Imaging Science in Dentistry 2023
https://doi.org/10.5624/isd.20230104

Dental age estimation in Indonesian adults: An investigation of the maxillary canine pulp-to-tooth volume ratio using cone-beam computed tomography

Khamila Gayatri Anjani[1], Rizky Merdietio Boedi[2,3], Belly Sam[1], Fahmi Oscandar[1,*]

[1]Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Universitas Padjadjaran, Bandung, Indonesia
[2]Centre of Forensic and Legal Medicine and Dentistry, University of Dundee, Dundee, UK
[3]Department of Dentistry, Faculty of Medicine, Universitas Diponegoro, Semarang, Indonesia

ABSTRACT

Purpose: This study was performed to develop a linear regression model using the pulp-to-tooth volume ratio (PTVR) ratio of the maxillary canine, assessed through cone-beam computed tomography (CBCT) images, to predict chronological age (CA) in Indonesian adults.
Materials and Methods: A sample of 99 maxillary canines was collected from patients between 20 and 49.99 years old. These samples were obtained from CBCT scans taken at the Universitas Padjadjaran Dental Hospital in Indonesia between 2018 and 2022. Pulp volume (PV) and tooth volume (TV) were measured using ITK-SNAP, while PTVR was calculated from the PV/TV ratio. Using RStudio, a linear regression was performed to predict CA using PTVR. Additionally, correlation and observer agreement were assessed.
Results: The PTVR method demonstrated excellent reproducibility, and a significant correlation was found between the PTVR of the maxillary canine and CA ($r = -0.74$, $P < 0.01$). The linear regression analysis showed an R^2 of 0.58, a root mean square error of 5.85, and a mean absolute error of 4.31.
Conclusion: Linear regression using the PTVR can be effectively applied to predict CA in Indonesian adults between 20 and 49.99 years of age. As models of this type can be population-specific, recalibration for each population is encouraged. Additionally, future research should explore the use of other teeth, such as molars. ***(Imaging Sci Dent 20230104)***

KEY WORDS: Age Determination by Teeth; Cone-Beam Computed Tomography; Forensic Dentistry; Radiography, Dental; Indonesia

Introduction

The pioneering work of Gustafson, which correlated regressive dental morphological changes to chronological age (CA) in adults, initiated the development of adult dental age estimation methods.[1] Since that ground-breaking study, extensive research has been conducted to explore less invasive methods of evaluating regressive dental changes through the use of radiographs.[2-4] Early research in this field utilised periapical[5] and panoramic[6-8] radiographs, both of which produce 2-dimensional (2D) images of the dental structure. However, 2D radiographs have limitations, including superimposition and unequal magnification, which can introduce potential inaccuracies. This is particularly problematic in adults, for whom a thorough examination of the secondary dentine is required.[9-11] Numerous studies have demonstrated that cone-beam computed tomography (CBCT) can provide a detailed examination of secondary dentine.[12] As a result, the use of CBCT, which offers 3-dimensional (3D) multiplanar views, has become increasingly common in adult dental age estimation.

Secondary dentine deposition is one of the most important age-related physiological changes in teeth.[13] As the volume of the pulp cavity gradually decreases with age, the forma-

This research is funded by the Universitas Padjadjaran through Lecturer Research Competency Programme 2023 (Riset Kompetensi Dosen Universitas Padjadjaran, RKDU).
Received May 19, 2023; Revised June 28, 2023; Accepted July 1, 2023
Published online August 2, 2023
*Correspondence to : Prof. Fahmi Oscandar
Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Universitas Padjadjaran, Jalan Sekeloa I, Bandung, Jawa Barat, 40132, Indonesia
Tel) 62-22-2533044, E-mail) fahmi.oscandar@fkg.unpad.ac.id

tion of secondary dentine begins and continues throughout the lifetime.[14,15] This process establishes an inverse correlation that can serve as a technique for estimating the dental age of adults.[16] A commonly employed method is the pulp-to-tooth volume ratio (PTVR).[17] The PTVR method is performed by calculating the total volume of the pulp and dividing it by the total volume of the tooth to normalise the value.[18]

Several studies have employed PTVR analysis with CBCT images for the purpose of estimating dental age. In 2011, Star et al.[19] examined incisors, canines, and premolars from a Belgian population, while Biuki et al.[20] (2017) focused on the incisors and canines of an Iranian population. Similarly, Asif et al.[21] (2019) studied incisors and canines from a Malaysian population. All of these investigations yielded satisfactory outcomes. Notably different regression models and variabilities have been reported in predicting CA using the progression of secondary dentine across populations.[22]

In many studies, permanent canines have been used due to their larger pulp dimensions, reduced dietary wear, and high survival rate. However, research involving canines has yielded varying R^2 values across different populations. For instance, Kazmi et al.[17] (2021) reported an R^2 value of 0.46 in a Pakistani population, while De Angelis et al.[23] (2015) found R^2 values ranging from 0.263 to 0.389 in an Italian population. The goal of the present study was to develop a linear regression model using the PTVR of the maxillary canine, as assessed through CBCT images, to predict CA in Indonesian adults. To the authors' knowledge, this is among the first studies to apply the PTVR method to this population.

Material and Methods

The Research Ethics Committee of Universitas Padjadjaran provided ethical clearance (899/UN6.KEP/EC/2021) for this analytical research design. Retrospective data were collected from CBCT scans of 158 patients, ranging in CA from 20 to 49.99 years. CA was determined by calculating the difference between the date of exposure and the patient's date of birth. The required data were gathered from the database of the dental hospital, and the collected dates were verified using the patient's national identity card.

The CBCT scans used in this research were initially conducted for various diagnostic purposes. For this study, no new scans were taken, nor was any additional radiation exposure imposed on the patients. The CBCT images were captured using an OP300 device (Instrumentarium Dental, Tuusula, Finland) at the Universitas Padjadjaran Dental Hospital. The exposure settings were tailored to each patient's clinical needs, with an 85 kV, a tube current ranging from 3 to 8 mA, and an exposure time of 1.7 to 8.7 s. The field of view varied between $250 \times 250 \times 250$ to $400 \times 400 \times 400$ based on the patient's clinical requirements, and the mean voxel size was $0.2\ mm^3$.

The minimum sample size for this study was determined *a priori* using a power analysis in G*Power (University of Düsseldorf, Düsseldorf, Germany) factoring in 3 predictors, an effect size of 0.15, and a power of 0.95. This calculation yielded a minimum total sample size of 89, indicating that the minimum sample size for each sex should be 45. Regarding inclusion criteria, the sample consisted of Indonesian male and female patients, aged 20 to 49.99 years, who had intact maxillary canines with fully erupted and closed apices. Measurements of the maxillary canines did not distinguish between left and right, with preference given to the right maxillary canine. The exclusion criteria included maxillary canines with restorations, impactions, periapical or periodontal lesions, and accessory canals. The final sample comprised 99 maxillary canines (Table 1).

First, the relevant Digital Imaging and Communications in Medicine file was imported into ITK-SNAP (www.itksnap.org, version 3.8; ITK-SNAP, UPenn and UNC, USA). This software was used to calculate the ratio of pulp to tooth volume by employing the labelling function and the region of interest (ROI) tool.[21] The volumetric measurements of the pulp and tooth structure were provided in the labelled voxels within ITK-SNAP, given in cubic millimetres (mm^3).

The initial step in the segmentation method involved calculating the pulp volume (PV) and tooth volume (TV) simultaneously. This was achieved by positioning the ROI to cover the entire tooth. The ROI was strategically placed to encompass the pulp area within the tooth, using the sagittal image with the largest pulp dimension as a reference. The process of labelling the PV area began by selecting a

Table 1. Distribution of samples by patient age and sex

Age range (y)	Minimum sample		Final sample	
	Male	Female	Male	Female
20-24.99	7	7	10	8
25-29.99	7	7	10	8
30-34.99	7	7	7	10
35-39.99	7	7	9	7
40-44.99	7	7	7	7
45-49.99	7	7	9	7
Total	42	42	52	47

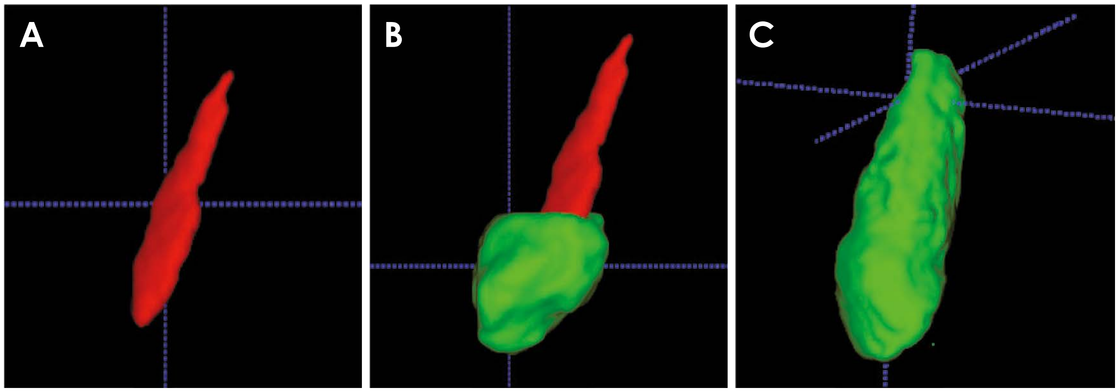

Fig. 1. Volume labelling process in ITK-SNAP. A. Labelling for pulp volume. B. Labelling for tooth volume, divided into the crown. C. Continuation of labelling to the root.

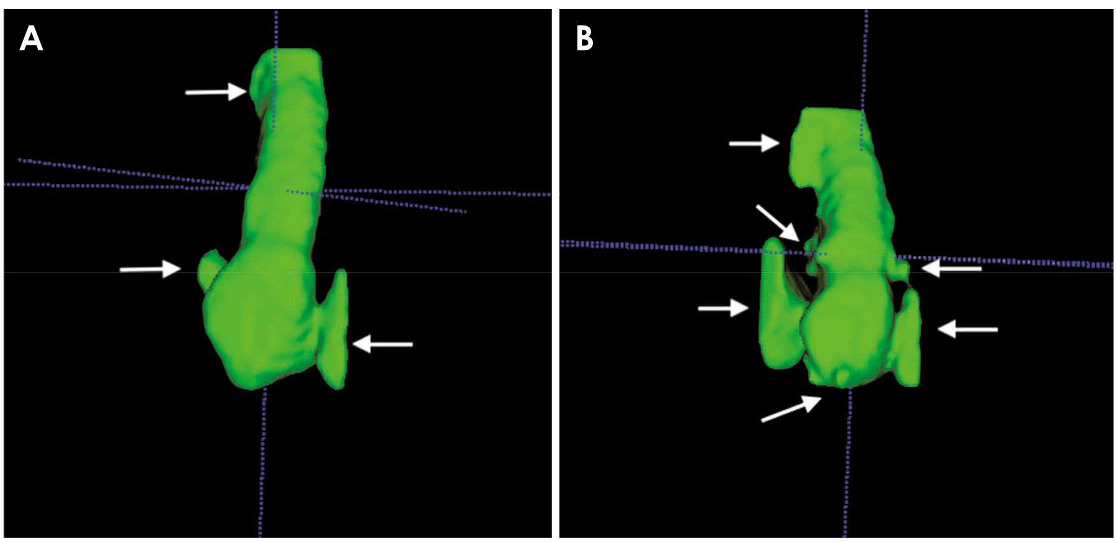

Fig. 2. Difference in labelling results between labelling the tooth volume in divisions (A) and as a whole unit (B). The label leakage appears more severe in B (white arrows), resulting in a more time-intensive cleaning process for the observer.

"label" to overlay the "clear label." The so-called pre-segmentation mode was then utilised for contrast thresholding to identify the pulp area. Here, the lower threshold was set to the minimum value, while the upper threshold was adjusted by the observer to ensure an accurate PV measurement.

During the process of TV measurement, label leakage to the adjacent structure was observed, which slowed down the process. To address this, for TV measurement, labelling of the crown and root regions was performed separately. The tooth was divided into 2 parts: the crown and the root. The crown division extended from the incisal region to the cementoenamel junction, while the root division spanned from the cementoenamel junction to the apex. The same labelling procedure used for the initial PV measurement was applied to both divisions, using the same label (Fig. 1). The ROI was positioned to overlap with the previous segmentation, ensuring labelling continuity. Contrary to the pulp area contrast thresholding, the upper threshold was adjusted to the minimum value, and the lower threshold was determined by the observer to accurately measure the TV.

This division-based labelling approach significantly reduced the time required for segmentation, saving approximately 5 minutes considering the whole tooth labelling process (total time: 20 minutes, Fig. 2). Notably, only 1 maxillary canine per CBCT scan was processed, meaning that if the right maxillary canine was chosen, the left maxillary canine was not included in the measurement. The segmentation process for each tooth took approximately 15 minutes.

The intraclass correlation coefficient was utilised to assess

Table 2. Mean and standard deviation values of measured volumetric variables across groups

Age (y)	Sex	Tooth volume	Pulp volume	Pulp-to-tooth volume ratio
20-24.99	M	796.2±57.2	41±65.7	0.054±0.009
	F	716±64.1	38.3±8.4	0.052±0.011
25-29.99	M	788.4±41.2	38.86±4.3	0.049±0.010
	F	686±43.2	33.34±5.6	0.049±0.004
30-34.99	M	762.3±67.3	30.56±3.87	0.040±0.006
	F	651.2±51.2	25.07±3.48	0.039±0.009
35-39.99	M	731.4±47.5	22.6±2.43	0.031±0.009
	F	631.6±62.1	21.41±2.31	0.034±0.010
40-44.99	M	741.2±49.9	27.86±3.92	0.038±0.012
	F	612.3±54.3	15.73±1.34	0.026±0.008
45-49.99	M	712.3±34.6	18.51±1.96	0.026±0.007
	F	598.2±28.1	13.69±3.35	0.023±0.006

intra- and inter-observer agreement. This value was measured by 2 observers using 20% of the sample.[24] To ensure reproducibility, 20 teeth were randomly selected and observed at 2-week intervals between the first and second observation. The first observer (KA) was an oral and maxillofacial radiologist with 3 years of experience. The second observer (RMB) was a forensic odontologist with 6 years of experience in dental age estimation.

The quantified volumetric measurements were subsequently recorded in Excel 365 (Microsoft Corp., Redmond, WA, USA) and converted to a ratio (PTVR) by dividing PV by TV (PTVR = PV/TV). Data analysis and visualisation were conducted using R (version 4.2.1; R Foundation for Statistical Computing, Vienna, Austria). Normality testing was done with the Shapiro-Wilk test, and the relationship between age and PTVR was determined using the Pearson correlation coefficient (r). A regression model was developed to predict age from PTVR, utilising the *caret* extension to execute a k-fold cross-validation linear model with 5 folds and 2 repetitions. The model was evaluated using the coefficient of determination (R^2), root mean square error (RMSE), and mean absolute error (MAE). The level of statistical significance was set at 0.05. Additionally, the pseudorandom number generator within R was set at a fixed value of 30 (set.seed = 30).

Results

The calculated reproducibility of the method was excellent, with intra-observer and inter-observer agreements of 0.826 and 0.942 for TV and 0.795 and 0.893 for PV, respectively. The mean and standard deviation distributions for PV, TV, and PTVR for each age group and sex are displayed in Table 2, all following a normal distribution. The relationship between PTVR and CA was found to be relatively strong ($r = -0.75$), which supports the regressive nature of the morphological changes via the decrease in PTVR corresponding to an increase in CA.

Table 3. Mean error across groups

Age (y)	Mean error (y)
20-24.99	−5.43
25-29.99	−1.08
30-34.99	−2.48
35-39.99	−0.414
40-44.99	4.78
45-49.99	6.18

−: underestimation, +: overestimation

A significant difference in PTVR was observed between the sexes. However, the inclusion of sex as a predictive variable was determined to be insignificant. The linear model can be expressed as follows:

$$\text{Age} = 53.8 - 492.3 \times \text{PTVR}$$

Here, 53.8 represents the regression intercept, while −492.3 is the slope of the PTVR ratio value. The current regression yielded an R^2 of 0.58, an RMSE of 5.85 years, and an MAE of 4.31 years. R^2 signifies the proportion of CA that is explained by the PTVR, and RMSE and MAE represent the error rate of the model. Figure 3 illustrates the reported

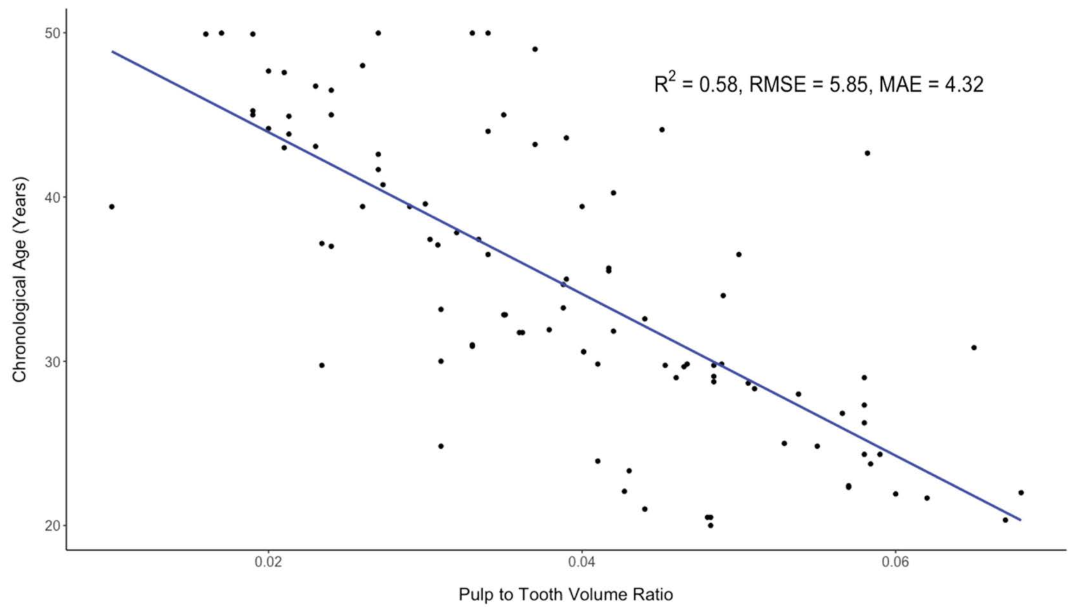

Fig. 3. Linear regression model predicting the chronological age (years) based on the pulp-to-tooth volume ratio (x-axis). The blue line represents the linear regression y=53.8−492.3×PTVR. PTVR: pulp-to-tooth volume ratio, RMSE: root mean square error, MAE: mean absolute error.

linear regression. The regression tends to produce an underestimation for most individuals under the age of 30 years and an overestimation for those above that age (Table 3).

Discussion

In the current study, 3D imaging was shown to produce reliable results for the prediction of CA in an Indonesian population through the PTVR method. This method quantifies the size of the pulp and tooth structure through volumetric approximation. Previous methods employing 2D imaging have also used this approach, measuring the length, width, or area of a tooth or pulp.[8,16,25] Regarding measurement accuracy in 3D imaging, micro-computed tomography (micro-CT) is considered the gold standard due to its superior spatial resolution, which allows for the exact volumetric quantification of dental structures.[26] However, micro-CT has certain drawbacks, such as the limitation of its use to post-mortem specimens and its higher operational costs.[27] In contrast, CBCT is more accessible and can be used on living individuals. However, the radiation aspects of CBCT are a concern, as the volumetric quantification process is directly related to the voxel size. A reduction in voxel size results in increased radiation exposure.[28] In this study, CBCT, which has smaller voxels for the field of view of the teeth and jaws, was chosen over CT. This is because CT has a larger voxel size and cannot display dental features such as the pulp chamber. Therefore, the dental age estimation model established using CBCT must be recalibrated for each population to achieve higher reliability. This is necessary because the risk of radiation exposure and method complexity must be balanced by increased method reliability and reproducibility.

In this study, modifications were made when measuring the TV by separating the crown and root labelling. This approach reduces the time required to assess the PTVR of the tooth, as it provides cleaner labelling results, thereby increasing observer agreement. However, the overall observer agreement of a volumetric measurement method using CBCT can also be influenced by observer expertise. As observed by Merdietio Boedi et al. in 2022,[2] an observer's expertise may be compromised when faced with a complex method. In the context of this research, the PTVR method can be considered an intermediate method compared to other volumetric approaches, as demonstrated in previous studies by Kazmi et al.[17] (2021) and Asif et al.[21] (2019), which reported high to excellent observer agreement. Similarly, the observer agreement results in this study were high to excellent, due to the inherent nature of the PTVR method and the additional modification used in TV measurement. However, it is crucial that a skilled observer conducts the volumetric tooth evaluation using CBCT to ensure consistent results.

This volumetric approach in this study revealed a high correlation coefficient of determination ($R^2=0.58$) between the PTVR output and CA for canines. Yang et al.[22] (2006) were the first to use CBCT images to establish a correlation between the pulp-tooth ratio and CA, finding an R^2 value of 0.29. Moreover, Adisen et al.[29] (2018) estimated age using the pulp-tooth ratio of maxillary canines, yielding an R^2 of 0.486. Further analysis by Merdietio Boedi et al.[2] (2022) reported an R^2 value of 0.6 for canines. However, variations may exist between populations, necessitating population-specific recalibration of the regression model to best align with the age estimation method used worldwide.

The regression modelling approach selected for this study was a linear regression model. This model was chosen over other approaches, such as polynomial[30] or log[14] normalisation, due to its better performance values. Additionally, the authors employed the *k*-fold cross-validation method to safeguard the model against overfitting.[31] Overfitting is a phenomenon in which a model performs well in the training phase but exhibits diminished overall performance when applied to real-world data. Therefore, these authors recommend: 1) conducting a model check when dealing with an adult's dental regression dataset to evaluate the performance of each modelling approach and 2) utilising a cross-validation method to report the model error to prevent overfitting.

The use of regressive dental changes in age estimation is influenced by a variety of factors, leading to a higher error rate compared to methods used for estimating the dental age of children or juveniles. For instance, a hard, fibrous diet requiring prolonged mastication, particularly in older individuals, can contribute to tooth wear. These factors highlight the impact of genetic and environmental influences on tooth size both within and between populations.[32,33] For this study, permanent maxillary canines were selected due to their distinctive shape, which makes them less prone to decay than other teeth. Tardivo et al.[34] (2013) indicated that simultaneous maxillary canines are better and stronger for age estimation, which aligns with the findings of the current study. In contrast, incisors are more susceptible to periodontal disease and often sustain mechanical or physical injury, leading to frequent loss of the dental crown. Similarly, molar teeth are highly susceptible to decay and subsequent repair.[35] While canines are often preferred for the reasons mentioned, research should be conducted on other teeth as well. This ensures that if canines are not available, dental age estimation can still be carried out using alternatives, such as molar teeth.

In conclusion, the findings of this study indicate that the linear regression derived from the PTVR method can be effectively used to predict CA in Indonesian adults aged between 20 and 49.99 years. The results demonstrated a strong correlation between PTVR and CA, and the method was found to be reliable in predicting dental age using maxillary canines from CBCT images. Importantly, every dental age estimation model based on regressive dental changes is population-specific, and recalibration for each population is encouraged. Consequently, it is crucial to recalibrate the PTVR method for each population to ensure accurate and reliable results. Future research should explore the use of other teeth, such as molars, for age estimation to provide alternative options when maxillary canines are unavailable or unsuitable for use.

Conflicts of Interest: None.

Acknowledgments

The authors would like to thank the oral and maxillofacial radiology and forensic odontology staff of the Faculty of Dentistry, Universitas Padjadjaran, Indonesia and the Centre of Forensic and Legal Medicine and Dentistry, University of Dundee, Scotland for their support in completing this research through inter-university collaboration.

References

1. Gustafson G. Age determination on teeth. J Am Dent Assoc 1950; 41: 45-54.
2. Merdietio Boedi R, Shepherd S, Oscandar F, Mânica S, Franco A. 3D segmentation of dental crown for volumetric age estimation with CBCT imaging. Int J Legal Med 2023; 137: 123-30.
3. Oscandar F, Rojiun ZA, Ibrahim N, Supian S, Tharmalingam D, Malinda Y. Preliminary research: correlation between pulp chamber volume of mandibular first molar and chronological age on deuteromalay subrace. Int J Med Toxicol Leg Med 2018; 21: 34-6.
4. Al-Omoush SA, Alhadidi A, Al-Kayed A, Saoud H, Alsoleihat F. Do upper third molars provide more accurate age estimation in the adult based on the pulp-to-tooth ratio than lower third molars? A cone-beam CT study. Saudi Dent J 2021; 33: 702-6.
5. Pilloud MA, Heim K. A test of age estimation methods on impacted third molars in males. J Forensic Sci 2019; 64: 196-200.
6. Goetten IF, Oenning AC, Silva RF, Nuzzolese E, Lourenço Junior E, Franco A. Diagnostic accuracy of the third molar maturity index (I_{3M}) to assess the age of legal majority in Northern Brazil - population-specific cut-off values. Int J Legal Med 2022; 136: 1507-14.
7. Uys A, Bernitz H, Pretorius S, Steyn M. Estimating age and the probability of being at least 18 years of age using third molars: a comparison between Black and White individuals living in South Africa. Int J Legal Med 2018; 132: 1437-46.

8. Yang Z, Geng K, Liu Y, Sun S, Wen D, Xiao J, et al. Accuracy of the Demirjian and Willems methods of dental age estimation for children from central southern China. Int J Legal Med 2019; 133: 593-601.
9. Agematsu H, Someda H, Hashimoto M, Matsunaga S, Abe S, Kim HJ, et al. Three-dimensional observation of decrease in pulp cavity volume using micro-ct: age-related change. Bull Tokyo Dent Coll 2010; 51: 1-6.
10. Yang Z, Fan L, Kwon K, Pan J, Shen C, Tao J, et al. Age estimation for children and young adults by volumetric analysis of upper anterior teeth using cone-beam computed tomography data. Folia Morphol (Warsz) 2020; 79: 851-9.
11. Merdietio Boedi R, Shepherd S, Oscandar F, Mânica S, Franco A. Regressive changes of crown-root morphology and their volumetric segmentation for adult dental age estimation. J Forensic Sci 2022; 67: 1890-8.
12. Merdietio Boedi R, Shepherd S, Mânica S, Franco A. CBCT in dental age estimation: a systematic review and meta-analysis. Dentomaxillofac Radiol 2022; 51: 20210335.
13. Helmy MA, Osama M, Elhindawy MM, Mowafey B. Volume analysis of second molar pulp chamber using cone beam computed tomography for age estimation in Egyptian adults. J Forensic Odontostomatol 2020; 38: 25-34.
14. Molina A, Bravo M, Fonseca GM, Marquez-Grant N, Martin-de-Las-Heras S. Dental age estimation based on pulp chamber/crown volume ratio measured on CBCT images in a Spanish population. Int J Legal Med 2021; 135: 359-64.
15. Salemi F, Farhadian M, Askari Sabzkouhi B, Saati S, Nafisi N. Age estimation by pulp to tooth area ratio in canine teeth using cone-beam computed tomography. Egypt J Forensic Sci 2020; 10: 2.
16. Kvaal SI, Kolltveit KM, Thomsen IO, Solheim T. Age estimation of adults from dental radiographs. Forensic Sci Int 1995; 74: 175-85.
17. Kazmi S, Shepherd S, Revie G, Hector M, Mânica S. Exploring the relationship between age and the pulp and tooth size in canines: a CBCT analysis. Aust J Forensic Sci 2022; 54: 808-19.
18. Abdinian M, Katiraei M, Zahedi H, Rengo C, Soltani P, Spagnuolo G. 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. Appl Sci (Basel) 2021; 11: 9984.
19. Star H, Thevissen P, Jacobs R, Fieuws S, Solheim T, Willems G. Human dental age estimation by calculation of pulp-tooth volume ratios yielded on clinically acquired cone beam computed tomography images of monoradicular teeth. J Forensic Sci 2011; 56 Suppl 1: S77-82.
20. Biuki N, Razi T, Faramarzi M. Relationship between pulp-tooth volume ratios and chronological age in different anterior teeth on CBCT. J Clin Exp Dent 2017; 9: e688-93.
21. Asif MK, Nambiar P, Mani SA, Ibrahim NB, Khan IM, Lokman NB. Dental age estimation in Malaysian adults based on volumetric analysis of pulp/tooth ratio using CBCT data. Leg Med (Tokyo) 2019; 36: 50-8.
22. Yang F, Jacobs R, Willems G. Dental age estimation through volume matching of teeth imaged by cone-beam CT. Forensic Sci Int 2006; 159 Suppl 1: S78-83.
23. De Angelis D, Gaudio D, Guercini N, Cipriani F, Gibelli D, Caputi S, et al. Age estimation from canine volumes. Radiol Med 2015; 120: 731-6.
24. Schmeling A, Geserick G, Reisinger W, Olze A. Age estimation. Forensic Sci Int 2007; 165: 178-81.
25. Cameriere R, Brogi G, Ferrante L, Mirtella D, Vultaggio C, Cingolani M, et al. Reliability in age determination by pulp/tooth ratio in upper canines in skeletal remains. J Forensic Sci 2006; 51: 861-4.
26. Bjørk MB, Kvaal SI. CT and MR imaging used in age estimation: a systematic review. J Forensic Odontostomatol 2018; 36: 14-25.
27. Vandevoort FM, Bergmans L, Van Cleynenbreugel J, Bielen DJ, Lambrechts P, Wevers M, et al. Age calculation using X-ray microfocus computed tomographical scanning of teeth: a pilot study. J Forensic Sci 2004; 49: 787-90.
28. Pauwels R. Cone beam CT for dental and maxillofacial imaging: dose matters. Radiat Prot Dosimetry 2015; 165: 156-61.
29. Adisen MZ, Keles A, Yorubulut S, Nalcaci R. Age estimation by measuring maxillary canine pulp/tooth volume ratio on cone beam CT images with two different voxel sizes. Aust J Forensic Sci 2020; 52: 71-82.
30. Duangto P, Iamaroon A, Prasitwattanaseree S, Mahakkanukrauh P, Janhom A. New models for age estimation and assessment of their accuracy using developing mandibular third molar teeth in a Thai population. Int J Legal Med 2017; 131: 559-68.
31. Triba MN, Le Moyec L, Amathieu R, Goossens C, Bouchemal N, Nahon P, et al. PLS/OPLS models in metabolomics: the impact of permutation of dataset rows on the K-fold cross-validation quality parameters. Mol Biosyst 2015; 11: 13-9.
32. Elgazzar FM, Elboraey MO, El-Sarnagawy GN. The accuracy of age estimation from pulp chamber/crown volume ratio of canines obtained by cone beam computed tomography images: an Egyptian study. Egypt J Forensic Sci 2020; 10: 40.
33. Farhadian M, Salemi F, Saati S, Nafisi N. Dental age estimation using the pulp-to-tooth ratio in canines by neural networks. Imaging Sci Dent 2019; 49: 19-26.
34. Tardivo D, Sastre J, Catherine JH, Leonetti G, Adalian P, Foti B. Age determination of adult individuals by three-dimensional modelling of canines. Int J Legal Med 2014; 128: 161-9.
35. Americano GC, Jacobsen PE, Soviero VM, Haubek D. A systematic review on the association between molar incisor hypomineralization and dental caries. Int J Paediatr Dent 2017; 27: 11-21.