forensic Dent Sci. 2011;3:81.
25. Al-Khateeb SN, Abu Alhaija ESJ. Tooth size discrepancies and arch parameters among different malocclusions in a Jordanian sample. Angle Orthod. 2006;76:459–65.
26. Sreedhar G, Sumalatha MN, Ramesh G, Nagarajappa R, Murari A, Agrawal A. Dimorphic mandibular canines in gender determination in Moradabad population of Western Uttar Pradesh. J Forensic Dent Sci. 2015;7:32–6.
27. Narang RS, Manchanda AS, Malhotra R, Bhatia HS. Sex determination by mandibular canine index and molar odontometrics: A comparative study. Indian J Oral Sci Vol. 2014;5.
28. Abdinian M, Katiraei M, Zahedi H, Rengo C, Soltani P, Spagnuolo G. Age Estimation based on pulp–tooth volume ratio of anterior teeth in cone-beam computed tomographic images in a selected population: a cross-sectional study. Appl Sci. 2021;11:9984.
29. Bhogte SA, Jois HS, Anusha AV, Pattnaik A, Rana M. Estimation of age by calculating Pulp-to-Tooth area ratio using CBCT in maxillary central incisors: A retrospective Cross-Sectional preliminary analysis on the Hyderabad population. J Indian Acad Oral Med Radiol. 2023;35:246–9.
30. Maroua AL, Ajaj M, Hajeer MY. The accuracy and reproducibility of linear measurements made on CBCT-derived digital models. J Contemp Dent Pract. 2016;17:294–9.
31. Aboshi H, Takahashi T, Komuro T. Age Estimation using microfocus X-ray computed tomography of lower premolars. Forensic Sci Int. 2010;200:35–40.
32. Prapanpoch S, Dove SB, Cottone JA. Morphometric analysis of the dental pulp chamber as a method of age determination in humans. Am J Forensic Med Pathol. 1992;13:50–5.
33. 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.
34. 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.
35. Akay G, Gungor K, Gurcan S. The applicability of Kvaal methods and pulp/tooth volume ratio for age Estimation of the Turkish adult population on cone beam computed tomography images. Australian J Forensic Sci. 2019;51:251–65.
36. Penaloza TYM, Karkhanis S, Kvaal SI, Nurul F, Kanagasingam S, Franklin D, et al. Application of the Kvaal method for adult dental age Estimation using cone beam computed tomography (CBCT). J Forensic Leg Med. 2016;44:178–82.
37. Lee S-M, Oh S, Kim J, Kim Y-M, Choi Y-K, Kwak HH, et al. Age Estimation using the maxillary canine pulp/tooth ratio in Korean adults: A CBCT buccolingual and horizontal section image analysis. J Forensic Radiol Imaging. 2017;9:1–5.
38. Ungar PS. Mammalian dental function and wear: a review. Biosurf Biotribol. 2015;1:25–41.
39. Li M, Chu G, Han M, Chen T, Zhou H, Guo Y. Application of the Kvaal method for age Estimation using digital panoramic radiography of Chinese individuals. Forensic Sci Int. 2019;301:76–81.
40. Babshet M, Acharya AB, Naikmasur VG. Age Estimation in Indians from pulp/tooth area ratio of mandibular canines. Forensic Sci Int. 2010;197:125–e1.
41. Landa MI, Garamendi PM, Botella MC, Alemán I. Application of the method of Kvaal et al. to digital orthopantomograms. Int J Legal Med. 2009;123:123–8.
42. Singh H, Patel V, Razdan RA, Jha D, Nayak P, Nayak S. Secondary dentin as an aid in gender predilection: A forensic study. Dent J Adv Stud. 2021;9:147–50.
43. Paewinsky E, Pfeiffer H, Brinkmann B. Quantification of secondary dentine formation from orthopantomograms—a contribution to forensic age Estimation methods in adults. Int J Legal Med. 2005;119:27–30.
44. Kvaal SI, Kolltveit KM, Thomsen IO, Solheim T. Age Estimation of adults from dental radiographs. Forensic Sci Int. 1995;74:175–85.
45. Trottier M, Keenan S, Fairgrieve SI. Individual age Estimation using pulp-to-tooth area ratio in single-rooted teeth. Can Soc Forensic Sci J. 2024;57:82–95.
46. Patel H, Parikh SJ, Shah JS. Application of Kvaal's age Estimation method in maxillary central incisor: A CBCT study. J Forensic Dent Sci. 2021;13:142–51.
47. Nicklisch N, Schierz O, Enzmann F, Knipper C, Held P, Vach W, et al. Dental pulp calcifications in prehistoric and historical skeletal remains. Annals Anat - Anatomischer Anzeiger. 2021;235:151675.
48. Ricucci D, Siqueira JF, Rôças IN. Pulp response to periodontal disease: novel observations help clarify the processes of tissue breakdown and infection. J Endod. 2021;47:740–54.
49. Nayak M, Kumar J, Prasad LK. A radiographic correlation between systemic disorders and pulp stones. Indian J Dent Res. 2010;21:369–73.

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