



Original Article

Snapshots of Age and Gender: Pulp Volume Analysis of Maxillary Teeth Using OnDemand 3D and ITK-SNAP

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Abstract

Introduction: In forensic investigations, age and gender determination is fundamental for the creation of the biological profile of the individual. Teeth are widely used in forensic and anthropological investigations to determine the gender and age of the human body, regardless of the cause of death and state of preservation of the body. Secondary dentin deposition by odontoblasts is a continuous process that causes progressive narrowing of the pulp chamber in all teeth. The deposition of secondary dentin can be assessed by destructive methods such as tooth sectioning for microscopic study or by conservative methods such as imaging examinations. Destructive methods are not acceptable for forensic purposes because they cause the loss of evidence. Therefore, non-invasive imaging technologies, such as CBCT, were employed for measuring pulp volume, addressing paucity in the literature comparing two software programs, OnDemand 3D and ITK-SNAP, and assessing any software errors among them. Based on this, the aim of the study was to estimate and compare pulp volume of the maxillary central incisor and canine using OnDemand 3D and ITK-SNAP software programs.

Methods: In this retrospective study, 125 Digital Imaging and Communications in Medicine (DICOM) files were obtained and the pulp volume of maxillary central incisor and canine was assessed using OnDemand 3D and ITK-SNAP.

Results: There was a statistically significant correlation between age and pulp volume but it was independent of gender.

Conclusion: To conclude, the results reveal statistically significant outcomes in estimating patient age based on pulp volume in CBCT scans using both OnDemand 3D and ITK-SNAP software programs. The formulas developed in this study are applicable for forensic age estimation of victims. Although no software errors were found, OnDemand 3D software was noted to be slightly more sensitive to technique than ITK-SNAP.

Keywords: Pulpvolume,CBCT, OnDemand, ITK snap, Central incisor, Canine



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Introduction

In forensic odontology, dental pulp volume has emerged as a valuable biomarker for determining age and gender. Utilizing advanced imaging technologies, the evaluation of pulp volume provides a precise, reliable, and non-invasive approach to demographic profiling (1). Teeth are highly regarded for age estimation due to their resistance to variations caused by nutrition, hormones, and environmental factors, unlike bones. Traditionally, methods focusing on tooth development and eruption have proven effective for determining the chronological age of both primary and permanent dentitions. Tooth development is particularly reliable for age estimation up to 16 years, while from 16 to 24 years, the analysis primarily relies on the maturation of third molars (2). Teeth have

immense value in forensic science as they, like long bones, follow distinct developmental stages and are minimally influenced by diseases, medications, or environmental conditions (3). This consistency makes them essential tools in forensic and anthropological studies (4). Age-related changes in dental tissues, especially within the pulp, involve the deposition of secondary dentin, leading to a gradual reduction in pulp volume. These measurable alterations provide a foundation for models used in age estimation. Furthermore, slight anatomical differences in pulp volume between genders may contribute to gender identification (1). Factors such as tooth wear, cavities, and changes in osmotic pressure can also influence age-related alterations in pulp volume. Traditionally, measuring morphological changes in pulp chamber



walls and volumes has required invasive procedures such as tooth extraction and sectioning (5). These methods are not only impractical for living individuals but are also sometimes restricted when examining human remains due to the potential loss of evidence and religious, cultural, or scientific concerns. Techniques such as aspartic acid racemization, which involve tooth sectioning, are invasive, complex, and time-intensive, further limiting their applicability (6).

In contrast, radiological approaches provide a non-invasive, practical, and ethically sound alternative, enabling the assessment of pulp volume reduction over time through advanced imaging techniques (7). These methods can be used on both living individuals and cadavers, supported by specialized software. However, a significant limitation of radiological techniques is the potential for image distortion due to tooth misalignment, which can lead to inaccuracies or even make assessments impossible.

Advancements in forensic odontology, particularly with the introduction of cone-beam computed tomography (CBCT), have addressed many of these challenges. CBCT offers superior three-dimensional imaging compared to traditional periapical and panoramic radiographs, allowing for accurate visualization of morphological features, such as pulp chamber size and its reduction over time due to secondary dentin deposition. The use of 3D imaging via Cone Beam Computed Tomography (CBCT) has recently enhanced the correlation between age and pulp chamber volume, overcoming many of the limitations associated with two-dimensional imaging (8).

With this foundation, the study aimed to assess and compare the pulp volume of maxillary Central Incisors (CI) and Canines (C) using OnDemand 3D and ITK-SNAP software programs, utilizing their sophisticated imaging and segmentation features for accurate analysis.

Materials and Methods

This retrospective study was conducted in the Department of Oral Medicine and Radiology after getting approval from the institutional review board (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 using 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 an acquisition time of 4.9 seconds, as recommended by the manufacturer, 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 125 Digital Imaging and Communications in Medicine (DICOM) files of patients with exposure parameters were selected with the aim of estimating age and gender by comparing pulp volume of maxillary

Central Incisor (CI) and Canine (c) using OnDemand 3D and ITK-SNAP software programs. The main objectives of the study were to determine pulp volume of maxillary central incisor and canine, to estimate age and gender using OnDemand 3D and ITK-SNAP software programs, and to compare the results and accuracy between two software programs.

Inclusion Criteria

CBCT scans of patients ranging between 20 and 70 years with fully erupted maxillary Central Incisor (CI) and Canine (C) and data on the age of the patient were included in the study.

Exclusion Criteria

CBCT scans with any decay or cavities, root canal therapy, restorations, excessive tooth wear reaching the incisal/occlusal third of the tooth crown, orthodontic or prosthetic devices, pulp calcification, dental fracture, impaction, severe rotation, periodontitis, and any periapical lesions in the region of interest were excluded from the study.

OnDemand 3D Software

A total of 125 DICOM files were downloaded into the OnDemand 3D viewer, and the following steps were performed: (1) selecting region of interest, (2) adjusting threshold value, there by delineating between pulp and remaining structures, (3) segmentation option, sculpting the image, by removing surrounding structures other than pulp, and (4) adding points in the remained pulp and finally obtaining pulp volume (Figure 1).

ITK-SNAP Software

The same 125 DICOM files were also analyzed using ITK-SNAP software, and the following steps were performed: (1) selecting the region of interest, (2) adjusting the threshold value, and (3) adding bubble to the entire pulp and obtaining the pulp volume (Figure 2).

Among the 125 scans, the analysis of 20 scans in each software was repeated by the same observer and another observer.

To validate the accuracy of pulp volume measurements, 5 extracted human teeth were selected based on criteria including the absence of caries, restorations, or root



Figure 1. OnDemand 3D

resorption. Each tooth was scanned and analyzed using two different software programs designed for volumetric assessment. Pulp chamber volumes were segmented and calculated independently in both programs. Validation of pulp volume measurements was performed by comparing the results obtained from each software for consistency and reliability.

Statistical Analysis

Pearson correlation coefficient (r) and linear regression analysis were used to analyze the data in SPSS software version 26.0.

Results

There was a strong correlation between age and pulp volume; in other words, as age increased, the volume of pulp decreased, with statistically significant results for both Central Incisor (CI) and Canine (C) using both OnDemand 3D and ITK-SNAP software programs. Additionally, the central incisor had more accuracy for age determination in both software programs.

A strongly negative correlation was found between age and pulp volume of both teeth in both of the software programs (Table 1) (Figures 3, 4, 5, 6).

After obtaining strong negative correlation coefficients, 95.0% Confidence Intervals were derived for both of the teeth in the two software programs (Table 2).

Based on the correlation coefficients, linear regression equations were developed using the following formula. linear regression equations = constant + (-B) (pulp

volume)

The predicted age was calculated using the regression equations derived (Table 3) and compared with actual age, where there was a minimal mean difference for the central incisor in OnDemand 3D, and there was a slightly higher mean difference for the canine in ITK-SNAP (Table 4).

Correlation between actual age and predicted age was calculated which exhibited a strong negative correlation for central incisor and canine in both of the software programs (Table 5).

Based on the results, pulp volume was independent of gender for both upper central incisor and canine in both OnDemand 3D and ITK-SNAP (Table 6).

Intra-Observer Variability

ONDEMAND 3D: 0.75
ITK SNAP: 0.89

Inter-Observer Variability

ONDEMAND 3D: 0.65
ITK SNAP: 0.85

Table 1. Relationship between Age and Pulp Volume of Both Teeth using Two Software Programs

Variables	n	Age (*r)	P-value
CI PV ON DEMAND	125	-0.963	0.000
C PV ON DEMAND	125	-0.926	0.004
CI PV ITKSCAN	125	-0.939	0.000
C PV ITK SCAN	125	-0.856	0.001

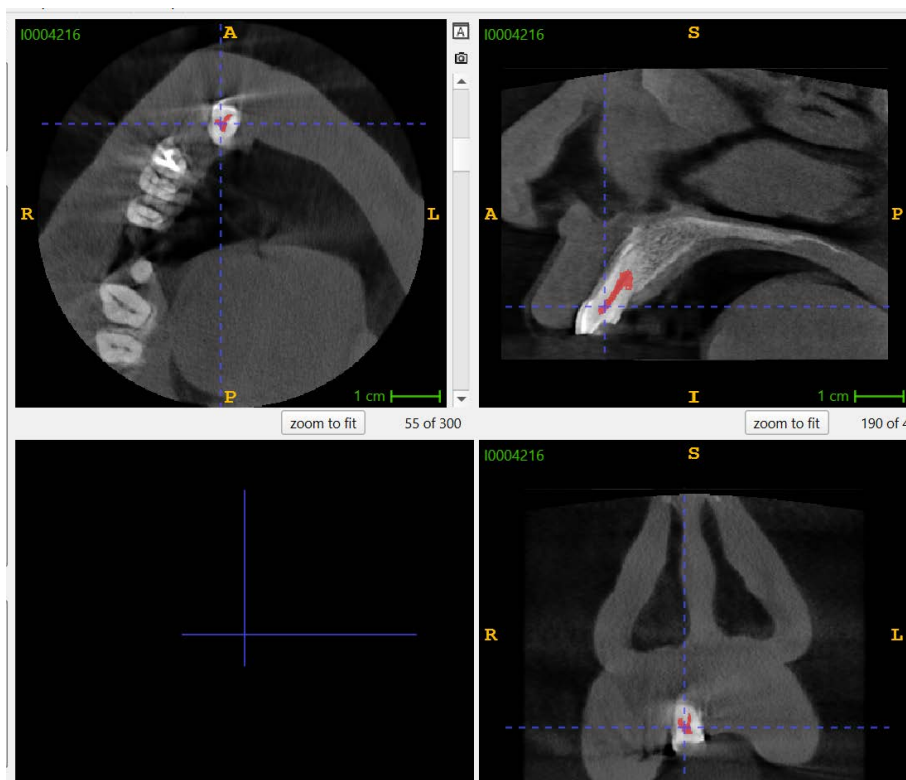


Figure 2. ITK-SNAP

The pulp volume measurements for the five extracted teeth showed a high level of agreement between the two software programs. The mean pulp volumes differed by less than 5%, and the intra-class correlation coefficient (ICC) was 0.95, indicating excellent reliability.

Discussion

Forensic odontology is the application of dental science in legal investigations. Its primary functions include identifying human remains through dental records and bite marks found on victims or crime scenes. The unique characteristics of an individual's teeth make dental records a vital tool in forensic identification (9). Teeth are highly resistant to mechanical damage, chemical influences, physical forces, and the passage of time, enabling them to remain well-preserved long after death. Dental records experience minimal changes due to aging, with only slight variations caused by factors such as diet, environmental conditions, and lifestyle. Consequently, various techniques have been developed for age estimation through dental

analysis. Determining the age of a person using dental characteristics is an essential method in forensic identification (5).

Techniques which analyze specific dental characteristics, such as amino acid racemization, have been utilized for age estimation in both tooth enamel and crown dentin, with studies indicating that crown dentin provides more accurate results compared to enamel. Multiple investigations have confirmed a strong correlation between the aspartic acid racemization ratio and chronological age. The method has generally produced positive outcomes; however, some studies have reported variations in accuracy, highlighting inconsistencies across different research groups. Since the above-mentioned procedures may be destructive and often require significant time and advanced laboratory equipment, they are less commonly used. Extracting a tooth for analysis is also considered ethically questionable (10).

The analysis of pulp volume as a marker for determining

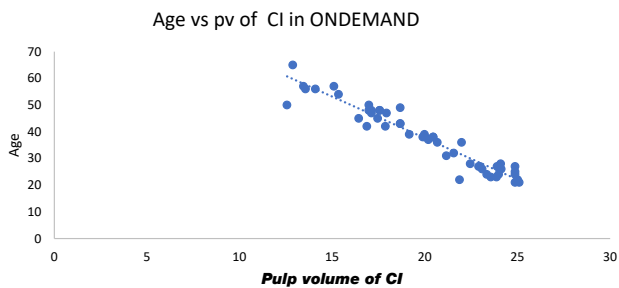


Figure 3. Correlation between Age and Pulp Volume of Central Incisor in OnDemand 3D

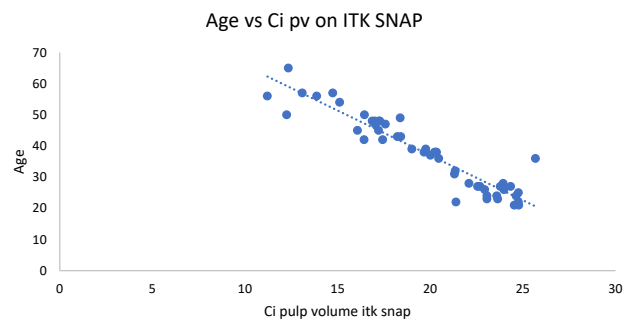


Figure 4. Correlation between Age and Pulp Volume of Central Incisor in ITK-SNAP

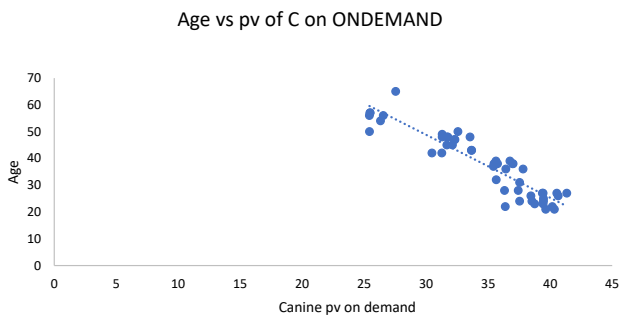


Figure 5. Correlation between Age and Pulp Volume of Canine in OnDemand 3D

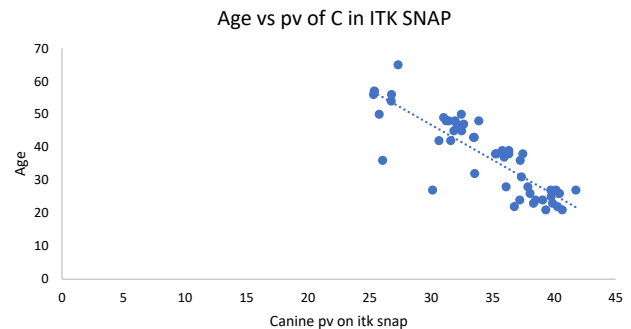


Figure 6. Correlation between Age and Pulp Volume of Canine in ITK-SNAP

Table 2. Coefficient Values for Pulp Volume of Central Incisor and Canine in OnDemand 3D and ITK-SNAP

Model	Unstandardized coefficients		Standardized coefficients	t	Sig	95% confidence interval for B		Correlations		
	B	Std error	Beta			Lower bound	Upper bound	Zero order	Partial	Part
Constant	99.76	2.63		37.83	.00	94.46	105.06			
Central incisor -ONDEMAND	-3.107	.130	-.960	-23.90	.00	-3.36	-2.84	-.960	-.960	-.960
Constant	94.55	3.124		30.26	.00	88.26	100.83			
Central incisor - ITK SNAP	-2.87	.155	-.937	-18.52	.00	-3.19	-2.56	-.937	-.937	-.937
Constant	99.76	2.63		37.83	.00	94.46	105.06			
Canine-ONDEMAND	-3.107	.130	-.960	-23.90	.00	-3.36	-2.84	-.960	-.960	-.960
Constant	94.55	3.12		30.26	.00	88.26	100.83			
Canine - ITK SNAP	-2.87	.155	-.937	18.52	.00	-3.19	-2.56	-.937	-.937	-.937

age and gender has significant potential in forensic odontology. This research focused on comparing the pulp volumes of maxillary central incisors and canines using OnDemand 3D and ITK-SNAP software programs, highlighting the role of advanced imaging tools in achieving accurate and non-invasive evaluations.

In our study, we found a correlation between age and volume of pulp in both of the software programs used, which was independent of gender. This is in accordance with a study done by Asif et al (11) using Mimics software. They concluded that pulp cavity/tooth ratio is a reliable age estimation method and it is independent of gender.

In our study, we analyzed the pulp volumes of central incisors and canines using OnDemand 3D software. While both teeth exhibited statistically significant results, the central incisor showed a stronger correlation than the canine, which is in accordance with the study done by Khandelwal et al (3) using Carestream CS 9300[®]. They concluded that validation of the equations for gender determination revealed higher prediction accuracy for CI (56.70%) compared to C (53.30%) and it is gender dependent, which is contradictory to our results and also the finding of the studies conducted by Meris Jušić et al (8) and Biuki et al (12), where the regression analysis showed the highest Pearson correlation coefficient (0.612) for the maxillary central incisor.

According to a study conducted by Andrade et al (13) using ITK-SNAP, when the pulp volume of one or both

teeth is used together with age or gender information, the other characteristic (gender or age) can be obtained with high accuracy using their formulas. However, in our study, when pulp volume of maxillary central incisor and canine was measured using ITK snap, only age was estimated but not the gender.

In our study, when central incisor and canine were compared, the central incisor had more prediction accuracy than the canine, which is in contradiction with a study done by Kazmi et al (2) using software Planmeca Romexis[®]. They concluded that predictions using the pulp volume of the mandibular canine produced the best estimates of chronological age.

Gulashi et al (14) performed a study using 3D DOCTOR, Able Software. They analyzed the pulp volume/tooth ratio of several types of teeth based on CBCT scans and found a higher correlation coefficient for the upper central incisors ($R^2 = 0.532$) than for the upper canines, which is consistent with our results.

Hazha Star et al (15) conducted a study titled "Human Dental Age Estimation by Calculation of Pulp-Tooth Volume Ratios Yielded on Clinically Acquired Cone Beam Computed Tomography Images of Monoradicular Teeth". They concluded that the variability in age explained by the pulp-tooth volume ratio is gender independent and highest for incisors, respectively, followed by premolars and canines, which is contrary to the present study.

In a systematic review and meta-analysis done by Yousefi et al (16) on dental age estimation using cone-beam computed tomography, CBCT was found to be a reliable and repeatable tool for dental age estimation. A strong inverse relationship was observed between pulp chamber volume and age, which is consistent with our study and many studies in the literature.

Dental CBCT is becoming increasingly prevalent in dental practices due to its ability to deliver high-quality

Table 3. Linear Regression Equations for Age Estimation

Tooth	Software	Regression equation
Central incisor	ONDEMAND	99.763-3.107(pulp volume)
Canine	ONDEMAND	119.309-2.350(pulp volume)
Central incisor	ITK SNAP	94.550-2.878(pulp volume)
Canine	ITK SNAP	110.593-2.216(pulp volume)

Table 4. Predicted Age by Keeping Obtained Pulp Volume in Regression Formulas

Tooth	Age	N	Mean	Standard deviation	Standard error of the mean	Mean difference
Central Incisor	Actual age	125	38.7400	11.83873	1.67425	
	Predicted age (ONDEMAND)	125	37.7429	11.37032	1.60801	-0.9971
	Actual age	125	38.7400	11.83873	1.67425	
	Predicted age (ITK SNAP)	125	37.7446	11.08742	1.56800	- 0.996
Canine	Actual age	125	38.7400	11.83873	1.67425	
	Predicted age (ONDEMAND)	125	37.7424	10.89891	1.54134	-0.998
	Actual age	125	38.7400	11.83873	1.67425	
	Predicted age (ITK SNAP)	125	34.6587	10.49451	1.48415	4.082

Table 5. Correlation between the Actual Age and Predicted Age

Variables	n	Actual age (*r)	P-value
Predicted age (ON DEMAND) using central incisor pulp volume	125	0.960**	0.000
Predicted age (ON DEMAND) using Canine pulp volume	125	0.921**	0.000
Predicted age (ITK SNAP) using central incisor pulp volume	125	0.937**	0.000
Predicted age (ITK SNAP) using Canine pulp volume	125	0.850**	0.000

Table 6. Relationship between Gender and Pulp Volume of both Teeth Using Two Software Programs

Variables	n	Gender (*r)	P-value
CI PV ON DEMAND	125	-.026	0.860
C PV ON DEMAND	125	.044	0.761
CI PV ITKSCAN	125	-.049	0.737
C PV ITK SCAN	125	.052	0.718

diagnostic images with minimal radiation exposure. Additionally, advancements in CBCT technology are ongoing (17). Various manufacturers are now offering units with improvements such as enhanced contrast resolution, smaller voxel sizes, and higher grayscale bit depth. These advancements, combined with refined separation and segmentation software, are expected to enable more accurate and time-efficient measurement of pulp-tooth volume ratios for entire single-rooted teeth in the near future (18).

OnDemand 3D is more sensitive to technique due to its manual segmentation tools and customizable image processing, capturing finer pulp details. In contrast, ITK-SNAP uses automated algorithms that prioritize consistency over detail, making it less responsive to operator technique.

Conclusion

The results reveal statistically significant outcomes in estimating patient age based on pulp volume in CBCT scans using both OnDemand 3D and ITK-SNAP software programs. The formulas developed in this study are applicable for forensic age estimation of victims. Although no software errors were found, OnDemand 3D software was noted to be slightly more sensitive to technique than ITK-SNAP.

Authors' Contribution

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Competing Interests

The authors declare that they have no conflict of interests.

Ethical Approval

This study was approved by the Institutional Ethics Committee Review Board, Vishnu Dental College, Bhimavaram, Andhra Pradesh (IECVDC/24/PG01/OMR/IVT/118).

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