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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

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Featured Application: Based on the findings of this study, pulp–tooth volume ratio of mandibular central incisors, maxillary lateral incisors, and maxillary canines can be used for age estimation in males. Pulp–tooth volume ratio of maxillary and mandibular central incisors, maxillary lateral incisors, and maxillary and mandibular canines can be used for age estimation in females. Additionally, age estimation was most accurate among females using the maxillary central incisors and among males using the mandibular central incisors and maxillary canines.

Abstract: The present study aimed to investigate the correlation between chronological age and pulp–tooth volume ratio in anterior teeth using cone beam computed tomographic (CBCT) images and provide equations for age estimation based on pulp–tooth volume ratio. In this cross-sectional study, CBCT images of 312 anterior teeth of the maxilla and mandible were examineαd. The chronological age and the sex of the patients were recorded. Tooth volume and pulp volume of the anterior teeth were measured using Mimics software, and then tooth–pulp volume ratio was calculated. Statistical analysis of data was performed using chi-square test, independent T-test, Pearson's correlation, and linear regression ($\alpha = 0.05$). Finally, equations were made based on the results of the regression analysis for age estimation in general and for males and females. The age of the subjects ranged between 16 and 69 years (mean 40.6 ± 12.74). The pulp–tooth volume ratio of the maxillary teeth was generally higher than the mandibular teeth. A significant inverse relationship between age and pulp–tooth volume ratio was observed for all anterior teeth. ($p < 0.05$). The strongest correlation between age and pulp–tooth volume ratio was reported for mandibular central incisor ($r = -0.58$, $p < 0.001$) and the weakest was for mandibular lateral incisor ($r = -0.36$, $p = 0.012$). Age estimation was most accurate among females using the maxillary central incisors ($p < 0.001$) and among males using the mandibular central incisors and maxillary canines ($p = 0.003$). Pulp–tooth volume ratio of mandibular central incisors, maxillary lateral incisors, and maxillary canines in males and maxillary and mandibular central incisors, maxillary lateral incisors, and maxillary and mandibular canines in females can be used for age estimation.

Keywords: cone beam computed tomography; age estimation; pulp–tooth volume ratio; cross-sectional study

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1. Introduction

Estimation of the age in forensic dentistry is of particular importance, especially in the case of unknown persons affected by war or natural disasters, criminals and undocumented immigrants, and those injured in accidents. In forensic dentistry, to determine

the age of individuals, application of dental indexes is better than those based on somatic development, as the development of teeth is less affected by hormonal and nutritional changes [1,2].

Mainly, dental age estimation is based on the growth, and biochemical and morphological alterations of teeth [3,4]. In adults, morphological changes are preferable to the other two methods, since calcification of dental tissues is a continuous process that can be evaluated by radiography [5]. Also, methods based on biochemical changes in teeth, such as aspartic acid removal, are time-consuming, complex, and invasive, and thus are rarely used [6]. On the other hand, the root formation of all permanent teeth, except for the third molar, is completed around the age of 16 when their apices close [7,8]. Therefore, age estimation using root development indexes such as Demirjian's and Willem's in adults is not applicable [9,10].

In the developmental process of teeth after maturation, secondary dentin deposition occurs on all walls of the dental pulp throughout a person's life, which continuously reduces the size of the pulp cavity. Based on this, the amount of reduction in pulp cavity size can be considered as an effective morphological criterion for estimating age in adults [11–13].

Secondary dentin deposition can be assessed by tooth extraction and incision or by imaging techniques [14]. Panoramic and periapical radiographs have been used to assess secondary dentin deposition [15,16]. However, these radiographic modalities have the disadvantages of being two-dimensional and providing a distorted view. Two-dimensional images also fail to provide accurate measurements due to the overlap of anatomical structures, radiographic geometry, and magnification [17,18].

To overcome the limitations of two-dimensional imaging for age estimation, studies have used three-dimensional modalities for this purpose. Cone beam computed tomography (CBCT) can be used as an accurate and ideal tool to assess dental pulp volume [19,20].

Several studies have used CBCT images for age estimation in different populations [21–24]. However, limited studies have been performed in Iranian sub-population. Therefore, the present study aims to investigate the correlation between chronological age and pulp–tooth volume ratio in anterior teeth using cone beam computed tomographic (CBCT) images and provide equations for age estimation based on pulp–tooth volume ratio.

2. Materials and Methods

The present study was an analytical cross-sectional study, conducted on CBCT images obtained in a private oral and maxillofacial radiology clinic in Isfahan, Iran, from March to November 2020. The study was approved by the Ethics Committee at the Isfahan University of Medical Sciences (#IR.MUI.RESEARCH.REC.1399.444).

2.1. Patients and Data Collection

A total of 312 teeth of 52 individuals were examined in this study from May to December 2020. CBCT images of individuals over 15 years old were chosen by simple sampling method. The chronological age was determined using date of imaging and birth date for each patient. Patients were contacted using the recorded phone numbers in case their age and sex data was not available.

Inclusion criteria were patients over 15 years old, availability of 6 anterior teeth (central incisor, lateral incisor, and canine) of the maxilla or mandible in the images, absence of pathologic lesions, cavities, or restorations, periodontal diseases, pulp stones, occlusal trauma, endodontic, restorative, or prosthetic treatment, and high quality of the images. In addition, due to registration of history and other considerations in the CBCT archive, patients with developmental anomalies or history of surgery of trauma in the craniofacial region were not included. Patients were excluded if their age and sex data was not recorded and were unavailable when contacted by phone. A total of 65 patients met the inclusion criteria and 13 of them were excluded, leaving 52 individuals for the study.

CBCT images were obtained by a Giano HR CBCT scanner (NewTom, Verona, Italy) with 360 degrees rotation with a pixel size of 150 μm. Imaging features of this device were

pulsed exposure with a maximum voltage of 90 kV, exposure current of 7 mA, and total exposure time of 8 s. Images were saved using NNT Viewer Version 10.1 software (NewTom, Verona, Italy) in digital imaging and communication in medicine (DICOM) format.

2.2. Image Analysis

All anterior teeth, including central incisor, lateral incisor, and canine tooth of both maxilla and mandible were examined in these images. DICOM file of the images were transferred into Mimics Medical Version 21.0 software (Materialise, Leuven, Belgium) for volumetric measurements. Images were examined independently by two trained observers (ICC = 0.93, $p < 0.05$). A proportional mask was created using the minimum and maximum thresholds from the threshold menu to select the minimum values appropriate for the anterior teeth and pulp of the teeth. Thereafter, using the "Edit Mask" tool, the masks were edited manually in all planes in order to remove the areas of the mask outside the outline of the teeth. The "Split Mask" option was then used in order to separate different teeth. By placing the numerical value of the minimum threshold of the previous mask in the numerical value of the new maximum threshold, a new mask was created for the pulps of the teeth. After determination of the volume of the tooth and the pulp, the pulp to tooth volume ratio was calculated (Figure 1).

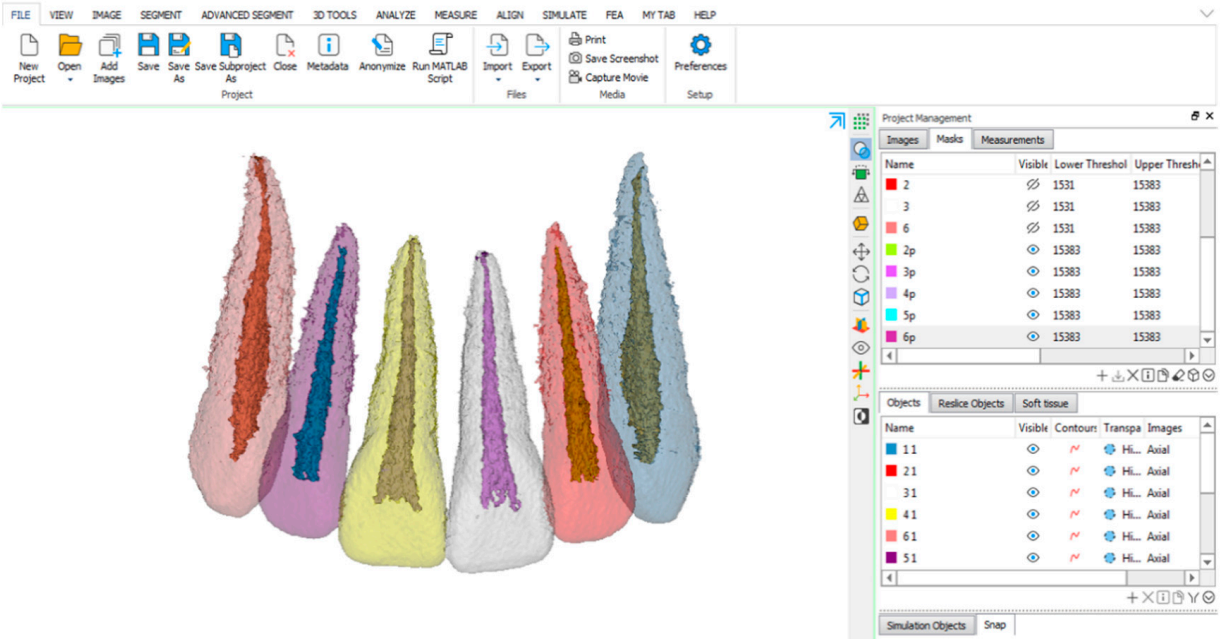

Figure 1. A screenshot from the Mimics software showing three-dimensional visualization of pulp and teeth of the maxillary anterior teeth in one of the cases.

2.3. Statistical Analysis

SPSS version 25 software (IBM, Armonk, NY, USA) was used for statistical analysis. Descriptive analysis was performed using descriptive statistical indicators such as minimum, maximum, mean, and standard deviation. All qualitative variables were reported as frequency and quantitative variables as mean and standard deviation. The data were assessed for normality using the Kolmogorov–Smirnov test. An independent T-test was used to survey the mean of the continuous quantitative variable of age between the two groups of men and women. A Chi-square test was used to compare the qualitative variable of tooth type between them. Pearson correlation coefficient was used to examine the relationship between continuous quantitative variables, including the pulp–tooth volume ratio and age. The regression model was also used to predict age based on pulp–tooth

volume ratio and also to make equations to predict the age according to the pulp–tooth volume ratio given. For all analyses, $p < 0.05$ was considered as statistically significant.

3. Results

Of the total 312 examined teeth, 160 belonged to women, and 152 belonged to men. The age of the subjects was between 16 and 69 years with an average of 40.6 ± 12.74 years (Table 1).

Table 1. Mean and standard deviation of age by sex in the sample.

Sex	Number	Mean Age (SD)	Minimum Age	Maximum Age	*p*-Value
Male	152	40.16 (12.47)	17	69	0.550
Female	160	41.01 (13.01)	16	48	
Total	312	40.60 (12.74)	16	69	

Pulp–tooth volume ratio had the highest value in the maxillary lateral incisor and the least value in the mandibular central incisor. Generally, maxillary teeth had higher pulp–tooth volume ratio compared with their mandibular counterparts (Table 2).

Table 2. Mean and standard deviation of pulp–tooth volume ratio in the studied teeth.

Tooth Type	Number	Mean (SD)	Minimum	Maximum
Maxillary central incisor	66	0.046 (0.010)	0.024	0.067
Mandibular central incisor	46	0.042 (0.010)	0.024	0.069
Maxillary lateral incisor	58	0.054 (0.015)	0.025	0.089
Mandibular lateral incisor	46	0.053 (0.014)	0.028	0.089
Maxillary canine	57	0.052 (0.014)	0.023	0.079
Mandibular canine	39	0.048 (0.012)	0.033	0.075

A significant inverse relationship was observed between age and pulp–tooth volume ratio for all teeth ($p < 0.05$). The strongest correlation between age and pulp–tooth volume ratio was reported for mandibular central incisor ($r = -0.58$, $p < 0.001$) and the weakest was for mandibular lateral incisor ($r = -0.36$, $p = 0.012$) (Table 3). Additionally, the correlation between pulp–tooth volume ratio and age in different teeth was stronger in women ($r = -0.47$, $p < 0.001$) than in men ($r = -0.38$, $p < 0.001$) (Table 4).

Table 3. Correlation coefficients between age and pulp–tooth volume ratio by type of teeth studied.

Tooth Type	Number	Pearson Correlation Coefficient	*p*-Value
Maxillary central incisor	66	−0.46	<0.001
Mandibular central incisor	46	−0.58	<0.001
Maxillary lateral incisor	58	−0.42	0.001
Mandibular lateral incisor	46	−0.36	0.012
Maxillary canine	57	−0.53	<0.001
Mandibular canine	39	−0.38	0.017
Total	312	−0.43	<0.001

In the next step, a linear regression test with the entering method was used to estimate the approximate age based on the pulp–tooth volume ratio. The pulp–tooth volume ratio of the anterior teeth explains up to 19% of the variance related to patients' chronological age (Table 5). Then, using the obtained results, an equation was compiled for each of the anterior teeth, to estimate the age of individuals based on the pulp–tooth volume ratio. These equations are shown in Table 6. Also, specific equations for each sex were compiled and are presented in Table 7. It should be noted that in cases where no equation

is provided for a particular tooth, it is considered that the pulp–tooth volume ratio could not be estimated for that specific target group.

Table 4. Pearson correlation coefficients between age and pulp–tooth ratio by sex and tooth type.

Tooth Type	Males		Females	
	Pearson Correlation Coefficient	*p*-Value	Pearson Correlation Coefficient	*p*-Value
Maxillary central incisor	−0.27	0.18	−0.67	<0.001
Mandibular central incisor	−0.59	0.003	−0.60	0.002
Maxillary lateral incisor	−0.41	0.026	−0.14	0.027
Mandibular lateral incisor	−0.37	0.08	−0.37	0.070
Maxillary canine	−0.53	0.003	−0.55	0.002
Mandibular canine	−0.11	0.67	−0.47	0.027
Total	−0.38	<0.001	−0.47	<0.001

Table 5. Linear regression results predicting age based on pulp–tooth ratio.

Tooth Type	Correlation Coefficient (R)	Coefficient of Determination (R^2)	Adjusted Coefficient of Determination (Adjusted R^2)	Standard Error of the Estimate	*p*-Value
Maxillary central incisor	−0.46	0.21	0.20	11.98	<0.001
Mandibular central incisor	−0.58	0.34	0.32	9.6	<0.001
Maxillary lateral incisor	−0.42	0.18	0.16	10.99	0.001
Mandibular lateral incisor	−0.36	0.13	0.11	11.01	0.012
Maxillary canine	−0.53	0.28	0.26	12.27	<0.001
Mandibular canine	−0.38	0.14	0.12	12.02	0.017
Total	−0.43	0.19	0.18	11.49	0.001

Table 6. Equations for estimating age. With the pulp–tooth volume ratio in the related equation of that tooth, the approximate age of the individual can be estimated.

Tooth Type	Equation for Estimating Age
Maxillary central incisor	Y = 68.65 − 581.75 X
Mandibular central incisor	Y = 66.48 − 625.91 X
Maxillary lateral incisor	Y = 57.57 − 336.43 X
Mandibular lateral incisor	Y = 55.21 − 287.34 X
Maxillary canine	Y = 69.26 − 517.23 X
Mandibular canine	Y = 60.32 − 405.65 X

Table 7. Equations for estimating age in different sexes.

Tooth Type	Males		Females	
	Equation for Estimating Age	*p*-Value	Equation for Estimating Age	*p*-Value
Maxillary central incisor	-	0.180	Y = 76.18 − 770.15X	<0.001
Mandibular central incisor	Y = 60.84 − 511.91X	0.003	Y = 73.36 − 762.76X	0.002
Maxillary lateral incisor	Y = 56.62 − 350.20X	0.026	Y = 57.49 − 301.78X	0.027
Mandibular lateral incisor	-	0.080	-	0.070
Maxillary canine	Y = 72.51 − 543.26X	0.003	Y = 72.01 − 614.28X	0.002
Mandibular canine	-	0.670	Y = 63.90 − 481.76X	0.027

4. Discussion

Based on the findings of the present study on an Iranian sub-population, in all the maxillary and mandibular anterior teeth, a significant negative correlation was observed between age and pulp–tooth volume ratio. In addition, pulp–tooth volume ratio of mandibular central incisors, maxillary lateral incisors, and maxillary canines in males and maxillary and mandibular central incisors, maxillary lateral incisors, and maxillary and mandibular canines in females can be used for age estimation. Age estimation was most accurate among females using maxillary central incisors and among males using mandibular central incisors and maxillary canines. Deposition of secondary dentin continues throughout an individual's life, reducing the size of the pulp cavity [11,12]. In addition, studies have shown that root canal system configuration changes overtime [25–27]. The present study found that this trend can be used for age estimation of individuals over 16.

In 1925, for the first time, Bodeckar noticed changes in the structure of teeth as age increases, and it was hypothesized that teeth could be used to estimate age. The first method of using teeth for estimating age was proposed by Gustafson in 1950 [28]. Over time, various methods have been proposed for this purpose, including the method introduced by Kvaal in 1995, in which the age of the tooth was estimated based on the amount of secondary dentin visible on radiography and the amount of pulp cavity. In this method, central incisors, lateral incisors, and second premolars of the maxilla and lateral incisors, canine, and first premolars of the mandible were examined in periapical intraoral radiography [29].

Yang et al. developed a pilot study in 2006, which for the first time CBCT was used to compare pulp–tooth volume ratio in 28 single-rooted teeth. In this study, a special software was used for volumetric measurements and a formula was presented for estimating the age with a coefficient of determination of 29% [21]. CBCT imaging technique was also used in this study for providing the volumetric information. High-resolution images and the relatively low radiation dose of CBCT images make it an optimal three-dimensional modality for the craniofacial region. The deposition of secondary dentin on the walls of the pulp cavity is often non-uniform, making measurements on two-dimensional images inaccurate.

Brkic et al. concluded that teeth in both jaws are reliable for estimating age. However, a stronger relationship was observed for maxillary teeth. According to the study of Biuki et al., the pulp–tooth volume ratio in all anterior teeth showed a significant relationship with age [24]. Nevertheless, canine teeth due to having large pulp cavities, less wear, and the possibility of remaining longer in the mouth are better options for age estimation [30]. In addition, Tardivo et al. have also successfully used canine teeth for age estimation purposes [31]. Similar to our findings, in the study of Biuki et al., the correlation between age and pulp–tooth volume ratio in maxillary canines was higher than in mandibular canine [24]. Therefore, they are more reliable for predicting the age in adults. Sakhdari et al. reported that the degree of the relationship between the pulp–tooth volume ratio of canine teeth and age was higher in women than men, which is in line with the results of this study. Although, it should be noted that the study of Sakhdari et al. not only reported a weak relationship in women, but also men did not show any significant relationship between age and the pulp–tooth volume ratio of the maxillary canine [32]. This study showed that in some teeth, including the mandibular canine and maxillary central incisor, the intensity of the correlation was higher in women than men, which is consistent with the study of Star et al. [33].

One of the limitations of this study was its focus on one specific population in Iran. Since the factors related to dental morphology and development are highly related to race, ethnicity, and environmental factors, and also due to the racial diversity in Iran, it is suggested that more comprehensive studies be designed and implemented on age estimation using pulp–tooth volume ratio. In addition, due to the wide age range in the present study, further studies on more limited age ranges are recommended. Due to the detailed explanation of software usage in this paper, other researchers can follow these methodological steps for further research purposes.

5. Conclusions

Pulp–tooth volume ratio of mandibular central incisors, maxillary lateral incisors, and maxillary canines in males and maxillary and mandibular central incisors, maxillary lateral incisors, and maxillary and mandibular canines in females can be used for age estimation.

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Data Availability Statement: The data presented in this study are available in request from the corresponding author.

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