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RESEARCH ARTICLE

Age estimation based on pulp/tooth volume ratio measured on cone-beam CT images

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Objectives: After tooth eruption, the size of the pulp cavity decreases with age owing to deposition of secondary dentine. The aim of this study was to investigate the relation between the chronological age and the ratio of pulp volume (PV) to tooth volume (TV) measurements using CBCT images of single rooted teeth.
Methods: Maxillary anterior, canine and mandibular canine/premolar CBCT scans of patients older than 15 years of age were collected from the archives between 2013 and 2015 years. Patients with CBCT scans of teeth were seen in detail and patients with known chronological age were included. Teeth with caries, filling or crown restorations, periapical pathologies or pulps that could not be identified were excluded. Consequently, 204 patients with 655 teeth were evaluated. The PV and the TV of each tooth was measured and then the PV/TV ratio was calculated. Simple linear regression analysis was performed in order to predict age estimation by using PV/TV.
Results: The PV/TV of all teeth ranged between 0.01 and 0.08. A negative correlation was found between the PV/TV ratio and age ($p < 0.05$). The regression analysis showed the highest Pearson correlation (0.532) for the maxillary central incisor tooth. Considering measurements of the PV/TV of all assessed teeth, there was no significant difference in the intercept between both gender ($p > 0.05$).
Conclusions: This study revealed that PV/TV ratio was not gender dependent and the strongest correlation was found between the age and PV/TV ratio measured on maxillary central incisors than other teeth.
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Keywords: age estimation; cone-beam CT; secondary dentine; pulp-tooth volume ratio

Introduction

Age estimation is important in forensic dentistry for both living and non-living subjects. Genetics, nutritional and hormonal factors may all affect human skeleton. Teeth are less affected from external factors when compared with other parts of the human skeleton.[1–5] Therefore, estimation of chronological age (CA) by using morphological and radiological analysis of teeth is more important not only for forensic dentistry but also for human anthropology and bioarchaeology. Mainly, odontological age estimation methods are based on the developmental,[6–10] morphological[1,11–16] and biochemical tooth changes.[17] Analysis of tooth development specifically helps in the age determination of children and adolescent; however, determination of age is difficult in adults as permanent dentition is already completed.[5] Methods that are based on biochemical tooth changes, such

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as aspartic acid racemization are time-consuming, complex and destructive and, therefore, are not commonly utilized.[2,4,5] On the other hand, the pulp–dentine complex show modifications related to age, mainly resulting in the reduction of the pulp chamber volume.[18] This reduction in volume occurs owing to continual deposition of secondary dentine in the pulp cavity after tooth eruption. As a result, the size of the pulp cavity gradually decreases with age.[2,4] Thus, secondary dentine deposition is a significant morphological criterion for age estimation in adult subjects.[11,12,15,16] Secondary dentine apposition can be evaluated by extracting and sectioning a tooth or by using 2D dental radiographic methods.[2,4,13,18] Both panoramic and periapical radiographs have been commonly utilized in order to assess this phenomenon by using the pulp/tooth area ratio method. The primary disadvantage of these conventional radiographic techniques is that they are 2D projections which are subject to considerable magnification and distortion errors.[2,4,5,16,19,20] Therefore, simultaneous assessment of the mesio-distal and bucco-lingual dimensions of teeth are recommended.[14] Recently, with the wide range use of 3D images in clinical dental practice, the potential relationship between age and the ratio of the pulp volume (PV) to entire tooth volume (TV) was investigated.[2,4,5,18,21,22] 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 in any plane with high accuracy and reproducibility. The ability to discriminate objects of different attenuation separated by very small distances is one of the most attractive qualities of CBCT imaging and is largely the result of flat panel detector technology and isotropic data acquisition.[23] Owing to this superior spatial resolution, the usage 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 and ideal tool for the evaluation of the PV.[5,18,20] Therefore, the aim of this study was to investigate the relationship between CA and the ratio of PV to TV measurements using available CBCT images of single-rooted teeth.

Methods and materials

This retrospective study was approved by Institutional Review Board of Baskent University (Project No. D-KA15/01). CBCT scans of patients who were older than 15 years of age were collected from the archives of a private imaging centre between 2013 and 2015. CBCT scans were obtained for various reasons such as impacted teeth, dental anomalies, implant planning or orthodontics. Single maxillary central, lateral, canine and mandibular canine, first and second premolar teeth were assessed retrospectively from patients with known CA. Teeth with caries, filling or crown restorations, periapical pathologies, anomalies or pulpal pathosis were excluded. Finally, 655 teeth of 204 patients were evaluated. All CBCT images were taken with the same device (Kodak CS9300, Carestream Health, Rochester, NY) using 60–90 kVp, 2–15 mA and 12–28 s scanning time. Field of view was between 5 × 5 cm and 10 × 5 cm and focal spot was 0.7 mm and the voxel size ranged between 0.09 and 0.2 mm. The images were analysed on the LENOVO Y50-70 notebook (Hong Kong SAR, China) with 15.6 inch, 1920 × 1080 resolution and 32-bit screen.

Two observers with 2-year experience in dentomaxillofacial radiology under the supervision of a senior dentomaxillofacial radiology specialist analysed the images. The observers used features such as contrast and magnification on images if deemed necessary. For volumetric measurements, axial CBCT scans were exported as DICOM files and then imported into a volumetric rendering software capable of measurements of vector-based segmentation technology (3D DOCTOR, Able Software Corp, Lexington, MA). This software allows tissue segmentation on consecutive axial and sagittal slices enabling pulp tissue visualization at each level apico-coronally. This ensured detailed slice-by-slice segmentation of the borders manually using a mouse with colour-delineation (turquoise green). Automated calculation of the TV (Figure 1a) and PV (Figure 1b) from the areas outlined on each slice was performed by the software. When any interpolation was observed, other observers also measured the same tooth and agreed. This measurement was performed twice by the observer and average volumes were taken from both the pulp and the tooth. Before the study, 10 teeth measurements were performed on CBCT images as a pilot study. PV and TV of all of these teeth were measured on axial and sagittal planes. Since no difference was observed between the two measurements, only sagittal plane with 0.18 mm section thickness and 0.5 mm intervals for each tooth was performed in the study. First of all, PV and TV of each tooth was measured and then the PV/TV ratio was calculated.

Reliability

Both observers were calibrated before the measurements in a special session. For the intraobserver agreement, 30 CBCT images were measured by the observers 1.5 months after the initial evaluation. Intra- and interobserver agreement was assessed by using intraclass correlation coefficient.

Statistical analysis

All statistical analyses were performed using SPSS for Windows 11.5 software program (SPSS Inc., Chicago, IL). Simple linear regression analysis was utilized in order to predict age estimation by using PV/TV as independent variables. Analysis of covariance was

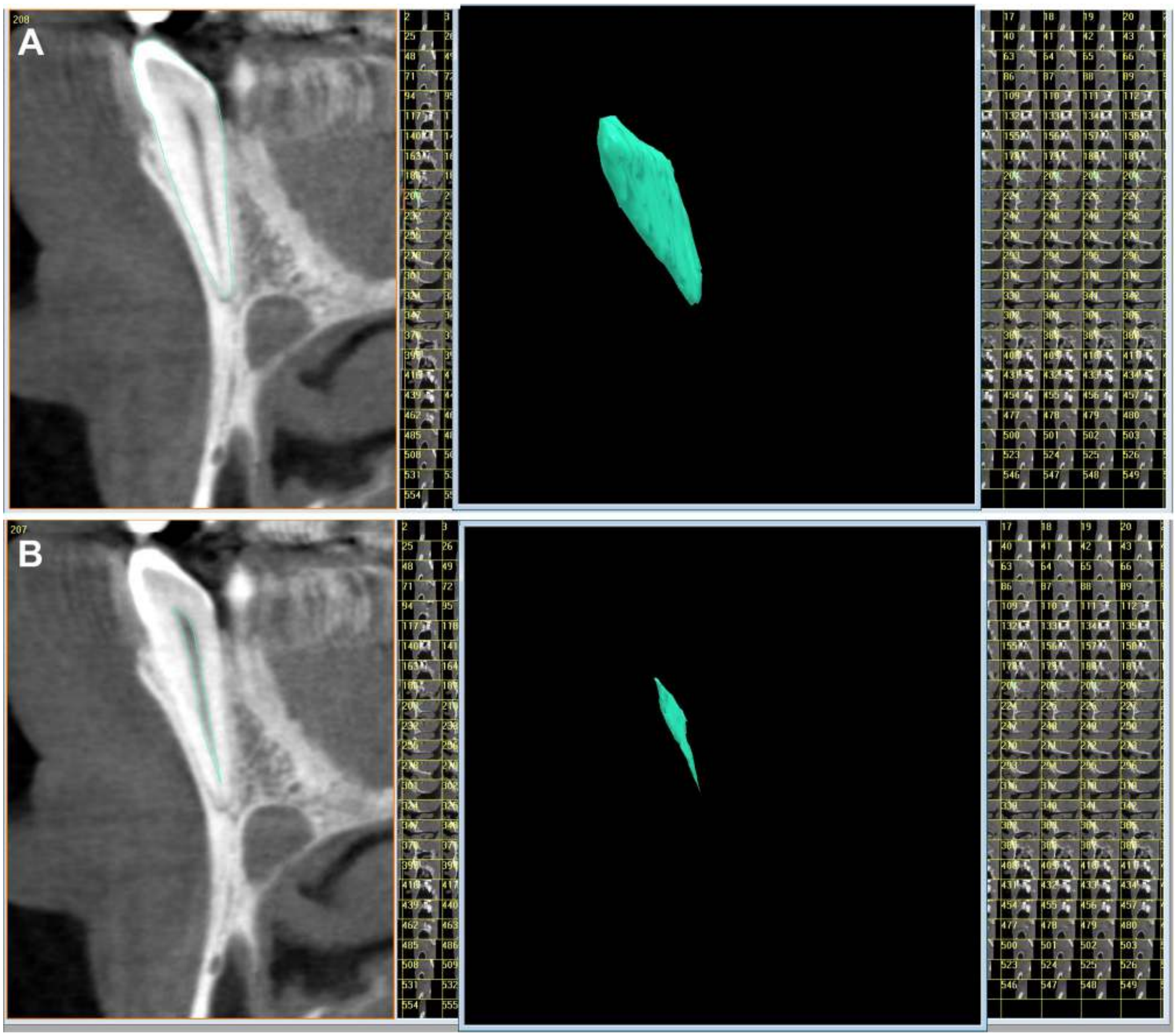

Figure 1 (a) The automated calculation of the tooth volume and (b) the pulp volume from the areas outlined on each slice was performed by the software.

applied to assess possible interactions between tooth measurements and gender. Significance level was set at $p = 0.05$.

Results

Intraclass correlation coefficient values indicating intraobserver and interobserver agreements ranged between 0.85–0.93 and 0.81–0.90, respectively. Intraobserver agreement was good and interobserver agreement varied between moderate and good.

The sample composed of 108 males (52.9%) and 96 females (47.1%). In this study, 91 maxillary centrals, 102 maxillary laterals, 113 maxillary canines, 131 mandibular canines, 125 mandibular first premolars and 93 mandibular second premolars were included. Distribution of assessed teeth according to age groups is shown in Table 1.

The calculated PV/TV of all teeth ranged between 0.01 and 0.08 (Table 2). There was a negative correlation between the PV/TV ratio and age ($p < 0.05$).

The regression equation was obtained for each tooth type and Pearson's correlation coefficient was calculated (Table 3). The regression analysis showed the highest Pearson correlation (0.532) for the maxillary central incisor tooth. When maxillary central incisors were used as explanatory variables for age estimation, the regression equation explained 53.2% of the total variance of age (Figure 2). The variability in age based on the Pearson correlations were 25.2, 21.7, 21, 20.7 and 15.3% for the maxillary laterals, mandibular second premolars, mandibular canines, mandibular

Table 1 The distributions of assessed teeth according to age groups

Age (years)	*Maxillary central incisor n (%)*	*Maxillary lateral incisor n (%)*	*Maxillary canine n (%)*	*Mandibular canine n (%)*	*Mandibular first premolar n (%)*	*Mandibular second premolar n (%)*
15–20	2 (2.2)	4 (3.9)	4 (3.5)	8 (6.1)	6 (4.8)	6 (6.5)
21–30	10 (11.0)	13 (12.7)	15 (13.3)	21 (16.0)	20 (16.0)	14 (15.1)
31–40	31 (34.1)	31 (30.4)	36 (31.9)	29 (22.1)	29 (23.2)	26 (28.0)
41–50	27 (29.7)	27 (26.5)	29 (25.7)	35 (26.7)	37 (29.6)	25 (26.9)
51–60	12 (13.2)	17 (16.7)	17 (15.0)	25 (19.1)	23 (18.4)	17 (18.3)
61–70	9 (9.9)	10 (9.8)	12 (10.6)	13 (9.9)	10 (8.0)	5 (5.4)
Total	91 (100)	102 (100)	113 (100)	131 (100)	125 (100)	93 (100)

first premolars and maxillary canines, respectively (Figures 3–7).

Considering measurements of the PV/TV of all assessed teeth, analysis of covariance did not show a significant difference in the intercept between both gender ($p > 0.05$). Therefore, no gender related formula was developed.

Discussion

Age estimation is of broader importance in forensic medicine, not only for identification purposes of the deceased, but also for living subjects. In living adults, the number of age estimation methods is greatly reduced because the skeletal processes and dental maturation are completed.[24] In this situation, physical examination, hormone dosage for females and some dental methods can be used.

After tooth eruption, the formation of secondary dentine causes PV to decrease. This change is considered as a valuable dental age predictor for adults and measured from dental radiographs.[2,24] Pulp/tooth area ratio as an indicator of age was presented by Cameriere.[25,26] This method requires a radiographic image of an examined tooth, computer-aided drafting software and trained personnel. Previous reports describe the correlation between secondary dentine deposition along the pulp chamber walls and age, as well as the possibility of detecting and measuring these changes on periapical or panoramic radiographs that are routinely used non-destructive techniques in dentistry.[1,11,15,16,19] However, these radiographs are 2D and fail to provide volumetric information regarding the teeth and related structures.

CBCT offers high quality images with relatively low radiation dose.[2,5,20,23] The use of CBCT scans for age assessment has several advantages compared with 2D techniques such as; it provides an objective criteria, namely PV/TV ratio, is a simple technique and is applicable to a wide range of subjects or specimens and does not require tooth extraction for sectioning.[4,14,17] Up to now, pulp/tooth area ratio have been used to compensate the magnification or angulation errors of the 2D radiographs.[11,15,16,19] The ratio between the PV and TV was used in the present study in order to eliminate bias in measurements that occur owing to individual variation. In this study, we preferred using consecutive sagittal plane images for the calculation of PV/TV since no difference was detected between axial and sagittal images in pilots. Also, observers found it easier and quicker to calculate volumes by using sagittal views when compared with axial ones. Unlike our study, authors of another study calculated only pulp chamber volume using CBCT images.[5] They found that the pulp chamber volume of maxillary and mandibular first molar teeth were useful for age estimation. This finding was explained by the fact that age-related formation of secondary dentine by time results in a decrease in pulp cavity volume. They also suggested that pulp chamber volume calculation was more accurate than the whole TV calculation owing to high image contrast between pulp and dentine.[5] The same authors performed another study and measured multiple types of tooth's pulp chamber.[27] They concluded that the pulp

Table 2 The mean and median values PV/TV of all assessed teeth

Tooth	*n*	*Mean ± SD*	*Median (Min–Max)*
Maxillary central incisor	91	0.031 ± 0.01	0.029 (0.01–0.06)
Maxillary lateral incisor	102	0.030 ± 0.01	0.029 (0.01–0.06)
Mandibular canine	131	0.042 ± 0.01	0.042 (0.02–0.08)
Mandibular second premolar	93	0.035 ± 0.02	0.033 (0.01–0.06)
Mandibular first premolar	125	0.038 ± 0.01	0.037 (0.02–0.08)
Maxillary canine	113	0.038 ± 0.01	0.036 (0.01–0.07)

Table 3 The regression equations, the Pearson's correlation coefficient (r^2) and the SE

Tooth	*n*	r^2	*Regression equation*	*SE*
Maxillary central incisor	91	0.532	Age = 68.3 − (837.5 × PV/TV)	83.2
Maxillary lateral incisor	102	0.252	Age = 61.1 − (611.7 × PV/TV)	105.3
Mandibular second premolar	93	0.215	Age = 62.9 − (627.2 × PV/TV)	125.5
Mandibular canine	131	0.210	Age = 65.9 − (574.3 × PV/TV)	97.9
Mandibular first premolar	125	0.207	Age = 62.6 − (548.1 × PV/TV)	96.7
Maxillary canine	113	0.153	Age = 60.5 − (479.3 × PV/TV)	107.1

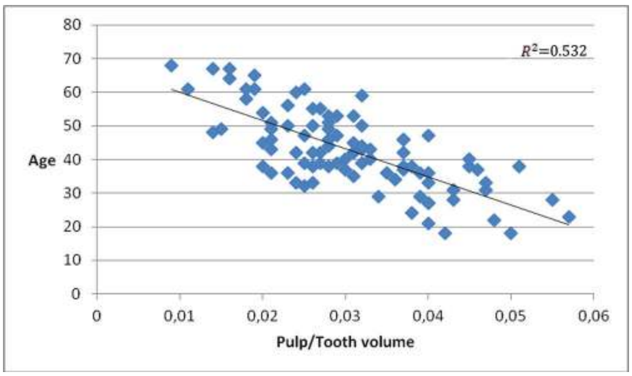

Figure 2 The regression equation of maxillary central incisor teeth.

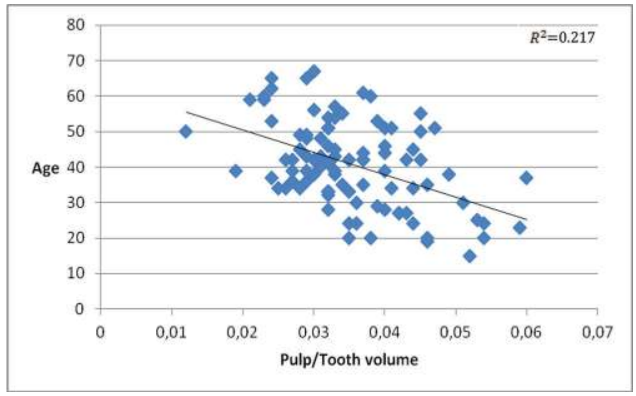

Figure 4 The regression equation of mandibular second premolar teeth.

chamber volume of the maxillary second molars had the largest correlation coefficient with age. Therefore, using multiple types of tooth may improve the accuracy of age estimation compared with only one type of tooth used.

In another study, a new technique was proposed for measuring dental volume based on the assimilation of the root and pulp chamber to geometric solids. By using this procedure, the details of the images are drawn manually and then measurements and calculations are performed. They stated that by using this method age estimation was accomplished in less than 15 min.[18] However, in the present study, we measured only pulp volume of the tested teeth and found no correlation between the CA and PV of any tooth. Therefore, we changed our methodology and measured PV/TV.

We found the strongest correlation between the age and PV/TV ratio measured on maxillary central incisors. Similarly, maxillary central incisor had been chosen to estimate age through the PV decreasing owing to individual ageing in other studies.[2,4,18] Also, Star et al[2] found the highest correlation for the maxillary incisor teeth. They assumed that the reason for this could be the relatively low number of canines and premolars included in the mentioned study. However, in the present study, we evaluated almost equal number of all teeth groups and only maxillary central incisors showed strong correlation with age.

Several studies suggested that the measurement of the pulpal size area in canines revealed better secondary dentinal deposition than the other teeth groups with

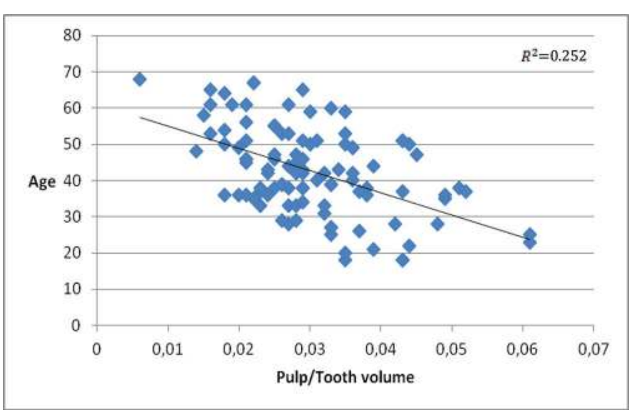

Figure 3 The regression equation of maxillary lateral incisor teeth.

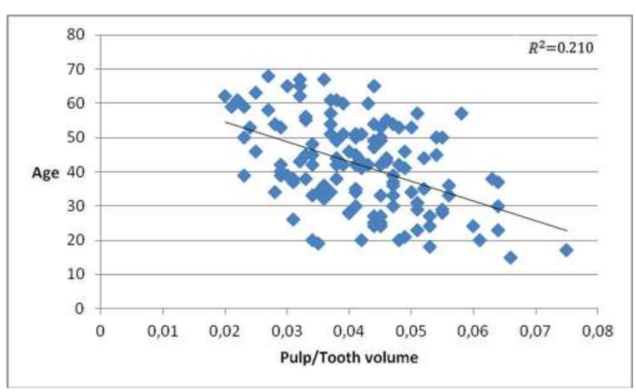

Figure 5 The regression equation of mandibular canine teeth.

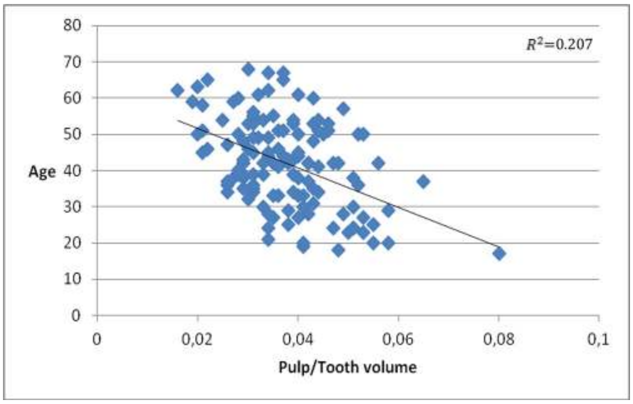

Figure 6 The regression equation of mandibular first premolars.

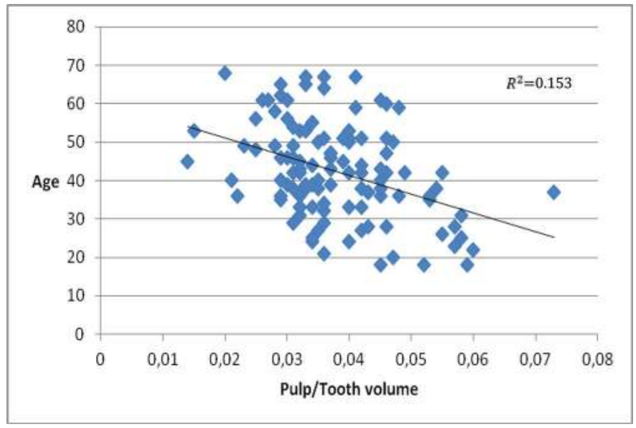

Figure 7 The regression equation of maxillary canines.

smaller pulp areas (*e.g.* lateral incisor).[4,15,19,21] Smaller size of such single-rooted teeth may lead to less clear images and inaccurate pulp tooth ratio measurement. Therefore, in the present study we did not include mandibular anterior teeth owing to their small pulpal sizes. We were also unable to show a significant difference between genders considering PV/TV in agreement with other studies.[2,16,18] Therefore, gender was not included in the regression equations in the present study. On contrary, Someda et al[22] found a significant difference between the genders in Japanese adults. It should be noted that greater samples for each age cohort are essential to clarify the role of gender. Further research is essential in order to assess differences between teeth groups, measurement techniques and populations.

The validity and accuracy of the image segmentation methodology we used to measure volume on CBCT images has been previously demonstrated.[20] The validity of this approach for subsequent clinical protocols was substantiated in that linear and volumetric CBCT measurements correlated highly with the direct physical measurements of peri-implant defects. However, in applying our results to clinical situations, it should be made clear that it is more difficult to segment unclear buccal peri-implant defects when compared with pulpal and tooth structures. Considering the reduced visibility of subtle tooth and related structures when CBCT units employing greater than 0.2 mm^3 voxel sizes are used, we preferred the voxel size under 0.2 mm^3 less than this apparent threshold.[20]

Authors by using 3D DOCTOR software capable of measuring vector-based segmentation technology measured the volume of nasopalatinal canal by segmenting the borders of this anatomical structure accurately on CBCT images.[28] The 3D DOCTOR software allows defect segmentation on consecutive sagittal slices of 0.18 mm in thickness, thereby enabling pulp tissue visualization at every level from the top to the bottom of the tooth structure. Using a computer mouse, a turquoise border was manually drawn on each slice to delineate PV and TV (mm^3) were then automatically calculated by the software. Age estimation conducted by using different third party software and comparing their measurements would be the question of our further research.

Conclusion

In conclusion, the measurement of the PV/TV using CBCT scans have provided high diagnostic images. This study revealed that PV/TV ratio was not gender dependent and the strongest correlation was found between the age and PV/TV ratio measured on maxillary central incisors followed by maxillary lateral incisors, mandibular second premolars, mandibular canines, mandibular first premolars and maxillary canines, respectively. Future studies may focus on modified techniques in order to obtain an optimized age estimation method by using CBCT images.

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