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ORIGINAL RESEARCH

AGE ESTIMATION BASED ON PULP / TOOTH VOLUME BY CONE BEAM COMPUTERIZED TOMOGRAPHY IMAGE

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ABSTRACT

Background and Objectives: Accurate age estimation is essential in forensic and clinical dentistry, with the pulp/tooth volume ratio (PTVR) emerging as a promising morphological marker. This study aimed to evaluate the relationship between PTVR and chronological age using cone beam computed tomography (CBCT) in a Kurdish adult population, and to develop a population-specific regression model for age estimation.

Methods: A cross-sectional study was conducted on 246 Kurdish adults aged 16–60 years who underwent CBCT imaging at a dental clinic in Sulaimaniah, Iraq. PTVR was measured in central incisors and canines using standardized CBCT protocols and volumetric analysis software. Stratified random sampling ensured proportional representation across age groups.

Results: A strong, statistically significant negative correlation was found between PTVR and chronological age in both central incisors and canines ($r = -0.94$, $p < 0.001$). Linear regression models demonstrated high predictive accuracy ($R^2 > 0.90$) for age estimation in both sexes. Sex-based differences in PTVR were observed in canines but not in central incisors. The predictive strength of the models varied across age groups, with the highest accuracy in 25-29 years ($R^2 = 0.706$, $P \leq 0.001$) and 55-60 years ($R^2 = 0.654$, $P \leq 0.008$) group.

Conclusion: PTVR measured via CBCT is a highly reliable indicator for age estimation in Kurdish adults, with strong predictive accuracy. The developed regression models can assist in forensic identification and legal documentation, highlighting the importance of population-specific data in forensic odontology.

***Keywords*: Age Determination by Teeth, Pulp Cavity, Secondary Dentin.**

INTRODUCTION

Oral health is closely linked to systemic well-being, with poor dental status associated with conditions such as cardiovascular disease and diabetes (Kaushik et al., 2018). Teeth, essential for mastication and as a barrier to pathogens, undergo significant structural changes throughout life [1]. Humans possess two dentitions: 20 primary teeth and 32 permanent teeth, each with distinct anatomical features [2]. The tooth's crown is covered by enamel, the hardest tissue in the body, while underlying dentin and pulp play critical roles in sensory function and defense [3,4]. With age, secondary dentin deposition reduces pulp chamber volume, compromising regenerative capacity and increasing susceptibility to necrosis [5].

Traditional age estimation in forensic dentistry relied on two-dimensional (2D) radiographs, which are limited by anatomical overlap and distortion, often resulting in inconsistent pulp/tooth ratio (PTVR) measurements [6]. While biochemical methods such as aspartic acid racemization have been explored, their invasiveness limits practical application [7].

The introduction of cone beam computed tomography (CBCT) has revolutionized dental imaging, enabling high-resolution three-dimensional (3D) visualization of pulp and tooth structures with reduced radiation exposure [8, 9]. Studies have demonstrated strong correlations between CBCT-derived PTVRs and chronological age, supporting its use in forensic age estimation [10, 11]. However, challenges remain, including variability in imaging protocols and a lack of population-specific data, particularly for underrepresented groups such as the Kurdish population [12].

Given the scarcity of research on dental age estimation in the Kurdish population and the limitations of previous methods, this study is necessary to provide accurate, population-specific age estimation models. The novelty lies in applying CBCT-based PTVR analysis to a homogeneous Kurdish sample in Sulaimaniah, addressing both single- and multi-rooted teeth. The aim was to establish a reliable, non-invasive method for chronological age estimation, enhancing forensic and clinical applications in this unique demographic.

METHODS AND MATERIALS

Study design and setting

This cross-sectional observational study was conducted at the Family Dental Clinic, Chwarbax Street, Sulaimaniah, Iraq, over a 13-month period (February 2024–March 2025).

Participants

Participants were Kurdish adults aged 16–40 years who underwent CBCT imaging at the clinic for routine dental diagnostics. Eligible individuals were identified through retrospective review of archived scans and prospective recruitment during the study period. Stratified sampling ensured proportional representation across nine age groups (16–19, 20–24, 25–29, 30–34, 35–39, 40-44, 45-49, 50-54, 55-60, years).

A stratified random sampling method was used. Sample size was calculated using G*Power (v3.1.9.7) based on a pilot correlation (r=0.52) between age and PTVR, yielding a minimum of 194 participants (α=0.05, power=80%). Allowing for attrition, 246 participants were included.

Participants were included if they were aged >16 years, self-identified as Kurdish, had at least one fully erupted and intact permanent tooth (excluding third molars), provided high-quality CBCT scans in DICOM format, and gave informed consent for the use of anonymized data. Individuals were excluded if they had dental trauma, caries, or restorations affecting the pulp, a history of orthodontic or periodontal surgery, systemic diseases influencing dentine deposition, previous endodontic treatment on the examined teeth, or poor-quality CBCT images.

Data Collection

CBCT scans were acquired using a standardized protocol (90 kVp, 5 mA, 8.9 s, voxel size 0.2 mm³, FOV 8×8 cm). DICOM files were imported into OnDemand 3D Dental software for segmentation. Individual teeth were isolated in axial, coronal, and sagittal planes. Grayscale thresholding (1,400–3,000 HU for dentine; 200–1,200 HU for pulp) differentiated tissues, with manual refinement to exclude non-tooth structures. 3D reconstructions enabled volumetric measurement of pulp and tooth, and PTVR was calculated as (pulp volume/tooth volume) × 100. Demographic and PTVR data were recorded in a secure, anonymized database.

Ethical Considerations

The study was approved by the Institutional Review Board of the College of Medicine, University of Sulaymaniyah (3170-29/09/2024). Written informed consent was obtained from all participants. Data were anonymized and stored securely, adhering to the Declaration of Helsinki.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics v27. Descriptive statistics summarized age and PTVR. Pearson's correlation assessed the relationship between age and PTVR. Multiple linear regression and one-way ANOVA (with Tukey post-hoc tests) evaluated predictors and group differences. Statistical significance was set at $p<0.05$.

RESULTS

The total number of participants examined was 246, among whom 117 were male and 129 were female. The mean age for males was 36.623 ± 11.594 years, while for females it was 36.379 ± 12.384 years. No statistically significant difference was observed in the mean age between males and females (Table 1).

Table 1. Mean ± (SD) of age by sex in in study participants

Sex	N	Age (Mean ±SD)	Min	Max	P-Value
Male	117	36.623 ± 11.594	16	58	0.873
Female	129	36.379 ± 12.384	16	60	
Total	246	36.495 ± 11.991	16	60	

The overall mean PTVR for central teeth was 0.033 ± 0.014. For central teeth in males, the mean PTVR was 0.033 ±0.013, and for females, it was 0.033±0.014. This difference in the mean PTVR for central teeth between genders was not statistically significant. The overall mean PTVR for canine teeth was 0.040 ± 0.015. In males, the mean PTVR for canine teeth was 0.043 ± 0.016, while in females, it was 0.037 ± 0.013. A notable significant difference was observed in the mean PTVR for canine teeth between genders ($P \leq 0.001$) (Table 2).

Table 2. Mean ± (SD) of PTVR in central and canine tooth by sex in in study participants.

Tooth Type	Total	Male	Female	P
Central	0.033 ± 0.014	0.033 ±0.013	0.033±0.014	0.659
Canine	0.040 ± 0.015	0.043 ± 0.016	0.037 ± 0.013	0.001

Table 3 shows the mean pulp-tooth ratio in central and canine teeth based on the participants' age groups. The most frequent age groups were 40–44 and 45–49 years. For the 45–49 years age group, the mean PTVR for central teeth was 0.022 ± .002, while for canine teeth, it was 0.029 ± 0.002. In the 40–44 years age group, the mean PTVR for central teeth was 0.026 ± 0.003, while for canine teeth, it was 0.034 ± 0.004.

Table 3. Mean ± (SD) of PTVR in central and canine tooth by age group in in study participants.

Age group (year)	N	PTVR (central teeth)	N	PTVR (Canine teeth)
16-19	24	0.057 ± 0.009	24	0.068 ± 0.011
20-24	26	0.049 ± 0.007	26	0.055 ± 0.011
25-29	30	0.043 ± 0.005	30	0.048 ± 0.005
30-34	29	0.034 ± 0.002	29	0.042 ± 0.004
35-39	29	0.031 ± 0.003	29	0.037 ± 0.005
40-44	32	0.026 ± 0.003	32	0.034 ± 0.004
45-49	35	0.022 ± .002	35	0.029 ± 0.002
50-54	26	0.017 ± 0.003	26	0.022 ± 0.005
55-60	15	0.015 ± 0.003	9	0.020 ± 0.009

A strong negative connection was detected between age and PTVR in central teeth among men ($r = -0.94$, $P < 0.001$). A significant negative connection was seen between age and PTVR in male canine teeth ($r = -0.94$, $P < 0.001$). This strong inverse Correlation was consistently observed across all tooth types in males ($r = -0.94$, $P \leq 0.001$). In females, a significant inverse correlation was also observed between age and PTVR in central teeth ($r = -0.94$, $P \leq 0.001$), as well as in canine teeth ($r = -0.92$, $P \leq 0.001$). This significant inverse correlation was similarly evident across all tooth types in females ($r = -0.94$, $P \leq 0.001$) (Table 4).

Table 4. Correlation between age and PTVR by sex.

Tooth Type	Male		Female	
	Pearson Correlation Coefficient	P-value	Pearson Correlation Coefficient	P-value*
Central	- 0.94	0.001	- 0.94	0.001
Canine	-0.94	0.001	-0.92	0.001
Total	-0.94	0.001	-0.91	0.001

*P-value calculated based on Spearman correlation coefficients

The correlation between age and PTVR according to tooth type is presented in Table 5. In central teeth, significant inverse correlations were observed between age groups and PTVR: for the 20–24-year group ($r = -0.446$, $P \leq 0.022$), the 25–25 ($r = -0.729$, $P \leq 0.001$), the 30–34 ($r = -0.466$, $P \leq 0.011$), the 40–44 ($r = -0.417$, $P \leq 0.017$), the 45–49 ($r = -0.438$, $P \leq 0.009$), and the 55–60-year group ($r = -0.687$, $P \leq 0.005$). No notable correlation was found between age and PTVR in the 16–19, 35-39, and 50-54 age groups. In canine teeth, significant inverse correlation were observed between age group 55–60-year and PTVR ($r = -0.685$, $P \leq 0.042$), in other age groups, there was no correlation between age and PTVR.

Table 5. Correlation between age and PTVR by tooth type.

Age group (year)	Central tooth		Canine tooth	
	Pearson Correlation Coefficient	P-value	Pearson Correlation Coefficient	P-value
16-19	0.243	0.253	- 0.285	0.177
20-24	- 0.446	0.022	- 0.090	0.661

25-29	- 0.729	0.001	- 0.147	0.438
30-34	- 0.466	0.011	- 0.171	0.376
35-39	- 0.155	0.422	- 0.223	0.244
40-44	- 0.417	0.017	0.053	0.773
45-49	- 0.438	0.009	- 0.181	0.299
50-54	0.150	0.465	- 0.261	0.198
55-60	- 0.687	0.005	- 0.685	0.042

*P-value calculated based on Spearman correlation coefficients

The PTVR was used to estimate age using a linear regression model. Age and pulp perimeter had a substantial negative association ($P < 0.001$), as shown by the Pearson correlation coefficient between them, which had an R2 value of 0.929. Based on this, the regression line was validated, and the regression equation was utilized for age estimation. Due to the strong association between age and PTVR in central teeth, age estimation was conducted for men ($R^2 = 0.932$, $P \leq 0.001$) and females ($R^2 = 0.927$, $P \leq 0.001$) using the regression equation. Similarly, for canine teeth, age estimation was conducted for males ($R^2 = 0.918$, $P \leq 0.001$) and females ($R^2 = 0.902$, $P \leq 0.001$) based on the regression equation (Table 6).

Table 6. Estimating age in male and female. With the pulp–tooth volume ratio in the related equation of that tooth.

Tooth Type	Male	Female
	Estimating Age	Estimating Age
Central	Y = 36.623 – 62.786 PV/TV	Y = 36.379 – 63.348 PV/TV
Canine	Y = 36.623 – 63.716 PV/TV	Y = 36.379 – 66.207 PV/TV
Total	Y = 36.495 – 63.072 PV/TV	Y = 36.459 – 63.236 PV/TV

Due to the significant correlation between age and PTVR in central and canine teeth, age estimation for different age groups was performed using a regression equation. Age estimation in age groups based on PTVR in central teeth was as follows: In the age group 25-29 years ($R^2 = 0.706$, $P \leq 0.001$), In the age group 45-49 years ($R^2 = 0.403$, $P \leq 0.016$), and the age group 55-60 years ($R^2 = 0.654$, $P \leq 0.008$). Age estimation in age groups based on PTVR in canine teeth was as follows: In the age group 55-60 years ($R^2 = 0.649$, $P \leq 0.059$) (Table 7).

Table 7. Age estimation in age groups. With the pulp–tooth volume ratio in the related equation of that tooth.

Age group (year)	Central tooth	Canine tooth
	Estimating Age	Estimating Age
16-19	Y = 17.333 – 18.253 PV/TV	Y = 17.333 – 19.252 PV/TV
20-24	Y = 22.076 – 25.330 PV/TV	Y = 22.076 – 23.388 PV/TV
25-29	Y = 26.866 – 34.905 PV/TV	Y = 26.866 – 28.743 PV/TV
30-34	Y = 31.965 – 39.576 PV/TV	Y = 31.965 – 33.712 PV/TV
35-39	Y = 37.034 – 38.824 PV/TV	Y = 37.34 – 39.381 PV/TV
40-44	Y = 41.843 – 45.435 PV/TV	Y = 41.843 – 43.305 PV/TV
45-49	Y = 46.685 – 50.652 PV/TV	Y = 46.685 – 49.794 PV/TV
50-54	Y = 51.846 – 52.309 PV/TV	Y = 51.846 – 53.246 PV/TV
55-60	Y = 57.333 – 61.822 PV/TV	Y = 57.333 – 57.976 PV/TV

DISCUSSION

Teeth are recognized as highly resilient to environmental and systemic influences, making them ideal for forensic age estimation, especially when other skeletal markers are compromised [13]. The present study demonstrated a significant negative correlation between PTVR and chronological age in both central incisors and canines among Kurdish adults, confirming that PTVR decreases as age increases [14]. This finding aligns with previous research, which consistently reported an inverse relationship between PTVR and age, supporting the use of secondary dentin deposition as a reliable marker for age estimation [15, 16]

Historically, 2D radiographic methods such as panoramic and periapical radiographs were used for age estimation, but these techniques are limited by image distortion and anatomical overlap [17]. The advent of CBCT has enabled more accurate, three-dimensional assessment of pulp and tooth volumes, overcoming the limitations of 2D imaging [18]. Comparative studies have shown that CBCT-based volumetric analysis provides higher predictive accuracy for age estimation than 2D methods [19].

The use of CBCT in this study provided a significant methodological advantage, as three-dimensional volumetric analysis offers greater accuracy and reproducibility compared to traditional two-dimensional radiographic techniques, which are prone to distortion and anatomical overlap [18]. This is in line with the findings of Mangulkar et al. [19], and Santos et al.[20], who reported that CBCT-based PTVR measurements yield higher predictive accuracy for age estimation than 2D methods. The high coefficient of determination ($R^2 > 0.90$) observed in our regression models further underscores the robustness of volumetric PTVR as an age predictor, echoing results from Anjani et al. [21], and Salma and Abdelfatah [22].

Sex-based differences in PTVR were observed in canine teeth, with males exhibiting higher mean values than females, a trend also reported by Manan et al.[23]. However, no significant sex difference was found in central incisors, which aligns with the findings of Safaei et al. [24], and Shafiei Rad et al. [25]. These results suggest that while sex may influence pulp volume in certain tooth types, central incisors remain a stable marker for age estimation across genders.

Notably, the strength of the correlation between PTVR and age varied across age groups. The association was weaker in younger participants, likely due to greater biological variability and less pronounced secondary dentin deposition in early adulthood [26]. This highlights the need for age-specific calibration of regression models and suggests that volumetric PTVR analysis may be most reliable in middle-aged and older adults.

Overall, this study provided a high-precision, population-specific model for age estimation in Kurdish adults, reinforcing the necessity of tailored approaches that consider genetic and environmental factors. Future research should expand sample diversity and explore advanced modeling techniques to further enhance accuracy.

While focusing on a specific ethnic population allowed for the development of a regionally tailored regression model, this approach limits the generalizability of the findings to other populations. The predictive strength of the regression model varied across age groups, likely due to small sample sizes in certain strata and the non-linear nature of secondary dentin deposition at different life stages. Furthermore, the study did not account for potential confounding factors such as systemic health conditions, subtle prior dental treatments, dietary habits, or orthodontic interventions, which may influence secondary dentin formation and thus affect the accuracy of age estimation models.

CONCLUSIONS

This study demonstrated that the PTVR in central incisors and canines, as measured by CBCT, is a highly reliable and effective parameter for age estimation in adults, showing a strong negative correlation with chronological age. The linear regression models developed exhibited excellent predictive accuracy, confirming PTVR as a valuable tool for forensic and legal age assessment in the Kurdish population. These findings highlight the importance of using population-specific models and support the practical application of CBCT-based PTVR analysis in forensic and anthropological contexts.

DECLARATIONS

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Ethics approval and consent to participate

Not applicable

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