AGE ESTIMATION BASED ON PULP–TOOTH VOLUME RATIO USING CONE-BEAM COMPUTED TOMOGRAPHIC IMAGES

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ABSTRACT

Objective: The present study aimed to investigate the correlation between chronological age and pulp/tooth volume (PV/TV) ratio of intercanine teeth using cone beam computed tomographic (CBCT) images and to provide equations for age estimation based on PV/TV ratio.

Methods: The study was conducted on CBCT scans of 30 patients of the Faculty of Dentistry University of Sarajevo. The sample included 17 males and 13 females with chronological age ranging from 17 to 54 years. A total of 180 teeth (central, lateral incisors and canines) were evaluated. Pulp and tooth volume of 180 teeth were measured using ITK software. Pearson's correlation was used to assess the correlation between chronological age and PV/TV ratio. The simple linear regression model was used to determine the formula in order to estimate chronological age.

Results: The regression analysis showed the highest Pearson correlation (0.612) for the maxillary central incisor. PV/TV ratio showed no statistical differences between male and female subjects ($p>0.05$), therefore no gender related formula was developed.

Conclusion: Strongest correlation was found between the age and PV/TV ratio measured on maxillary central incisors. This study showed that PV/TV ratio was not gender dependent. The obtained valid regression formula in this study can serve as a tool for age estimation. This formula should be further validated on a larger sample size.

Keywords: Age estimation, Cone-beam computed tomography, Pulp volume, Tooth volume, Pulp/tooth (PV/TV) ratio.

Introduction

The age estimation of living or deceased individuals is an important aspect of forensic investigation [1]. Of the many procedures for age estimation, dental age is an efficient method to estimate the chronological age of humans [2]. The morphology and arrangement of teeth vary from person to person and are unique to an individual, as are the fingerprints. Therefore, the use of dentition is the method of choice in the identification of the unknown [3]. The pulp-dentin complex is one of the dental structures showing modifications related to age. It mainly results in the reduction of the pulp chamber volume due to the continual deposition of secondary dentin by odontoblasts along the pulp chamber walls [4]. There are two types of physiologic dentin: primary dentin, deposited before root formation is complete, and secondary dentin, formed after root completion and continues to be formed throughout life [5]. After root completion, secondary dentin is deposited in the pulp cavity wall as long as the tooth is still vital, reducing the pulp chamber. The amount of secondary dentin can be an indicator of age [6]. In children, age estimation using teeth is relatively simple and is done based on the developmental stage of the teeth. But age estimation in adults is a challenge in forensic medicine [7].

Numerous adult dental age estimation methods have been developed based on measurements of pulp chamber volume reduction. Most of these methods are invasive, requiring the extraction of teeth [8]. Reduced pulp chamber volume resulting from secondary dentin deposition can be calculated using histological, biochemical and radiographic techniques. However, histological and biochemical methods have disadvantages, such as being time-consuming and involving complex laboratory procedures [9]. Also, they are destructive methods because one or more teeth must be destroyed and prepared in microscopic sections being unethical and impossible to do in living subjects [10].

Radiological techniques play an important role in dental age determination. These methods offer a simple, non-invasive and reproducible means of providing proof of age for both living and dead human beings. Radiographic images that can be used in age identification include panoramic radiographs, X-rays, magnetic resonance images (MRI) and cone-beam computed tomography (CBCT) images [11]. Decreased pulp volume with secondary dentin accumulation was assessed by calculating the length, width and area measures without dental extraction on two-dimensional dental radiographs or on microscopic sections of the teeth [12]. However, the accuracy of these conventional methods has certain limits, such as image distortion and superimposition, different magnifications and the availability of only linear measurements [13]. One of the biggest limitations of this radiologic technique is the image deformation that occurs when a tooth is malpositioned, leading sometimes to some incertitude in the developmental stage definition or even to the impossibility of evaluation. [14]. Forensic odontology has benefited from the use of periapical and panoramic radiographs especially with the introduction of cone beam computed tomography (CBCT) in clinical practice. The advantage of CBCT over intraoral periapical and panoramic imaging in dental age estimation comes from the availability of three-dimensional multiplanar navigation allowing more detailed observation of morphological features. Among these features is pulp chamber size demonstrating a time-dependent reduction in volume following the progressive deposition of secondary dentin [15]. In recent years, using CBCT has enabled the use of 3D images for evaluation of the correlation between age and size of the pulp chamber. Several researchers estimated age by using 3D CBCT to overcome the limitations of 2D images [16]. CBCT enables 3D visualization of the teeth without superimposition, distortion or magnification. In CBCT imaging, voxels are isotropic and range from 0.4 mm to as small as 0.075 mm. Images can be constructed on any plane with high accuracy and reproducibility. The ability to differentiate objects of different attenuation separated by very small distances is one of the most important qualities of CBCT imaging and is largely the result of flat panel detector technology and isotropic data acquisition. Owing to this superior spatial resolution, the use of CBCT was recommended for identifying and assessing root canals, evaluating anatomical variations and detecting root fractures and resorption. CBCT may also be considered as an accurate tool for the evaluation of pulp volume [17]. Any tooth can be used for age estimation [18].

Materials and methods:

The present study was an analytical cross-sectional study conducted using CBCT images of patients from the Faculty of Dentistry, University of Sarajevo. The research was approved by the Ethics Committee of the Faculty of Dentistry No. 01-4-2-44-6/2021. The CBCT images used in this study were taken for routine therapeutic treatments and clinical evaluation. To observe ethical considerations, all information provided was treated as confidential, and the names of individuals were not released at the analysis and reporting stage.

The inclusion criteria were patients with the maxillary and mandibular central incisors, lateral incisors and canine teeth, absence of pathologic lesions, caries, periodontal diseases, pulpal calcification, occlusal trauma, endodontic, restorative or prosthetic treatment. Teeth that were not fully erupted and teeth with open apical foramen were excluded from the study. Study involved single rooted teeth for volumetric analysis. The sample included 17 males and 13 females with chronological age ranging from 17 to 54 years, in total 180 teeth (central incisors, lateral incisors and canines).

All the CBCT images were taken using the CBCT scanner Galileos comfort plus and face scanner (Sirona the dental company, Germany) with power voltage of 98kV, power intensity of 15-30mAs, scanning time 14 seconds, rotation 200°. Fixed visual field was 15 cm, and resulting scan volume was 15x15x15 cm. Isotropic voxel size was 0.25/ 0.125 mm.

CBCT images are imported to the Digital Imaging and Communications in Medicine (DICOM) format to ITK-SNAP version 3.8 segmentation software, which is an useful tool to separate the anatomical structures on 3D images. The software ITK-SNAP was used for measuring pulp chamber and tooth volumes using automatic segmentation or seed region-growing. Segmentation process was done automatically by selecting threshold ranges appropriate for tooth structures density [20].

Segmenting the chamber space is based on difference of the gray levels corresponding to surrounding dentine tissue (high intensity structure) and the present pulp tissue (low intensity tissue).

First, it is necessary to locate the “regions of interest” (ROIs) in the sagittal section of teeth in the

Image 1. ITK Snap software

intercanine region. Pulp chamber volume segmentation was accomplished by selecting a “label” to paint above the “clear label”. Then, the contrast thresholding in the “pre segmentation mode” was set to a minimum in the lower and upper thresholds as desired to segment and paint the pulp chamber fully. Tooth volume segmentation was performed with the same method. After adding a “seed” inside the structure to reconstruct, in this case the pulp chamber and whole tooth, this seed grows and finally three-dimensional model of pulp chamber and tooth was reconstructed with their volumes calculated automaticaly by the software in mm3.

(Image 1.)

Pulp/tooth volume ratio was analysed to find out the regression formula of age estimation. All measurements (pulp chamber volume, tooth volume and the percentage ratio: pulp/tooth volume) and additional information (age, gender, teeth group) were analyzed using the statistical program (SPSS Statistics ver. 27.0.0. Windows).

Pearson correlation coefficient was used to evaluate the correlation between chronological age and the pulp/tooth volume ratios. Simple linear regression model was considered as the dependent variable and the pulp/tooth volume ratio was considered as the predictive variable to determine the formula to estimate chronological age. Statistical significance was set at P≤0.05.

Results

A total of 180 pulp and tooth volumes were analysed in 30 patients, 17 female and 13 males. The mean age of the observed patients was 35.8±10.58 years. The mean age of the female was 33.29±9.27 and of the male was 39.08±11.64.

In the total sample, the observed mean pulp volume of the first mandibular incisor was 10.3+±5.7, with a median of 8.75 mm3 and an interquartile range of 6.2 to 11.9 mm3. The mandibular second incisor had a mean pulp volume of 12.1±6.6 mm3, with a median of 12.5 and an interquartile range of 5.8 to 16.7 mm3. The mandibular canine pulp volume was 22.2±11. mm3, with a median of 21.6 mm3 and an interquartile range of 13.1 to 27.8 mm3. In the maxilla, the mean pulp volume of the first incisor was 17.7±7.6 mm3, with a median of 19 mm3 and an interquartile range of 12.4 to 21.3 mm3. The mean pulp volume of the second incisor was 15.03±7.09 mm3, with a median of 14.95 and an interquartile range of 9.2 to 19.9 mm3. The maxillary canine had a mean pulp volume of 27.6±14.3 mm3, with a median of 28.1 mm3 and an interquartile range of 18.6 to 34 mm3 (Table 1).

Tooth	Pulp volume			Tooth volume		
	Mean±SD	Median	IQ range	Mean±SD	Median	IQ range
Mandibular central incisor	10.3±5.7	8.75	6.2-11.9	221.09±56.42	229.2	182.6-246.1
Mandibular lateral incisor	12.1±6.6	12.5	5.8-16.7	237.26±58.26	232.45	192.6-258.4
Mandibular canine	22.2±11.8	21.6	13.1-27.8	417.09±101.99	384.10	347.9-446.8
Maxillar central incisor	17.7±7.6	19	12.4-21.3	435.89±69.82	441.10	383.1-485.5
Maxillar lateral incisor	15.03±7.09	14.95	9.2-19.9	4299.09±47.72	296.25	272.6-336.1
Maxillar canine	27.6±14.3	28.1	18.6-34.8	543.22±102.11	529.45	462.7-584.5

Table 1. Pulp and tooth volumes

Mean tooth volume of the first mandibular incisor was 220.09+56.42, with a median of 229.2 mm3 and an interquartile range of 182.6 to 246.1 mm3.The mandibular second incisor had a mean tooth volume of 237.26±58.26 mm3, with a median of 232.45 and an interquartile range of 192.6-258,4 mm3. The mandibular canine tooth volume volume was 417.09±101.99 mm3, with a median of 384.10 mm3 and an interquartile range of 347.9 to 446.8 mm3. In the maxilla, the mean tooth volume of the first incisor was 435.89±69.8 mm3, with a median of 441.10 and an interquartile range of 383.10 to 485.5 mm3. The mean tooth volume of the second incisor was 299.09±47.72 mm3, with a median of 296.25 mm3 and an interquartile range of 272.6 to 336.1 mm3. The maxillary canine had a mean tooth volume of 543.22±102.11 mm3, with a median of 529.45 mm3 and an interquartile range of 462.7 to 584.5 mm3.

The ratio of PV/TV volume in the central mandibular incisor had a median value of 0.058 (0.042-0.070). In the lateral mandibular incisor, the median value of PV/TV was 0.049 (0.032-0.068).

Mandibular canine PV/TV had a median value of 0.054. Maxillary central incisor had a median PV/TV of 0.065 (0.041-0.078). Maxillary lateral incisor had a median PV/TV value of 0.037 (0.024-0.044). Maxillary canine had a median PV/TV of 0.056 (0.036-0.063). PV/TV showed no statistical differences between the male and female subjects (p>0.05). Therefore, no gender related formula was developed (Table 2).

Tooth	n	PV/TV ratio		
		Mean±SD	Median	IQ range
Mandibular central incisor	30	0.047±0.023	0.048	0.033-0.069
Mandibular lateral incisor	30	0.049±0.024	0.049	0.032-0.068
Mandibular canine	30	0.053±0.024	0.054	0.038-0.066
Maxillar central incisor	30	0.062±0.028	0.065	0.041-0.078
Maxillar lateral incisor	30	0.034±0.014	0.037	0.024-0.044
Maxillar canine	30	0.05±0.021	0.056	0.036-0.063

Table 2. Ratio of pulp volume and tooth volume

The regression equation was obtained for each tooth group and correlation coefficient was calculated. The regression analysis showed the highest Pearson correlation (0.612) for the maxillary central incisor. When maxillary central incisors were used as explanatory variables for age estimation, the regression equation explained 61,2% of the total variance of age. After that, the best results were shown using maxillar canine (r=0.698), the regression equation explained 48,8% of the variance of age. (Table 3).

Figure (1-6)

Tooth	r	R^2 linear	Regression equation	SE
Mandibular central incisor	-0.64*	0.410	Age=52.707+(-289.311*PV/TV)	65.37
Mandibular lateral incisor	-0.62*	0.384	Age=49.096+(-269.324*PV/TV)	64.45
Mandibular canine	-0.51**	0.257	Age=47.480+(-222.460*PV/TV)	71.51
Maxillar central incisor	-0.78*	0.612	Age=56.088+(-598.551*PV/TV)	90.02
Maxillar lateral incisor	-0.59*	0.352	Age=49.434+(-221.305*PV/TV)	56.69
Maxillar canine	-0.70*	0.488	Age=53.504+(-354.447*PV/TV)	68.65

*r - Pearsons correlation, * - p<0.001, **-p<0.05, R^2 – Variance described*

Table 3. The regression equations, correlation coefficient (R^2) and the SE (n=30)

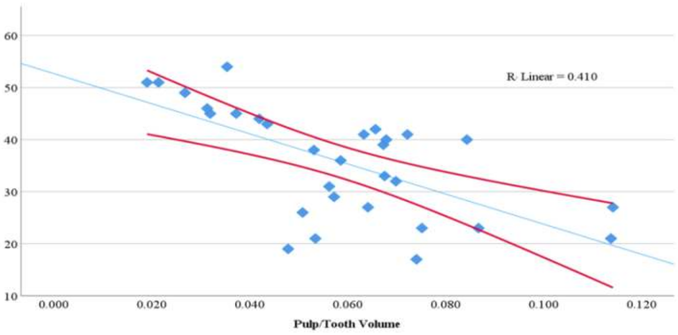

Figure 1.
The regression equation of mandibular central incisor teeth

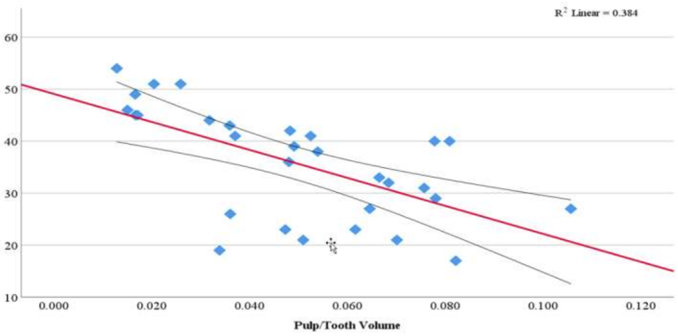

Figure 2.
The regression equation of mandibular lateral incisor teeth

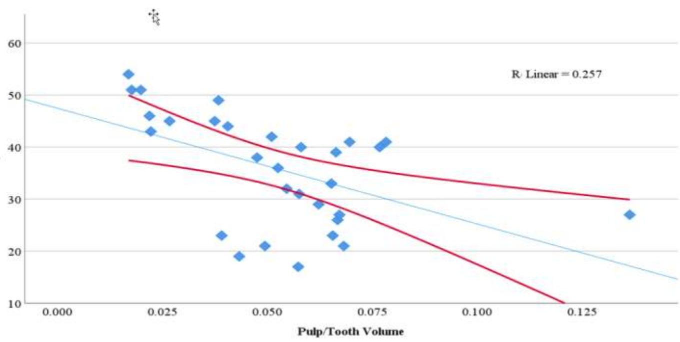

Figure 3.
The regression equation of mandibular canine teeth

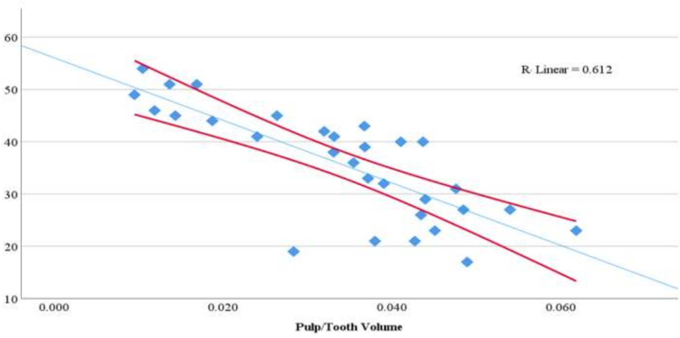

Figure 4.
The regression equation of maxillar lateral incisor teeth

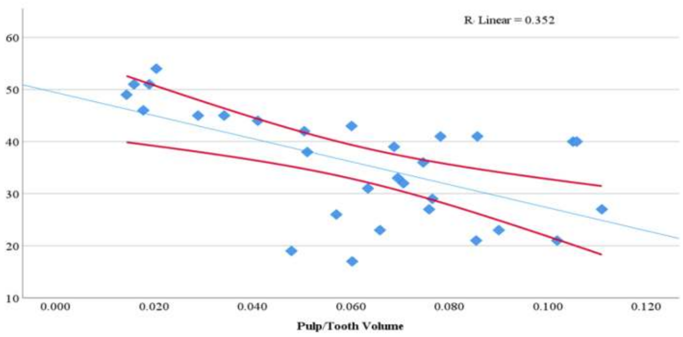

Figure 5.
The regression equation of maxillar central incisor teeth

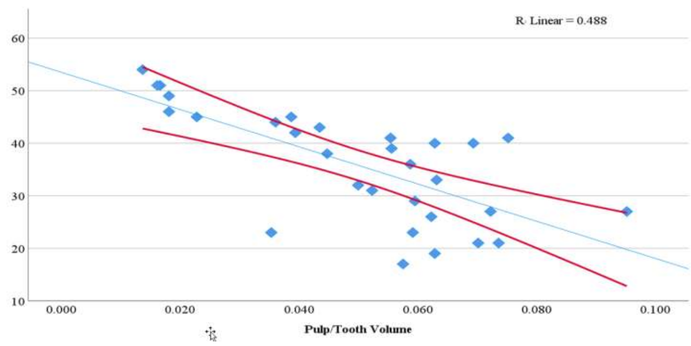

Figure 6.
The regression equation of maxillar canine teeth

Discussion

Based on the results of the present study, the mean PV/TV ratio in the maxillary canine (543.22±102.11 mm3) was higher compared to other teeth. In the present study, the regression equation was obtained for each tooth group and the correlation coefficient was calculated. The regression analysis showed the highest Pearson correlation (0.612) for the maxillary central incisor. PV/TV ratio showed no statistical differences between the male and female respondants (p>0.05). Therefore, no gender related formula was developed.

The increasing use of three-dimensional images in dental practice made the research of association between age and PV/TV ratio easier in samples from Belgium [2, 21], Italy [4,22], Turkey [17], Iran [23, 24]. Malaysia [19, 25], Spain [27] and China [28, 29].

Yang et al. developed a pilot study in which for the first time CBCT was used to compare the PV/TV 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 0.29 and a standard deviation of 8.3 years. In addition, it was reported that it is possible to calculate PV/TV ratios in living individuals by three-dimensional evaluation of CBCT images [2].

Star et al. reported a weak correlation between PV/TV ratio and chronological age in 111 single-rooted teeth in the Belgian population. Their study included 64 incisors, 32 canines and 15 premolars from CBCT scans of 54 male and 57 female. Their results showed that age estimation is the best predicted by incisors, followed by premolars and canines [21].

The relationship between chronological age and PV/TV ratio in maxillary canines was reported by Angelis et al. where the correlation on maxillary canines was moderate (R2 = 0.39) and significant in both genders with females showing a higher correlation than males. However, they reported that this method of age estimation is gender-independent [22]. Pinchi et al. showed a significant correlation between PV/TV ratio and chronological age. This author also found that this method of dental age estimation was gender-independent [4].

In research from Turkey, Gulsahi et al. measured pulp volume and tooth volume on CBCT scans of 655 maxillary incisors and canine and mandibular canine and premolars. The authors reported the highest Pearson correlation (0.532) for the maxillary central incisor and the lowest value with maxillary canines, similar to results from our study [17].

According to the study of Biuki et al., PV/TV ratio in all anterior teeth showed a significant relationship with age. Similar to our findings, the correlation between age and PV/TV ratio in maxillary canines was higher compared to mandibular canines, which is explained by the anatomy, morphology and size of canines and the minor effect of irritating factors on secondary dentin formation [23].

Haghanifar et al. aimed to evaluate the predictive power of the PV/TV ratio of maxillary and mandibular central incisors and canines obtained from the sagittal and axial views of CBCT. The regression analyses indicated that maxillary central incisors were more reliable for age estimation R2 = 0.586 compared with the other anterior teeth [24].

Asif et al. investigated the association between chronological age and PV/TV ratio among the Malaysian population in these 3 grupes of teeth (maxillary right canines, maxillary left canines and maxillary right central incisors). Result showed that the best indicator in age estimation is maxilary central incisor, followed by the right canine and the maxillary left canine [19].

In their second study, Asif at al. used two approaches to volumetric analysis to examine the relationship between chronological age and PV/TV ratio: pulp cavity/tooth ratio and pulp chamber/crown ratio (up to CEJ). Although both methods obtained a strong correlation with chronological age, the result was better with the pulp chamber/crown ratio method [25]. Further analysis found no significant difference between the estimated and chronological ages related to gender and voxel sizes [26].

According to Molina et al. the highest coefficient of determination (R2) value was provided by the upper incisors (36.6%) and the difference between chronological and estimated age was less than 5 years in 31.3% of the sample and less than 10 years for 65.7% [27].

Yang et al. investigated the association between chronological age and the PV/TV ratio using CBCT in children and young adults from Eastern China. They reported that CBCT scans may become an efficient method to estimate the chronological age of children and young adults [28].

Ge at al. Another showed that maxillary second molars are the best indicatos in age estimation [29].

One of the major limitations of our study was the small number of teeth in the validation sample; thus, it is recommended to perform validation of the established model on a larger scale.

Conclusion

The results indicated relationship between chronological age and PV/TV ratio for all groups of investigated teeth in the study.

The regression analysis showed the highest Pearson correlation for the maxillary central incisor tooth. This method of dental age estimation is gender independent as there was no statistically significant difference in the coefficient of correlation between male and female subjects.

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