Indian J. Applied & Pure Bio. Vol. 40(3), 2285-2294 (2025). **ISSN: 0970-2091**
A web of Science Journal

Age and gender estimation based on Volumetric assessment of Pulp - A Cone Beam Computerized Tomographic Study

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Abstract

Accurate age and gender estimation plays a pivotal role in forensic investigations, particularly in cases involving unidentified individuals. Dental tissues, especially the pulp-dentine complex, are less susceptible to environmental damage and physiological changes, making them valuable biomarkers. The reduction of pulp volume due to secondary dentine deposition has been shown to correlate strongly with age. Cone Beam Computed Tomography (CBCT) offers a non-invasive and high-resolution imaging modality for evaluating these changes in three dimensions.The aim is to estimate age and gender by assessing pulpal volume of maxillary central incisors and canines using CBCT imaging.

A retrospective study of 123 CBCT scans (ages 20–70) was conducted using ONDEMAND 3D software. Healthy, fully erupted maxillary central incisors and canines were analyzed for pulp volume (mm^3). Statistical tools included t-tests, ANOVA, Pearson's correlation, and linear regression.

Pulp volume had a strong negative correlation with age (Central Incisor r = -0.937; Canine r = -0.944). Regression equations for Central Incisor: Age = 88.773 – 2.195 × Pulp Volume, Canine: Age = 115.669 – 2.224 × Pulp Volume. Age prediction was more accurate in younger groups, with canines showing better consistency across all ages. Gender differences in pulp volume were not statistically significant.

CBCT-based pulp volume measurement is a reliable, non-invasive tool for age estimation, especially with maxillary canines.

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Though gender-based differences exist, they lack statistical significance. Further research with broader samples is recommended.

Key words : Pulp volume, Cone-Beam Computed Tomography, Age determination by teeth, Forensic Imaging, Upper Central Incisor, Cuspid, Gender identify.

In forensic investigations, determining age and sex is crucial for developing an individual's biological profile.[5] Age estimation plays a significant role in human identification, whether dealing with intact remains or fragmented bodies, by narrowing down the pool of potential matches within a given population.[6] Similarly, sex determination is essential, particularly in cases involving skelet al remains. Teeth, are more resistant to external influences because of their enamel and unique chemical composition.

Techniques based on biochemical changes in teeth, such as aspartic acid racemization, are often time-intensive, complex, and destructive, making them less commonly used. Conversely, the pulp-dentine complex undergoes age-related changes, primarily reflected in the reduced volume of the pulp chamber.[3] This volume reduction is caused by the continuous deposition of secondary dentine in the pulp cavity following tooth eruption, leading to a gradual decrease in pulp cavity size with age. Consequently, secondary dentine deposition serves as a critical morphological indicator for age estimation in adults.[12]

The evaluation of secondary dentine apposition can be performed by extracting and sectioning a tooth or utilizing two-dimensional (2D) dental radiographic techniques.This extraction causes lack of evidence which is not acceptable in forensics.[7] Several studies using 2D radiographic methods have estimated age based on pulp-tooth linear measurements and pulp-tooth area ratios. However, these techniques have limitations, including the superimposition of structures, difficulty in assessing pulp changes, and challenges in recognizing the overall shape of the tooth.[11]

To address these shortcomings, three dimensional (3D) technology has been introduced in dentistry, allowing researchers to more effectively analyze the reduction in pulp cavity size caused by secondary dentine formation.[1]

With the increasing use of three-dimensional imaging techniques in clinical practice, datasets from cone beam CT, CT, and Micro CT are now being utilized to explore the relationship between age and the volume ratio of the pulp cavity to the entire tooth. CBCT is more effective in enhancing clarity of critical structures. CBCT provides high-resolution, distortion-free, and non-magnified three-dimensional images, along with multiplanar views.[8]

CBCT allows for the calculation of pulp cavity volume by determining the area of the pulp cavity in each slice and integrating these areas with the image thickness to obtain the volume using various techniques. Accurate segmentation of the entire pulp region is

essential to achieve reliable results during this process.[13] Based on this, study was aimed to estimate age and sex by measuring the pulp volume of maxillary central incisor and canine using CBCT.

This retrospective study was conducted in department of oral medicine and radiology department, after getting approval from institutional review board with no IECVDC/ 24/PG01/OMR/IVT/118.The study protocol was approved by the Institutional Ethics Committee Review Board, Vishnu Dental College, Bhimavaram, Andhra Pradesh. The Cone beam computed tomography (CBCT) scans were acquired by a CBCT unit, CRANEX 3D (SOREDEX, PaloDEx Group Oy Nahkelantie, Tuusula Finland), with a flat panel detector and radiation protection for patients and personnel. The scan was set at 90 'kVp, 10 mA, with a 4.9-second acquisition time, as recommended by the manufacturer, with a field of view (FOV) of 61×41 mm or 61×81 mm and a standard resolution of 300 µm voxel size.

A total of 123 Digital Imaging and Communications in Medicine (DICOM) files were selected, each obtained from patients who had undergone CBCT scans with specified exposure parameters. The inclusion criteria comprised subjects aged between 20 and 70 years, with the presence of at least one healthy, fully erupted permanent maxillary central incisor and canine, both exhibiting completely formed roots. These individuals had undergone maxillary anterior CBCT imaging as part of their diagnostic or treatment planning procedures. The exclusion criteria involved teeth showing signs of periapical or periodontal disease, orthodontic or prosthetic appliances, pulp calcifications, tooth fractures, developmental anomalies, impacted teeth, endodontically treated teeth, restorations, or regressive changes.

These scans were categorized into five groups based on age, with each group representing a ten-year age interval , Group1: 20-30 years, Group 2: 31-40 years,Group 3: 41-50 years, Group 4 : 51-60 years, Group 5: 61-70 The scans were exported to OnDemand 3D software, where the region of interest (ROI) was defined.

The protocol employed for pulp volume estimation was executed through a series of methodical and standardized steps, as detailed below- Masking of image, fine tuning, followed by threshold adjustment, sculpting, and the use of the pick tool to isolate the pulp tissue. Later with the pick tool points are marked along the pulp . The volume of pulp was measured in cubic millimeters (mm^3). The collected data were tabulated and subjected to statistical analysis for further evaluation. The tests performed were Independent t-tests, One-way ANOVA (Analysis of Variance), Post hoc analysis using Tukey's Honestly Significant Difference (HSD) test, Pearson's correlation coefficient , Simple linear regression analysis.

The study population demonstrated a near-uniform distribution across the 123 samples.

Comparison of pulp volume Between males and females :

For the Central Incisor, males had a higher mean of 20.81 than females : 18.81

with a mean difference of 1.996; however, the difference was not statistically significant P = 0.060. Similarly, for the Canine, males showed a higher mean 32.56 compared to females 30.72 with a mean difference of 1.841, but this difference was also not statistically significant P = 0.081. (Table-1).

Table-1. Comparison of pulp volume in males and females.

	Gender	N	Mean	Std. Deviation	Mean difference	T value	P value
Central Incisor	Male	61	20.8072	5.86329	1.996	1.898	0.060
	Female	62	18.8105	5.80238			
Canine	Male	61	32.5590	5.83133	1.841	1.759	0.081
	Female	62	30.7171	5.78173			

Comparison of Pulp Volume among age groups.

Maxillary central incisor :

When the pulp volume of maxillary central incisor was measured among age groups there was notable decrease in pulp volume from younger to older age with a mean value of 27.92 mm^3 in younger age group (Group 1) and 19.80 mm^3 in older age group (Group 5) with statistical significance. (Table-2).

Table-2. Comparison of maxillary central incisor pulp volume among age groups

		N	Mean	Std. Deviation	95% Confidence Interval for Mean		F value	P value
					Lower Bound	Upper Bound		
Central Incisor	20-30	25	27.9228	1.15273	27.4470	28.3986	690.465	.000
	30-40	25	23.9348	1.20239	23.4385	24.4311		
	40-50	25	19.5368	1.48803	18.9226	20.1510		
	50-60	24	15.0996	1.10659	14.6323	15.5669		
	60-70	24	12.0100	1.05903	11.5628	12.4572		
	Total	123	19.8007	5.89457	18.7486	20.8529		

Maxillary canine :

When the pulp volume of maxillary canine was measured among age groups there was notable decrease in pulp volume of 39.28 mm^3 in younger age group (Group 1) to 23.29 mm^3 in older age group (Group 5) with statistical significance. (Table-3).

Table -3 : Comparison of maxillary canine pulp volume among age groups

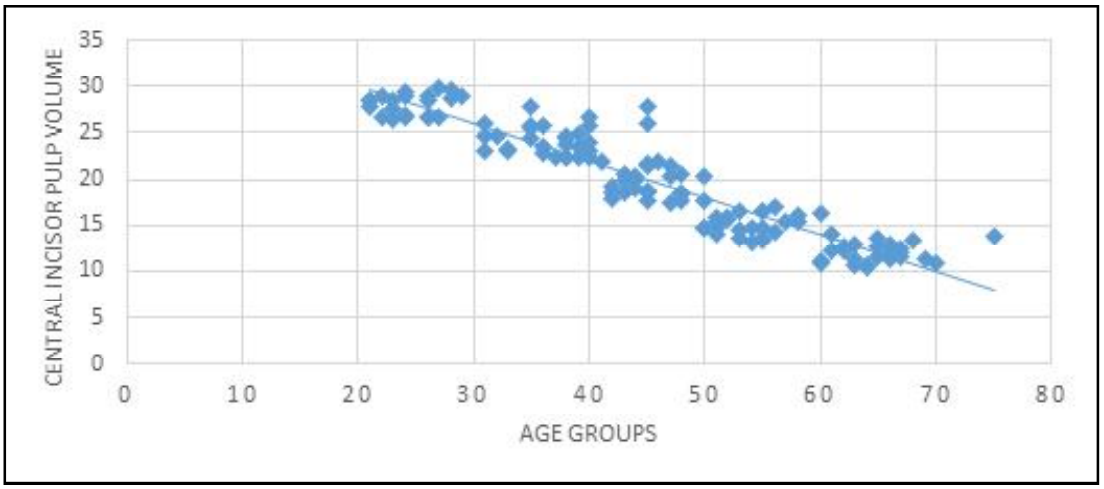
		N	Mean	Std. Deviation	95% Confidence Interval for Mean		F value	P value
					Lower Bound	Upper Bound		
Canine	20-30	25	39.2864	1.26293	38.7651	39.8077	715.418	.000
	30-40	25	35.9148	.98835	35.5068	36.3228		
	40-50	25	31.7400	1.36393	31.1770	32.3030		
	50-60	24	27.4117	1.23464	26.8903	27.9330		
	60-70	24	23.2979	1.02683	22.8643	23.7315		
	Total	123	31.6306	5.85600	30.5853	32.6758		

Correlation analysis between age and pulp volume :

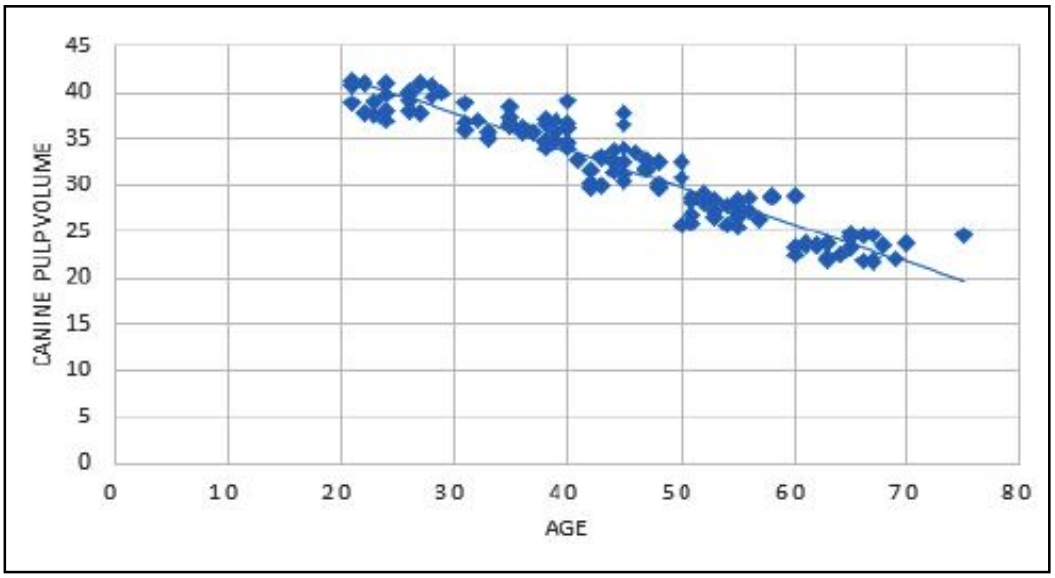
Correlation analysis between age and pulp volume for the central incisor and canine teeth, revealed a strong negative relationship between age and pulp volume for both the central incisor ($r = –0.937$, $p < 0.01$) and canine ($r = –0.944$, $p < 0.01$), indicating a significant decrease in pulp volume with increasing age. Additionally, a very strong positive correlation was observed between the pulp volumes of the central incisor and canine ($r = 0.984$, $p < 0.01$). All correlations were statistically significant at the 0.01 level (Graph 1,2).

Correlation analysis between gender and pulp volume :

The correlation between gender and pulp volume was weak and not statistically significant for both the canine ($r = –0.158$, $p = 0.081$) and central incisor ($r = –0.170$, $p = 0.060$) (Table-4).



Graph 1. Correlation between age and pulp volume of Central Incisor



Graph 2. Correlation between age and pulp volume of canine

Table-4. Correlation between gender and pulp volume

Correlations

		gender	canine	central incisor
gender	Pearson Correlation	1	-.158	-.170
	Sig. (2-tailed)		.081	.060
	N	123	123	123
canine	Pearson Correlation	-.158	1	.984**
	Sig. (2-tailed)	.081		.000
	N	123	123	123
central incisor	Pearson Correlation	-.170	.984**	1
	Sig. (2-tailed)	.060	.000	
	N	123	123	123

Age Estimation Formula: A predictive model for age estimation was developed for both teeth using pulp volume

1. *Age estimation formula for Central Incisor:*

The regression equation for predicting age based on pulp volume of the central incisor is:

$$\text{Age}=88.773-2.195(\text{PV})$$

2. Age Estimation Formula for Canine :

The regression equation for predicting age based on pulp volume of the canine is:

$$\text{Age}=115.669-2.224(\text{PV})$$

Relationship between the actual age and chronological age

The comparison between chronological and predicted ages across different age groups showed varying levels of agreement. In the 21–50-year age groups, differences in means were small and statistically non-significant for both central incisors and canines ($p > 0.05$), indicating good prediction accuracy. In the 51–60 age group, the predicted age for the central incisor was significantly higher than the actual age ($p = 0.029$), suggesting overestimation. Conversely, in the 61–70 age group, the predicted age for the central incisor was significantly lower than the chronological age ($p = 0.005$), indicating underestimation. (Table-5)

Table-5. Relationship between the actual age and chronological age

Age Group		groups	N	Mean	Std. Deviation	Mean difference	T value	P value
21- 30 years	Central incisor	Chronological age	25	26.64	5.85	-.842	-.661	.512
		predicted age	25	27.48	2.53			
	Canine	Chronological age	25	26.64	5.85	-1.656	-1.276	.208
		predicted age	25	28.29	2.80			
31-40 years	Central incisor	Chronological age	25	36.88	3.29	.643	.762	.450
		predicted age	25	36.23	2.63			
	Canine	Chronological age	25	36.88	3.29	1.08	1.370	.177
		predicted age	25	35.79	2.19			
41- 50 years	Central incisor	Chronological age	25	45.28	2.54	-.608	-.735	.466
		predicted age	25	45.88	3.26			
	Canine	Chronological age	25	45.28	2.54	.2008	0.254	0.801
		predicted age	25	45.07	3.03			
51 to 60 years	Central incisor	Chronological age	24	53.95	2.710	-1.670	-2.249	.029
		predicted age	24	55.62	2.427			
	Canine	Chronological age	24	53.95	2.710	-.747	-.950	.347
		predicted age	24	54.70	2.74			
61-70 years	Central incisor	Chronological age	24	64.95	3.482	2.547	2.980	.005
		predicted age	24	62.41	2.323			
	Canine	Chronological age	24	64.95	3.482	1.105	1.300	.201
		predicted age	24	63.85	2.28			

The intra and inter observer variabilities were o.75, 0.65 respectively.

Forensic odontology is the application of dental science in legal investigations. The unique characteristics of an individual's teeth make dental records a vital tool in forensic identification.[2] Dental records serve as critical evidence, aiding in determining an individual's age, sex, and ethnicity, whether they are a victim or a suspect.[14]

Numerous studies in the literature have focused on the comparison between pulp and tooth volume, primarily analyzing their relationship in different age group, but there is a limited research dedicated exclusively to pulp volume assessment. Understanding pulp volume is crucial, as it plays a significant role in forensic age estimation. Given the limited number of studies solely investigating pulp volume, this study aims to bridge that gap by providing a more detailed analysis, contributing valuable insights to the field of dentistry.

The study focused on central incisor and canine, instead of posterior teeth in order to address the lack of existing literature on anterior teeth. Anterior teeth typically have a single canal, making the assessment of pulp volume more straightforward compared to multi-rooted posterior teeth.

When pulp volume for both central incisor and canine were evaluated among genders, the findings indicated that, on average, males had a higher pulp volume than females. For central incisor the mean value for males is 20.80, where as females is 18.8 with no statistical significant results (Graph-1). For canines the mean for males is 32.55, where as females is 30.71 which also showed no statistical significant results which is in accordance with Andrade *et al*.,[1] study conducted in brazillian population. In contrast to present study, research conducted by Khandelwal *et al*.[8] study conducted in Lucknow population reported different mean pulp volumes for maxillary central incisors and canines.

Maxillary canine had more pulp compared to maxillary central incisor as canines are the longest tooth in oral cavity which contains more pulp which supports the present study findings are similar to study done by Katge *et al*.[9].

The study presents comparison of maxillary central incisor pulp volume across various age groups. The results indicate a clear decline in pulp volume as age increases, these findings align with Andrade *et al.*[1] who has done study using 232 teeth[1], Khandelwal s et al using 180 teeth in CBCT [8] where they noted decrease in pulp volume as age increases.

When pulp volume of maxillary canine was measured across age groups the results show a significant decline in maxillary canine pulp volume with age ($p < 0.001$) Graph-2. These findings align with studies done in the literature done by Andrade *et al*.[1], and Khandelwal *et al.,*[8] where they concluded that, as age increases the pulp volume of canine decreases but the mean values across the studies may differ based on the geographical location.

The present study assessed the pulp volumes of the maxillary central incisors and maxillary canines. In contrast, a study conducted by Ge *et al*.[4], which focused on age estimation based on the pulp volume of first molars, also concluded that pulp volume decreases with advancing age.

Compared between maxillary central incisor and canine high pearson correlation significance was seen for canine than central incisor which is in accordance with a study done by Khandelwal *et al.*[8]

When correlation between gender and pulp volume of maxillary central incisor and canine were evaluated our study reveals weak correlation with r value of – 0.158 in central incisor and r= – 0.170 for canine which is not in accordance with a study done by Khandelwal *et al.*[8], Kazmi *et al.*[10]. This difference may be attributed to sample size and geographical variations.

The age of sample was predicted using formulas and compared with the actual age. Predicted age based on central incisor pulp volume showed accurate estimation in younger groups, but overestimation and underestimation in the 51–60 and 61–70 age groups, respectively. Canine pulp volume provided consistent age predictions across all age groups with no significant differences.

These findings are in accordance with a study done by Khandelwal *et al.*[8] using maxillary central incisor and canine but in contradictory is a study done by Andrade *et al.*[1] using same maxillary central incisor and canine where they found that maxillary central incisor is effective in age prediction. These variations may attribute to geographic variations.

The regression formula derived may not be universally applicable, as genetic, environmental, and lifestyle variations can influence dental structures differently. This highlights the necessity for further research incorporating larger, heterogeneous samples to enhance the accuracy and reliability of dental age estimation techniques.

Our study found that the mean pulp volume is higher in males compared to females for both the maxillary central incisor and canine. Pearson correlation coefficients for pulp volume and age in both teeth indicate a weak negative correlation between these variables. Given the strong overall negative correlation between pulp volume and age, our findings contribute to the growing body of evidence supporting the use of dental pulp volume as an age estimation tool in forensic science.

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