

Age Estimation by Kvaal's Method Using CBCT Scans of Mandibular Canine Teeth in an Iranian Population

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Introduction: Age estimation of individuals older than 21 years remains a challenge in forensic medicine. This study sought to assess the accuracy of age estimation by Kvaal's method using cone beam computed tomography (CBCT) scans of mandibular canine teeth in an Iranian population. **Materials and Methods:** In this cross-validation study, information of 150 test subjects and 30 controls was collected from the files of patients presenting to Shahid Beheshti University of Medical Sciences, School of Dentistry from 2014 to 2015. The parameters used in the Kvaal's method were measured in mandibular canine teeth on CBCT scans of patients. First, the regression formula suggested by Kvaal *et al*, was used for age estimation. Then we designed our own formula for age estimation according to Kvaal's method in our Iranian population and the fitness of statistical model was assessed. **Results:** Use of multiple linear regression model for assessment of the correlation of parameters in Kvaal's method according to CBCT images of mandibular canines and age in a step by step fashion showed that all variables namely pulp length/root length, pulp length/tooth length, pulp width/root width at the cemento-enamel junction (CEJ) and pulp width/root width at the mid-point of CEJ and mid-root were significant in age estimation ($P < 0.005$ for all four). In this model, R^2 was found to be 0.567, which indicated appropriate fitness of the regression model this should be revised "optimal". In this model, no significant linear correlation was noted between independent variables such that the variance inflation factor was maximally 1.4. **Conclusions:** Although most of the variables mentioned by Kvaal were effective in age estimation, some errors were seen in age estimation in the modeling and cross-validation phase. Thus, some other variables need to be included in the model to increase the accuracy of Kvaal's formula in the Iranian population.

Key words: Age Determination; Cone-Beam Computed Tomography; Forensic Dentistry; Mandibular Cuspid

Introduction

Several methods have been proposed for age estimation of individuals older than 21 years, yielding controversial results (1-4). To date, quantification of racemization of aspartic acid in dentin and cementum annulation has offered the most reliable results with regard to age estimation. However, both methods can only be used for corpse. Teeth can be used when other methods of identification cannot be successfully used. In situations when the corpse is disintegrated or decomposed or has been in water for long periods of time, the teeth often remain intact or undergo minimal changes compared to other body parts. Also, teeth are ideal for skeletal age estimation (1, 2).

Both calcification and eruption of teeth can be used for dental age estimation. The Demirjian's method is the most commonly used method worldwide for this purpose, which is based on tooth calcification. In this method, calcification of seven teeth in the mandibular left quadrant is assessed on panoramic radiographs (1, 2). During tooth development, formation of secondary dentin is started after dentinogenesis, and odontoblasts surrounding the pulp chamber continuously deposit secondary dentin layers along the pulp chamber walls. In 1889, Laccasagne was the first to estimate age based on changes in adult teeth (3). Later in 1925, Bodecker showed that secretion of secondary dentin was age-related. Secondary dentin is formed and deposited on the pulpal surface of primary dentin over time; this process gradually reduces the size of pulp chamber (4).

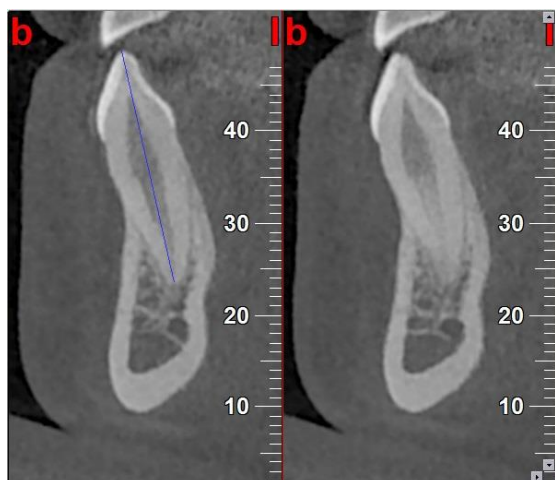


Figure 1. T: Maximum tooth length

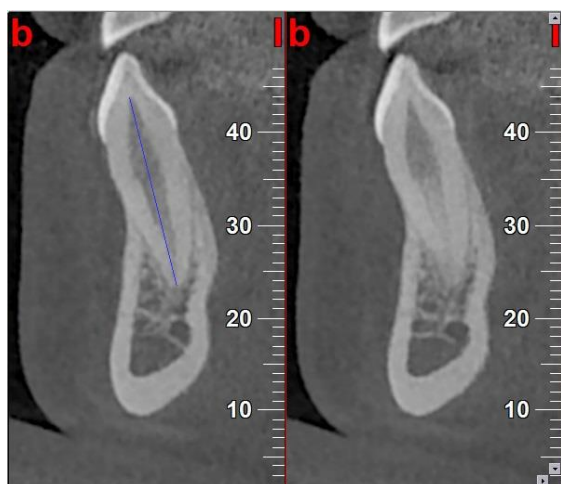


Figure 2. P: Maximum pulp length

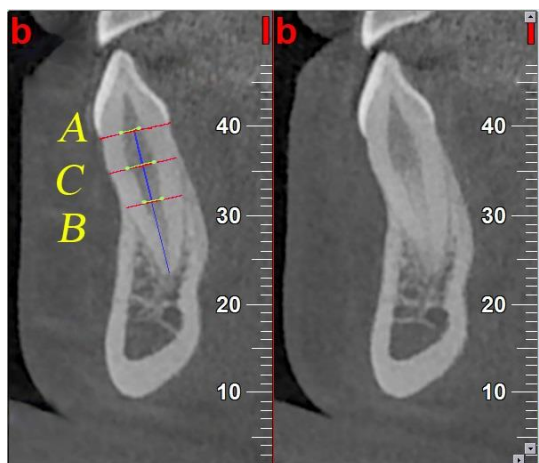


Figure 3. R: Root length from the cemento-enamel junction (CEJ) to the apex. Level A (yellow): Root (red) and pulp (green) width at the CEJ; Level B (yellow): Root (red) and pulp (green) width at the mid-root; Level C (yellow): Root (red) and pulp (green) width at the midpoint between the CEJ and mid-root

In 1950, Gustafson introduced the first scientific method of age estimation based on examination of teeth for secondary dentin deposition, attrition, gingival recession, cementum formation and root translucency. However, this method of age determination was invasive and required tooth extraction (5). Kvaal *et al.*, in 1995 introduced a method of age determination that did not require tooth extraction. They indirectly assessed secondary dentin deposition on radiographs and related that to age (6).

Most other age estimation methods such as the Johnson's method, (7) Solheim's method, (8, 9) Lamendin's method (10) and Bang's method (11) require extraction and sometimes sectioning of teeth. However, Kvaal's method of age determination is unique in that it can be used for age estimation of adults without extracting or damaging the teeth. This method is exclusively based on radiographic measurements and does not depend on other factors such as root transparency or periodontal retraction; thus, it does not require tooth extraction (12, 13). However, this method has not been tested on Iranian populations (14). The first formula by Kvaal and Solheim is for the extracted teeth and has an additional variable, that is, measurement of the translucent apical segment according to the Bang's method. (11) This formula is referred to as Kvaal's first formula. The second formula suggested by Kvaal (Kvaal's second formula) is used for the teeth in the oral cavity and does not include the additional variable mentioned above. (9) In the current study, we used Kvaal's second formula.

Although researchers reported high accuracy of age determination, they called for further studies on the effects of ethnicity, race and culture on modeled parameters and concluded that the best results would be obtained when formulas unique for each population are used (6). The aim of study is age estimation by Kvaal's method using CBCT scans of mandibular canine teeth in an Iranian population.

Materials and Methods

This study was approved in the Ethics Committee of Shahid Beheshti University of Medical Sciences, School of Dentistry (IR.SBMU.RIDS.REC.1394.41). In this cross-validation study, information was collected from the files of patient's referred to Shahid Beheshti University of Medical Sciences, School of Dentistry from 2014 to 2015. Based on a previous study (15) and considering the type one error of 0.05 ($\alpha=0.05$), type two error of 0.1 ($\beta=0.1$), study power of 90% and minimum correlation coefficient of $r=0.25$, sample size was calculated to be 150 in the test group. Thirty controls were also included.



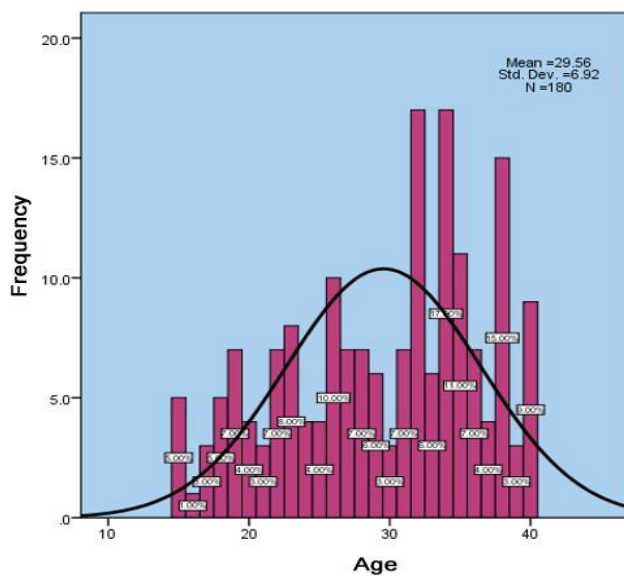


Figure 4. Age distribution of study subjects

Totally, 180 patients with an age range of 15 to 40 years were randomly selected and randomly divided into two groups. The test group included 150 patients and the control group included 30 patients. The inclusion criteria were age range of 15-40 years, (16) presence of fully erupted mandibular canine teeth with mature roots and no rotation, root canal treatment, restoration or other dental treatments, caries, periodontitis or periapical lesions on CBCT scans of patients and Iranian ethnicity. The CBCT scans of patients out of this age range, those with missing or carious mandibular canines and subjects with non-Iranian ethnicity were not included. The CBCT scans of the patients were retrieved from their files in the archives of the Department of Maxillofacial Radiology, School of Dentistry, Shahid Beheshti University of Medical Sciences. The CBCT scans had been ordered for various reasons such as third molar extraction surgery, orthodontic treatment, implant placement, etc. Allocation of CBCT scans to the test and control groups was completely random and was done by the use of a table of random numbers. The CBCT scans of all patients had been taken by NewTom VGi X ray unit (QR srl, Verona, Italy) with the exposure settings of 110kVp, 3.6 seconds and standard resolution.

We used mandibular canine teeth for age determination in this study because they seemed to be most suitable for this purpose due to having a large pulp chamber, lower risk of erosion and attrition, and higher likelihood of remaining in the mouth for longer periods of time (17). All patients were Iranian and had fully erupted canine teeth with developed (mature)

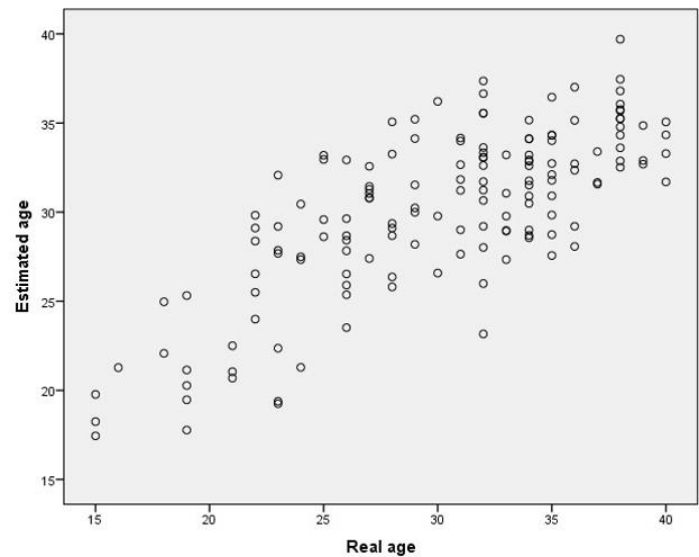


Figure 5. Actual age versus the estimated age

roots. Also, the selected teeth had to have no rotation, root canal treatment, restoration, other dental treatments, caries, periodontitis or periapical lesions. The parameters used in Kvaal's method for age determination include the followings:

T: Maximum tooth length (Figure 1)

P: Maximum pulp length (Figure 2)

R: Root length from the cemento-enamel junction (CEJ; Figure 1) to the apex

Level A: Root and pulp width at the CEJ

Level B: Root and pulp width at the mid-root

Level C: Root and pulp width at the mid-point between the CEJ and mid-root (6) (Figure 3).

Using NNT Viewer software (QR srl, Verona, Italy), all the afore-mentioned parameters were measured on the images of the samples. First, the regression formula suggested by Kvaal *et al.*, for age estimation using canine tooth was used; that is: $\text{Age} = 158.8 - 255.7 (M)$ where M was the mean value of the six variables [maximum tooth length (T), maximum pulp chamber length (P), root length from the cemento-enamel junction to the apex (R), root and pulp width at the cemento-enamel junction (level A), root and pulp width at the mid-root (level B) and root and pulp width at the point half way between the cemento-enamel junction and mid-root (level C)]. Thus, M was a new independent variable, which was entered into the regression formula. (6) We used the afore-mentioned variables suggested by Kvaal *et al.*, to create our own regression formula for our study population (test group) using SPSS software (version 22). We tested our created regression formula on our



Table 1. The results of multiple regression analyses for the correlation of X1, X2, X3 and X5 variables with age

Model	Non-standardized coefficients		Standardized coefficients		Multiple linear coefficients		
	B	Standard error	Beta	t	Level of significance	Tolerance	Variance inflation factor
Constant value	25.199	6.183		4.075	0.000		
X5	-54.345	5.349	-0.618	-10.160	0.000	0.804	1.244
X3	38.012	8.985	0.271	4.230	0.000	0.723	1.383
X2	-17.758	6.103	-0.181	-2.910	0.000	0.769	1.301
X1	-8.713	3.892	-0.146	-2.238	0.000	0.699	1.431

control group for the purpose of cross-validation. Eventually, the simple and multiple linear regression models were used for our data to find an exclusive formula for age estimation in the Iranian population. We then assessed the efficacy of this formula for age estimation in our control group. To assess the multicollinearity and fitness of model, the tolerance and variance inflation factor were used.

Results

To assess the fitness of statistical model, 150 test and 30 control subjects in the age range of 15-40 years were evaluated. The mean age of patients was 29.5 ± 6.9 years (Figure 4). Of patients, 90 (50%) were females and 90 (50%) were males. The mean age was 30.9 ± 7.1 years in females and 28.1 ± 6.3 years in males.

The interclass correlation coefficient for the nine variables was >0.75 , which indicated excellent reliability.

When the regression equation obtained by Kvaal's method was used for the canine teeth, age estimation errors ranged from two years to 36 years, which indicated that this estimation was not accurate.

By using Kvaal's six variables in our study population and using Kvaal's regression equation for canine teeth (mentioned earlier) as a template, we created our own regression equation for the canine teeth and age= $66.47 - 67.14$ (M) was obtained based on our data. As stated earlier, M was the mean of the six variables. In the cross-validation phase, we tested our created formula on the control group and found that errors ranged from two to 17 years. Thus, this model was not suitable for age determination in an Iranian population.).

Use of multiple linear regression model for assessment of the correlation of Kvaal's method according to CBCT scans of mandibular canine teeth and age in a step by step method revealed that among the five variables namely X1=pulp

length/root length, X2=pulp length/tooth length, X3=pulp width at level A/root width at level A, X4=pulp width at level B/root width at level B and X5=pulp width at level C/root width at level C, X4 had to be eliminated from the study despite the presence of a significant association among them. The remaining four variables had the required efficacy. ANOVA showed that the total regression with regard to the correlation of age with the remaining four variables was significant ($P < 0.001$).

In this model, R^2 was found to be 0.569 (adjusted $R^2 = 0.567$) and standard error was found to be 4.107, indicating adequate fitness. Table 1 shows the estimations derived from using this model. Based on the results presented in Table 1, X1, X2, X3 and X5 variables were all significant for age determination ($P < 0.05$ for all four). The significance of variables was in the following order: X5, X2, X3 and X1, respectively. Thus, as shown in Table 1, the constant value and the four variables namely X1, X2, X3 and X5 had a significant correlation with age, and presence of all these variables is necessary for age estimation.

For this model, no significant co-linearity was found between the independent variables and the variance inflation factor was maximally 1.4. Figure 5 shows the distribution of actual age of the subjects compared to their predicted age. According to Figure 5, the linear nature of this correlation and its fitness are evident.

Regression equation

Age= $25.2 - 8.7$ (pulp length/root length) + 38.01 (pulp length/tooth length) - 17.8 (pulp width at level A/root width at level A) - 54.3 (pulp width at level C/root width at level C).

The results of cross validation on 30 controls revealed that the mean difference between the actual age and predicted age was 1.6 years with a standard deviation of 11.3 years. Minimum and maximum errors of prediction were 7.3 and 15.6 years, respectively.



Discussion

Assessment of dental radiographs for age estimation has been rarely considered in forensic medicine and use of CBCT scans for this purpose has not been evaluated before. Our results showed that the use of Kvaal's parameters on human mandibular canine teeth was not significant for age estimation of adults in the Iranian population although a significant association was noted between four variables related to canine teeth (namely pulp length/root length, pulp length/tooth length, pulp width at level A/root width at level A and pulp width at level C/root width at level C) and age. Therefore, variables other than the mentioned four must probably be considered for age determination in an Iranian population.

Insignificant change in teeth during growth and development and their easy use for age estimation as well as the advantages of radiographic techniques over other modalities have resulted in the recent interest in this topic. (18) At present, three-dimensional (3D) images of teeth can be obtained by CBCT in living individuals (19, 20). We used CBCT in this study, which is ideal for evaluation of tooth cross-sections and does not have magnification errors related to geometric distortion. According to Cameriere *et al*, CBCT is the best imaging modality for volumetric studies. (21) Yang *et al*. mentioned that introduction of CBCT enabled capturing 3D radiographic images with high quality and low patient radiation. (22).

Assessments of pulp/tooth surface and pulp/tooth volume ratios are indirect methods used to determine the quantity of the deposited secondary dentin. Dentin deposition is an age-related process, which occurs along the internal tooth surfaces. Secondary dentin is well protected from the effects of environmental factors. Secondary dentin was used in this study since it is surrounded not only by the enamel and cementum, but also with primary dentin (21). Thus, it can be used for age estimation since it is not influenced by the effects of environmental factors on human remains (23). In most previous studies, the pulp/tooth surface area ratio was used for age estimation in different population. (24-27). However, due to the 2D nature of radiographs, they cannot provide accurate information about a 3D object (28). Fewer studies used pulp/tooth volume ratio for age determination. (16, 28, 29) Due to anthropological and racial differences, a suggested formula for a specific population may not be suitable for use in other populations. Thus, we performed the current study on an Iranian population to find a formula that well suits our own population. It was assumed that our subjects represented a "normal Iranian population".

Sakhdari *et al*, in 2015 estimated age using the pulp to tooth surface area ratio on digital panoramic radiographs of 120 patients over 12 years of age. The regression equation they suggested for males under- or over-estimated the actual age. In females, the suggested equation correctly estimated age in 16% of the subjects. They concluded that the pulp tooth surface area ratio cannot be used as an index for age determination alone but can be used in conjunction with other indices for this purpose. In their study, AutoCAD software was used for calculation of surface area. (24) In the current study, we made measurements on CBCT scans irrespective of sex of patients and used the parameters in Kvaal's method for age estimation. However, we chose a limited age range to eliminate the confounding factors present in wider age groups. Considering the obtained correlation coefficient, the regression model in our study was more suitable for the Iranian population compared to their study.

Moshfeghi *et al*, in 2014 estimated age in an Iranian population based on pulp tooth surface area ratio. They evaluated mandibular canine, first premolar and lateral incisor teeth and found that the parameters in the Kvaal's method for the canine tooth were suitably applicable for age determination. Pulp width is a more suitable variable than pulp length. (30) Pulp length/tooth length, pulp width/root width at the CEJ, pulp width/root width at the mid-root and pulp width/root width at the mid-point of CEJ and mid-root of mandibular canine teeth can be used for age estimation. In the current study, due to the advantages of mandibular canine tooth, (17) these measurements were made only on this tooth. We also used CBCT scans since they have a higher accuracy than panoramic radiography. Also, CBCT does not have the problems related to magnification and angular limitations. In our study on mandibular canine teeth, among Kvaal's variables, only the pulp width/root width at the mid-root had no significant association with age.

Kanchan-Talreja *et al*, in 2012 evaluated the versatility of Kvaal's method for age determination in adults in an Indian population and found that significant differences existed between the actual age and estimated age using this method. They stated that such significant errors in Kvaal's formula for age estimation in an Indian population may be due to the fact that deposition of secondary dentin in Indians is affected by both genetics and environment (14).

Jaannathan *et al*, in their study in 2011 in India evaluated the accuracy of age estimation according to the pulp tooth volume ratio of mandibular canine teeth on CBCT scans and



concluded that a modification of Yang's formula (22) was acceptable for this purpose in an Indian population. (28). In the current study, we used Kvaal's formula. Measurement of Kvaal's parameters is an easier, more accessible and more applicable method in Iran because the software programs for volume calculation on CBCT scans, designed by Jonathan (24) are not currently available in Iran. Thus, according to Jonathan's methodology (24) (who first assessed the Yong's original formula), we first assessed Kvaal's original formula on mandibular canine teeth and then designed an exclusive formula for the Iranian population.

Fekri Zaher *et al*, in 2011 estimated age based on the pulp tooth surface area ratio of the maxillary incisors on periapical radiographs in an Egyptian population. They used AutoCAD software and found no significant difference between the estimated age and the chronological age (26).

Jeevan *et al*, in 2011 estimated age based on the pulp tooth surface area ratio of the canine teeth and the Cameriere's method (21) using radiovisiography in an Indian population. They calculated the pulp tooth surface area ratio using Adobe Photoshop CS3 software. Their findings confirmed the validity of dental age estimation in forensic odontology in both living and dead individuals. They found that dental age estimation was more accurate in individuals younger than 45 (16-44) year. (31).

Cameriere *et al*, in 2009 estimated age based on pulp tooth surface area ratio of canine teeth in a Portuguese population to test the accuracy of the Cameriere's method. Using this method, age estimation error was (2.5 years) (25).

In 2009, Landa *et al*, in a private radiology department in Balbao applied Kvaal's method for age estimation using digital Orthopantomographs. They used three single-rooted mandibular teeth and found that Kvaal's regression formula was not suitable for their population (not significant). Also, the values obtained by their own designed regression equation were far from the actual age, (32) which was in line with our findings. We found similar results using Kvaal's method on CBCT scans of an Iranian population.

Yang *et al*, in 2006 estimated dental age on CBCT scans using volume matching and volume calculation software. Their study was pilot and designed to assess the accuracy of this software. They calculated the volume of two teeth using Archimedes volume substitution method and found that this software was suitable for volume calculation. They found important results with regard to dental age estimation using CBCT as a non-invasive method in living individual. (22). As

mentioned earlier, the available software programs in Iran do not have such capability and we could not design one; thus, we decided to assess Kvaal's method, which is more practical in Iran.

Bosmans *et al*, in 2005 evaluated the applicability of Kvaal's dental age estimation method on panoramic radiographs. They calculated the parameters in Kvaal's method using Adobe Photoshop 6.0 software. They evaluated six teeth including maxillary central and lateral incisors and second premolar, and mandibular lateral incisor, canine and first premolar on panoramic images. They found that the results of Kvaal's method in adults and application of Kvaal's original regression formula on the data obtained from panoramic radiographs (given that they have optimal quality and resolution) for all teeth and the three mandibular teeth are comparable with the application of the original technique on conventional periapical radiographs. However, it was not suitable for age estimation according to each tooth and the three maxillary teeth (33). Our findings were in agreement with theirs since we only assessed one single tooth (mandibular canine).

In a study by Soomer *et al*, regarding reliability and validity of dental age estimation in adults, eight methods were assessed; out of which, the second Kvaal's method, which was also used in our study, provided low accuracy (mean age error) and precision (standard error). In the first Kvaal's method, extracted teeth were used for age estimation and thus, in addition to the afore-mentioned five variables, the length of the translucent root area was also taken into account. In Kvaal's second method, this variable is eliminated since teeth in the oral cavity are assessed. However, it was reported that both Kvaal's methods significantly underestimated the actual age (34).

Kvaal *et al*, in 1995 estimated adults' age using dental periapical radiographs. They evaluated pulp length to root length, pulp length to tooth length and pulp width to root width at three different levels (CEJ, mid-root, mid-point of CEJ and mid-root) and found a linear regression formula for each of the six teeth namely maxillary central and lateral incisors and second premolar and mandibular lateral incisor, canine and first premolar. However, their study was not a cross-validation study and they did not assess the accuracy of their obtained regression formula in a control group (6). Kvaal *et al*. suggested that each population requires its own regression formula (6). Thus, the regression formula obtained by Kvaal *et al*, for mandibular canine was not suitable for age



estimation in our study population; however, significant associations were found between age and pulp length/root length, pulp length/tooth length, pulp width at level A/root width at level A and pulp width at level C/root width at level C, indicating that further studies are required in this respect on the Iranian population to find possible confounders to be included in the regression formula. Kvaal *et al.* used periapical radiographs in their study. In the current study, we used CBCT scans to overcome the technical errors of conventional radiography. Cameriere *et al.*, in 2007 stated that external factors such as mastication, type of food and duration of mastication can all affect the deposition of secondary dentin (21). Mandojana stated that demographic factors such as sex or type of tooth should also be considered for age determination (35). Ritz-Timme in 2000 stated that morphological methods based on radiographic examination of dental and skeletal development are mostly applicable during childhood and adolescence and their accuracy decreases in adulthood (36). Thus, further studies are required to find external factors with possible application for age determination in addition to Kvaal's four variables, which showed significant associations with age in our Iranian population.

Use of CBCT for assessment of age estimation based on canine teeth was strength of this study since no previous study has attempted to estimate age based on CBCT scans. Small sample size was a limitation of the current study. Also, use of special software programs for calculation of volume could have resulted in more accurate findings; however, they could not be used since they are not yet available in Iran.

Conclusion

Although most of the variables mentioned by Kvaal were effective in age estimation, some errors were seen in age estimation in the modeling and cross-validation phase. Thus, some other variables need to be assessed to increase the accuracy of Kvaal's formula in the Iranian population.

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Conflict of Interest: 'None declared'.

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