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# Sex estimation by volumetric evaluation of the maxillary canine using cone-beam computed tomographic images

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## Abstract

**Background** Teeth can be a reasonable part of sex estimation in case of being the single evidence available or in doubt although they are not as accurate as bones in sex estimation. The size of teeth is greater in males than in females. In this study, it was aimed to determine cut-off values of the tooth volume (TV) and root volume (RV) of the maxillary canines and to evaluate the validity of the method for discriminating between males and females.

**Methods** Cone beam computed tomography (CBCT) images of 250 individuals aged 18 to 63 years with equal age and sex distribution were assessed retrospectively. The sample divided into reference set including 168 images of 84 females and 84 males and validation set including 82 images of 48 females and 34 males. Receiver operating characteristic (ROC) curve analysis, and Youden's index were used to determine cut-off values of the volumetric measurements and to test the discriminative performance of the method.

**Results** The optimal cut-off values of  $TV \geq 581 \text{ mm}^3$  and  $RV \geq 334 \text{ mm}^3$  for estimating sex were established from the reference set. The sensitivity (Se), specificity (Sp), and accuracy (Ac) were 0.77 for  $TV \geq 581 \text{ mm}^3$  while they were 0.82, 0.77, and 0.79 for  $RV \geq 334 \text{ mm}^3$ . When we tested the previously derived cut-off values of TV of the maxillary canine, the Se, Sp, and Ac were found to be respectively 0.71, 0.90, and 0.82 for  $TV \geq 619 \text{ mm}^3$  and 0.97, 0.27, and 0.56 for  $TV \geq 510 / 460 \text{ mm}^3$  (right/left).

**Conclusions** The identified cut-off values of TV and RV of the maxillary canines can be used to estimate sex with moderate accuracy when the only evidence available is teeth or in case of doubt. The method's applicability should be assessed for different populations.

**Keywords** Sex determination, Teeth, Maxillary canine, Cone-beam computed tomography, Forensic sciences

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## Introduction

Dental morphological and morphometric features provide valuable biological and cultural insights into individuals or human populations. Sex estimation serves as the initial step in establishing the biological profile of skeletal remains in forensic sciences and anthropology. There are various morphological and biochemical methods for sex estimation. The biochemical analysis of teeth, based on DNA and Barr bodies, offers the highest accuracy for sex estimation. However, it has limitations such as high cost, time-consuming processes, equipment requirements, and an invasive procedure that involves the destruction of the sample. Additionally, these methods may encounter challenges in cases of insufficient preservation of remains or limited DNA extraction from the sample. In contrast, morphological methods based on sex differences in bones and teeth are non-invasive, comparatively easier, faster, and more cost-effective than biochemical methods, proving advantageous, particularly in instances of mass disasters. Teeth are resistant to environmental conditions as the hardest structures in the body. Although teeth give less accurate results in sex estimation than bones, they are valuable tools for use in case of burning, purification, and fracture [1–5].

Many studies have been carried out using tooth size as an indicator for sex estimation and various methods have been proposed. In these studies, morphometric features of the teeth were usually assessed with linear measurements and the canines and subsequently the molars were found to be the most sex-differentiated permanent teeth [3, 6]. The accuracy of odontometric techniques for sex estimation has been reported around 80% in general [1, 2]. In the last decade, studies have been carried out on whether better results in sex estimation can be obtained by volumetric measurements using various tomographic imaging techniques and software programs, and with different parameters and statistical approaches [1, 7–13]. Tardivo et al. [1], using computed tomography (CT) images, found the accuracy of logistic regression models constructed with tooth volume of the canines between 82 and 86%. They reported the cut-off values of tooth volume for the right and left maxillary canines as 0.510 cm<sup>3</sup> and 0.460 cm<sup>3</sup>, respectively. Kazzazi et al. [13] measured the root volume using CT and found the highest percentage of sexual dimorphism in the maxillary second incisor followed by the maxillary canine. They reported the accuracy of the discriminant functions between 80 and 100%. Manhaes-caldas et al. [7] measured the crown volume of the maxillary central, the maxillary and mandibular canines and the mandibular laterals using cone beam computed tomography (CBCT) and achieved an accuracy of 59–84%. In another study using CBCT, De Angelis et al. [12] proposed a simple method for sex estimation. They found the accuracy of sex discrimination based on

the threshold value (0.619 cm<sup>3</sup>) of tooth volume of the maxillary canines to be 80.5%. In studies using micro-CT and discriminant analysis, an accuracy of 60–96% with various volumes and ratios of the maxillary and mandibular canines [8, 9], and between 66 and 90% with various volumes and surface areas of the maxillary and mandibular anterior and premolar teeth have been reported [10]. In another study on micro-CT, Sorenti et al. [11] found the accuracy of the logistic regression models derived by various area and surface ratios of the mandibular molars as 74.36%.

In this study, it was aimed to determine the diagnostic cut-off values of the volumetric measurements of the maxillary canines on CBCT images for sex estimation and to test the validity of the method.

## Methods

Our investigational protocol was approved by the Non-Interventional Clinical Research Ethics Board at İzmir Demokrasi University (Approval no. 2023/03–20). The study was performed on 250 CBCT images of 118 females and 132 males, aged 18 to 63 years, from the archive of the Department of Oral and Maxillofacial Radiology at Hacettepe University Faculty of Dentistry, recorded between January 2017 and December 2021. Study population was consisted of contemporary Turkish people from Middle Anatolia in Turkey. Turkey is situated in one of the most diverse regions of Europe and Asia due to the complex genetic background and widespread presence of Turkish people in both the Near East and Europe [14]. Hacettepe University Faculty of Dentistry is a state hospital that can receive patients from all regions of Turkey, with a particular emphasis on the central parts.

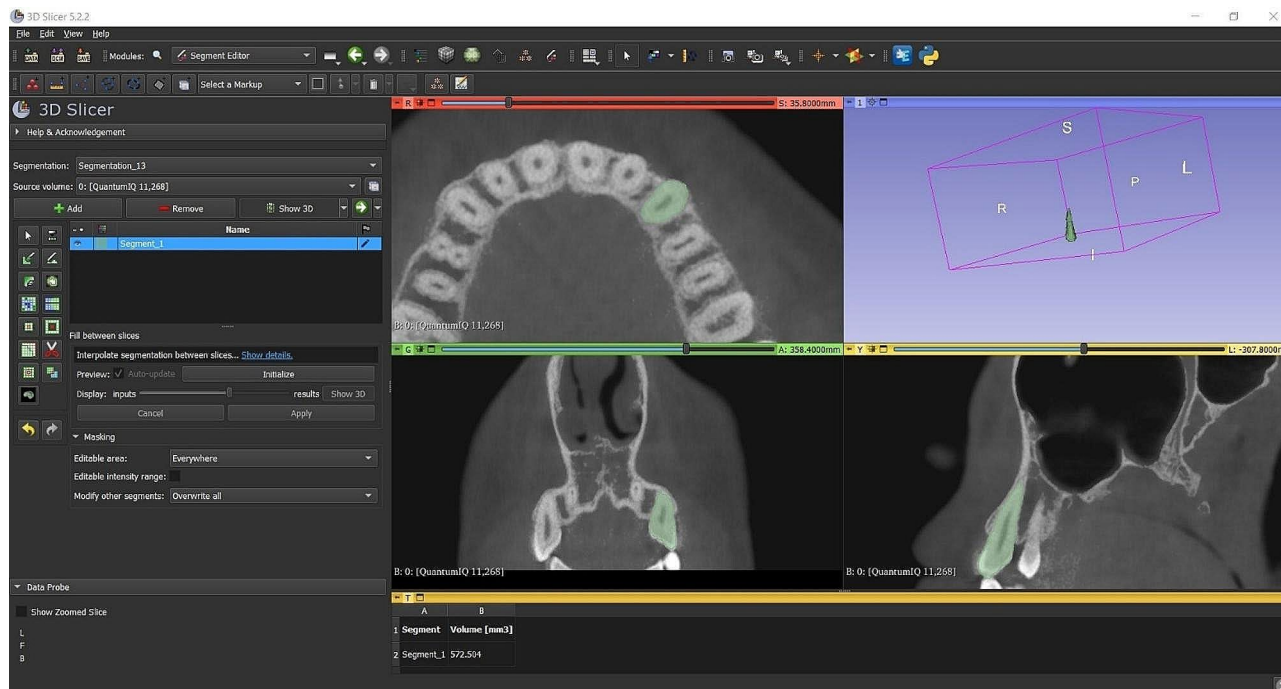
Images were selected, ensuring an equal sex and age distribution. Age and sex information of the individuals were recorded. Other inclusion criteria for the study encompass the following:

- The images should have diagnostic quality and be free from factors such as artifacts that could affect measuring.
- There should be at least one maxillary canine present on the right or left side.
- The canines should have completed apical development.
- The canines should be free of caries, notably attrition involving dentin, restoration, fracture, resorption, shape or size anomalies, or pathology.
- No maxillofacial anomalies or deformities should be present.

All images were randomly divided into two samples; reference set (N:168) and validation set (N:82). The reference set was constructed, ensuring the number equality

**Table 1** The number of the subjects according to the age groups and sex for both datasets

Age Groups	Reference set			Validation set		
	Female	Male	Total	Female	Male	Total
18–29 years	28	28	56	18	10	28
30–44 years	28	28	56	16	16	32
45–63 years	28	28	56	14	8	22
Total	84	84	168	48	34	82



**Fig. 1** Volume measurement sample of the maxillary canine (3D Slicer Software, Segment Editor module)

**Table 2** Volumetric measurements of the maxillary canine in females and males

Measurements	Females		Males		p
	Min – Max (mm <sup>3</sup> )	Mean ± SD (mm <sup>3</sup> )	Min – Max (mm <sup>3</sup> )	Mean ± SD (mm <sup>3</sup> )	
TV	358–702	504 ± 78	447–1015	660 ± 116	0,000*
RV	180–408	278 ± 53	235–645	391 ± 77	0,000*

TV, tooth volume; RV, root volume

\* P < 0.05

of subjects per sex in three age groups, then, the validation set consisted of the remaining subjects. Table 1 shows age and sex distribution of the subjects for both samples.

All CBCT images were acquired with a CBCT device (i-CAT Next Generation, Imaging Sciences International, Hatfield, PA, USA) with a tube voltage of 120 kVp with variation in the field of view, acquisition voxel size, tube current (3–7 mA), and exposure time.

The measurements were conducted on the left maxillary canines. If the left maxillary canine was not present, the right-side canines were used. The images were numbered to provide observer blinding during measuring. For the volumetric measurements of canines, CBCT

images were transferred to 3D Slicer version 5.0.3 software (Surgical Planning Lab, Harvard Medical School, Harvard University, Boston, MA, USA). In the “Segment editor module”, each canine tooth was manually defined in the axial section and evaluated by creating a ROI (Region of interest) in every 2–3 slices from the crown to the root apex. Missing ROIs were created with the “filling between sections” feature in the program, and thus 3D models of the teeth were obtained. The “Segment statistics module” in the program was used to calculate the volumes in these models. The tooth volume (TV) and root volume (RV) of canine teeth were evaluated in mm<sup>3</sup> (Fig. 1). All the measurements were carried out by a single observer - oral and maxillofacial radiologist. To assess

intra-observer agreement, measurements were repeated on 24 randomly selected images two weeks after the initial measurements. To explore inter-observer agreement, the same 24 images were evaluated by another observer - oral and maxillofacial radiologist.

The statistical analysis of the data was performed using IBM SPSS (ver. 20) and easyROC web tool [15]. The significance level for the analysis was set at 5%. Intra-observer and inter-observer agreements were evaluated using the intra-class correlation coefficient (ICC).

To determine which statistical method to be used in determining the difference between the averages of the independent groups, the suitability of the data to the normal distribution was first tested with the Kolmogorov-Smirnov and Shapiro Wilk tests, and it was observed that the variables were not normally distributed. Spearman correlation coefficient was used for the relationship between age and the volumetric measurements and the difference between age groups and sexes was examined with the Mann Whitney U test. Males were coded as 1, and females as 0. The optimal cut-off values of the TV and RV for sex estimation were established from the reference dataset using the Youden's index. Measurements equal to or above the determined cut-off value were classified as male (coded as 1); measurements below the cut-off value were classified as female (coded as 0). Receiver operating characteristic (ROC) curve analysis was performed. The discriminative ability for sex estimation of the determined cut-off values as well as the previously established cut-off values of the canine volume, 619 mm<sup>3</sup> by De Angelis et al. [12], and 510 mm<sup>3</sup> and 460 mm<sup>3</sup> (for right and left side, respectively) by Tardivo et al., [1] were evaluated by area under the ROC curve (AUC), accuracy (Ac, i.e., overall percentage of correct predictions), sensitivity (Se, i.e., true positive rate considered to indicate the probability of the method correctly classifying males), specificity (Sp, i.e., true positive rate considered to indicate the probability of the method correctly classifying males), positive and negative predictive values (PPV and NPV), positive and negative likelihood ratios (LR+ and LR-).

## Results

The ICC values for intra-observer agreement were 0.989 (95% CI; 0.974–0.995) and 0.984 (95% CI; 0.963–0.993) for TV and RV, respectively. It represents excellent agreement when greater than 0.90 [16]. Similarly, the ICC values for inter-observer agreement were 0.992 (95% CI; 0.982–0.997) for TV and 0.978 (95% CI; 0.948–0.990) for RV.

Out of 250 CBCT images, 168 (67.2%) were included in reference set and 82 (32.8%) were in validation set. Females and males were equally distributed in the reference set. The mean age of the sample ranged from 18

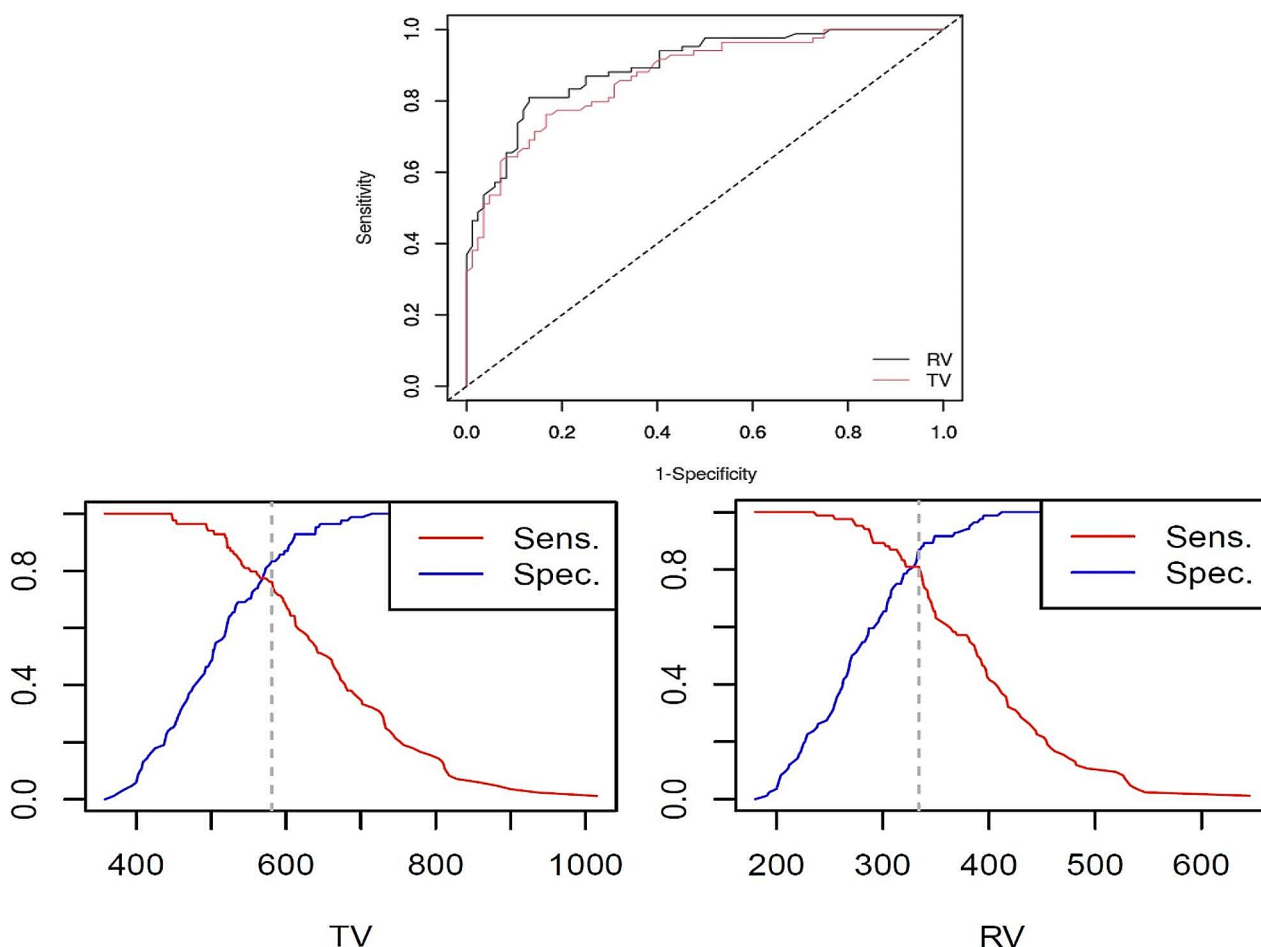
to 63 years old was 36.3±11.7 in females and 36.9±12.0 in males. In the reference sample, the mean ages of males and females were respectively 36.8±11.9 and 37.0±12.4. In the validation sample, they were 35.4±11.5 and 36.7±11.4. No statistically significant correlation between age and the maxillary canine's TV and RV measurements nor difference was found between the age groups ( $p>0.05$ ).

The descriptive statistics of the TV and RV in males and females were presented in Table 2. It was found that the mean tooth and root volumes of the maxillary canine were significantly greater in males than in females ( $p<0.05$ ).

The optimal cut-off values of 581 mm<sup>3</sup> for TV and 334 mm<sup>3</sup> for RV to discriminate the females and males were established. Their AUC values were 0.870 (95% CI, 0.818 to 0.922) and 0.896 (95% CI, 0.849 to 0.942), respectively (Fig. 2). Tables 3 and 4 presented respectively the contingency data and the performance measures of the derived cut-off values (TV≥581 mm<sup>3</sup> and RV≥334 mm<sup>3</sup>) as well as those of the previous cut-off value (TV≥619 mm<sup>3</sup>). For the other previously derived cut-off values of right TV≥510 mm<sup>3</sup> and left TV≥460 mm<sup>3</sup>; AUC, Ac, Se, and Sp were found to be, respectively, 0.621 (95% CI, 0.551–0.690), 0.561 (95% CI, 0.447–0.670), 0.971 (95% CI, 0.847–0.999), and 0.271 (95% CI, 0.153–0.418).

## Discussion

Sexual dimorphism in tooth size, a well-known phenomenon, is explained by genetic point of view rather than role of sex hormones in dental development [17–20]. Differences in tooth size and in sexual dimorphism among pre-historic or modern populations have been widely reported in the literature [13, 14, 21–25]. This study confirmed a significant difference in the tooth and root volumes of maxillary canines between the sexes, with males exhibiting larger teeth, in contemporary Turkish individuals from Middle Anatolia. While various studies have explored tooth size as an indicator for sex estimation, recent advancements in imaging techniques, particularly CBCT, have offered new avenues for accurate measurements. The utilization of CBCT offers several advantages in developing sex estimation methods, primarily due to its increased usage in dentistry. This technology allows volumetric measurements of tooth tissues, including root volume, without the necessity for invasive procedures such as tooth extraction, offering a more accurate representation of size compared to linear measurements [7, 13]. The canines are reported to show the highest sexual dimorphism in most studies using linear measurements [3, 6, 24, 26–28]. Among the previous studies using volumetric measurement, some studies [7, 10], have found that mandibular canines show the most sex differences, while other has reported it's the maxillary canines [1]. We conducted a pilot study using CBCT and assessed



**Fig. 2** The ROC, sensitivity, and specificity curves of the optimal cut-off points of tooth volume (TV) and root volume (RV) for discriminating between females and males

sex differences in dental tissue volumes and ratios (tooth volume, tooth volume without enamel, crown and root volumes, enamel, dentin and pulp volumes, crown/root, enamel/tooth, dentin/tooth, pulp/tooth volume ratios) of the maxillary and mandibular canines and second molars. Tooth volume, tooth volume without enamel, crown volume, and root volume exhibited statistically significant differences between the sexes for all teeth, while none of the ratios displayed a significant difference. Among these variables the tooth and root volumes of the maxillary canines emerged as the most distinctive and reliable indicators for sex estimation [29]. Therefore, the present study aimed to establish the cut-off values for the tooth and root volumes of the maxillary canines ( $TV \geq 581 \text{ mm}^3$  and  $RV \geq 334 \text{ mm}^3$ ) to improve accuracy of sex estimation and subsequently evaluate their performance in comparison with the previously proposed cut-off values of  $TV \geq 619 \text{ mm}^3$  by De Angelis et al. [12], and  $TV \geq 510 \text{ mm}^3$  (for right side) and  $TV \geq 460 \text{ mm}^3$  (for left side) by Tardivo et al. [1].

A prediction using diagnostic cut-off values inherently involves two types of errors: Type I errors (false positives,

i.e., the definition of a female as a male) and Type II errors (false negatives, i.e., the definition of a male as a female). An ideal method minimizes both errors, requiring the determination of optimal cut-off values. The Se ( the probability of correctly classifying males) and Sp ( the probability of correctly classifying females) values are crucial indicators of diagnostic accuracy. In the current study, the derived cut-off value of  $TV \geq 581 \text{ mm}^3$  achieved predicting sex with 77% of the Se, Sp, and Ac values, while the previously established cut-off value of  $TV \geq 619 \text{ mm}^3$  were with respectively 0.71, 0.90 and 0.82. The new cut-off value of TV did not significantly improve the discrimination performance, exhibited a higher Se but considerably lower Sp and slightly lower Ac values. However, Sp of the cut-off value of  $TV \geq 619 \text{ mm}^3$  was considerably higher than Se, means that the value of  $619 \text{ mm}^3$  can successfully differentiate females in our population but, it may produce a significant false negative result. On the contrary, De Angelis et al. [12], in the original study conducted on 87 Italians aged 15 to 83 years, have reported higher Se value than Sp, indicated the value of  $619 \text{ mm}^3$  give a more accurate sex estimation for males. On the other

**Table 3** The contingency data showing discriminating performance of TV ≥ 581 mm<sup>3</sup>, RV ≥ 334 mm<sup>3</sup> and TV ≥ 619 mm<sup>3</sup> in both datasets

Sex	Reference set			Validation set		
	TV ≥ 581	RV ≥ 334	Total	TV ≥ 581	RV ≥ 334	Total
Male	64 <sup>TP</sup>	68 <sup>TP</sup>	84	26 <sup>TP</sup>	84	84
Female	14 <sup>FP</sup>	11 <sup>FP</sup>	84	11 <sup>FP</sup>	84	84
Total	78	79	168	37	168	168
	< 581	< 334	Total	< 581	< 334	Total
Male	20 <sup>FN</sup>	16 <sup>FN</sup>	84	8 <sup>FN</sup>	34	34
Female	70 <sup>TN</sup>	73 <sup>TN</sup>	84	37 <sup>TN</sup>	48	48
Total	90	89	168	45	82	82
	< 619	< 619	Total	< 619	< 619	Total
Male	10 <sup>FN</sup>	24 <sup>TP</sup>	34	6 <sup>FN</sup>	34	34
Female	43 <sup>TN</sup>	5 <sup>FP</sup>	48	37 <sup>TN</sup>	48	48
Total	53	29	82	43	82	82

TV, tooth volume; RV, root volume; TP, True positives; FP, False positives; FN, False negatives; TN, True negatives

**Table 4** The discrimination performance measures of TV ≥ 581 mm<sup>3</sup>, RV ≥ 334 mm<sup>3</sup> and TV ≥ 619 mm<sup>3</sup> in both datasets

Measures	Reference set		Validation set		
	TV ≥ 581	RV ≥ 334	TV ≥ 581	RV ≥ 334	TV ≥ 619
Ac	0.798 (0.729–0.856)	0.839 (0.775–0.891)	0.768 (0.662–0.854)	0.793 (0.689–0.874)	0.817 (0.716–0.894)
Se	0.762 (0.657–0.848)	0.810 (0.709–0.887)	0.765 (0.588–0.893)	0.824 (0.655–0.932)	0.706 (0.525–0.849)
Sp	0.833 (0.736–0.906)	0.869 (0.778–0.933)	0.771 (0.627–0.880)	0.771 (0.627–0.880)	0.896 (0.773–0.965)
PPV	0.821 (0.718–0.889)	0.861 (0.765–0.919)	0.703 (0.541–0.858)	0.718 (0.560–0.883)	0.828 (0.656–0.918)
NPV	0.778 (0.676–0.871)	0.820 (0.724–0.905)	0.822 (0.670–0.910)	0.860 (0.715–0.931)	0.811 (0.665–0.933)
LR+	4.57 (2.79–7.48)	6.18 (3.53–10.83)	3.34 (1.92–5.79)	3.59 (2.09–6.18)	6.78 (2.88–15.97)
LR-	0.29 (0.19–0.42)	0.22 (0.14–0.34)	0.31 (0.16–0.57)	0.23 (0.11–0.48)	0.33 (0.19–0.56)

TV, tooth volume; RV, root volume; Se, sensitivity; Sp, specificity PPV, positive predictive value; NPV, negative predictive value; LR+, positive likelihood ratio; LR-, negative likelihood ratio; values are reported with 95% confidence intervals in the parenthesis.

hand, the correct prediction rate was similar for both studies. Regarding other previous cut-off values of right TV ≥ 510 mm<sup>3</sup> and left TV ≥ 460 mm<sup>3</sup>, the correct prediction rate for our population (62%) did not achieve as high as those of the original study (85–84%) conducted on French individuals by Tardivo et al. [1]. Comparison with other study highlighted variations in statistical method and sex marker, Manhaes-Caldas et al. [7] have reported slightly lower performance with a cut-off value of 0.5 calculated with a specific model including the crown volume of the maxillary canine. The crown volume has showed 72% Se, 77% Sp, and 74% overall accuracy for sex estimation in Brazilian population. The differences among the results could be attributable to differences in populations as well as study methodology, sample size, and observer variations. Different magnitude of sex dimorphism is suggested among populations because of interactions of genetic and environmental influences [26, 27, 30]. The environmental factors, such as poor nutrition and recurrent illnesses, may play role in the variations in tooth size [21]. In addition, secular increase in tooth sizes have been reported in various populations, attributed to factors such as improvements in living conditions and nutritional status [31, 32]. Such variations due to ethnic, cultural, and socioeconomic factors may result in potential errors in the sex estimation. Accordingly, many researchers have emphasized the need for the development of population-specific standards for the sex estimation [5, 24, 25, 30]. The previous

studies conducted on contemporary Turkish people from Turkey have focused on linear measurements (mesiodistal and/or buccolingual dimensions) of all teeth for sex estimation [14, 24]. İşcan and Kedicici [24] created the discriminant functions for sex estimation using different combinations of teeth or variables and observed that the maxillary canine, the mandibular canine and second molar contributed the most to these models. The accuracy achieved in between 73% and 77%. Ateş et al. [14] determined that dimensions of the mandibular canine, maxillary canine and second incisor served as discriminating variables, when using anterior teeth for sex estimation. The classification accuracy of the discriminant functions was found to be 76% for the maxillary anterior teeth and 81% for the mandibular anterior teeth. These accuracy rates are similar to our result, however, there are differences in the used measures (linear measurements) and statistical models between the studies. Hence, the applicability of the volumetric method across various populations or within the populations can be examined in further studies.

The present study included intact teeth of individuals aged from 18 to 63 years to avoid any potential source of bias for sex estimation. Regarding physiological attrition, severe worn teeth, were not included to the study sample. Furthermore, no significant relationship between age and the examined parameters was found. This indicates that this method holds consistent applicability across different age groups. However, in advanced age, the probability of encountering severe attrition increases, impacting the tooth size and altering the TV measurements, which may diminish the method's applicability of for older individuals. On the other hand, cement deposition, another age-related change, could potentially compensate for the volume reduction caused by attrition [33]. However, this possibility requires examination, and the cut-off value of TV can be tested in future studies, especially for severe worn teeth. As an alternative to TV, for the worn or decayed tooth, the cut-off value of the RV can be used to estimate sex. Moreover, the cut-off value of  $RV \geq 334 \text{ mm}^3$  demonstrated superior performance compared to  $TV \geq 581 \text{ mm}^3$ , but still could not exceed 80% Ac and provided slightly more accurate predictions for males with a higher Se value (82%) than Sp (77%). This is lower than a previous study [13] where, like our study, root volume for sex determination was assessed using CT, and an accuracy of 97% was achieved with the discriminant function including maxillary canine. This discrepancy may be attributed to the difference in the populations, which Kazzazi et al.'s [13] study sample were consisted of Iranian archaeological subjects.

This study attempts to establish forensic standards for sex estimation in Turkish individuals using a simple method that involves a single tooth and volumetric measurement of the maxillary canine on CBCT images. The performance of dental volumetric techniques for sex estimation was not

improved with the derived cut-off values of volumes of the maxillary canines and remained still lower than those achieved with other osteometric techniques. The method partially meets the Mohan and Daubert criteria [34], indicating that the techniques used in forensic investigations should provide a minimum of 80% accuracy and a maximum of 10% intra-observer error rate for admissibility in a court of law, as it presents excellent intra-observer reliability but borderline accuracy value.

Although the volumetric measurements can be more time-consuming and challenging than linear measurements, De Angelis et al. [12] reported that the application of the method is very simple to be achieved by everyone and that more tools to measure tooth volume is also available, such as a test tube filled by water, which can also apply for root volume. The study is not without limitations. The sample size, although comprehensive, may not fully represent the entire population's diversity. The factors of tooth position or impaction, which could potentially influence TV measurements and, in turn, the performance of the method, were not considered. Additionally, the study's findings might be influenced by the used software and measurement techniques.

## Conclusions

The method based on the total tooth and root volumes in the maxillary canines can be useful in case where maxillary canine is single evidence and/or its crown is destructed, to estimate sex with moderate accuracy [35] in the field of forensic sciences and anthropology. The cut-off values of TV and RV in this method were respectively  $581 \text{ mm}^3$  and  $334 \text{ mm}^3$  for contemporary Turkish individuals. Future research could explore the method's applicability to different populations and assess the method's precision and robustness across various measurement techniques.

## Abbreviations

Ac	Accuracy
AUC	Area Under the ROC Curve
CBCT	Cone Beam Computed Tomography
FN	False Negative
FP	False Positive
LR	Likelihood Ratio
NPV	Negative Predictive Values
PPV	Positive Predictive Values
ROC	Receiver Operating Characteristic
ROI	Region of interest
RV	Root Volume
Se	Sensitivity
Sp	Specificity
TN	True Negative
TP	True Positive
TV	Tooth Volume

## Author contributions

CÖK: Conception, study planning, data collection, data analysis and interpretation, article writing. HÖY: Study planning, data analysis and interpretation, article writing. GA: Data collection, data analysis and interpretation, critical review. All authors read and approved the final manuscript.

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### Data availability

The datasets generated and/or analysed during the current study are available from the corresponding author upon reasonable request.

### Declarations

#### Ethics approval and consent to participate

Our investigational protocol was approved by the Non-Interventional Clinical Research Ethics Board at Izmir Democracy University (Approval no. 2023/03–20). This study was conducted retrospectively and did not contain personally identifiable information. The exemption from informed consent was approved by the Non-Interventional Clinical Research Ethics Board at Izmir Democracy University. All methods were carried out in accordance with relevant rules and regulations.

#### Consent for publication

Not applicable.

#### Competing interests

The authors declare no competing interests.

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### References

- Tardivo D, Sastre J, Catherine JH, Leonetti G, Adalian P, Foti B. Gender determination of adult individuals by three-Dimensional modeling of canines. *J Forensic Sci.* 2015;60(5):1341–5.
- Capitaneanu C, Willems G, Thevissen P. A systematic review of odontological sex estimation methods. *J Forensic Odontostomatol.* 2017;2(35):1–19.
- Thapar R, Angadi PV, Hallikerimath S, Kale AD. Sex assessment using odontology and cranial anthropometry: evaluation in an Indian sample. *Forensic Sci Med Pathol.* 2012;8(2):94–100.
- Bašić Z, Anterić I, Vilović K, Petaros A, Bosnar A, Madžar T, et al. Sex determination in skeletal remains from the medieval Eastern Adriatic coast—discriminant function analysis of humeri. *Croat Med J.* 2013;54(3):272–8.
- Dumančić J, Scott GR, Savić Pavičin J, Anić-Milošević S, Medančić N, Brkić H. Canine crown sexual dimorphism in a sample of the Modern Croatian Population. *Dent J.* 2023;11(7):175.
- Angadi PV, Hemani S, Prabhu S, Acharya AB. Analyses of odontometric sexual dimorphism and sex assessment accuracy on a large sample. *J Forensic Leg Med.* 2013;20(6):673–7.
- Manhaes-Caldas D, Oliveira ML, Groppo FC, Haiter-Neto F. Volumetric assessment of the dental crown for sex estimation by means of cone-beam computed tomography. *Forensic Sci Int.* 2019;303:109920.
- García-Campos C, Martinon-Torres M, Martínez de Pinillos M, Modesto-Mata M, Martín-Frances L, Perea-Pérez B, et al. Modern humans sex estimation through dental tissue patterns of maxillary canines. *Am J Phys Anthropol.* 2018;167(4):914–23.
- García-Campos C, Martinon-Torres M, Martín-Frances L, Martínez de Pinillos M, Modesto-Mata M, Perea-Pérez B, et al. Contribution of dental tissues to sex determination in modern human populations. *Am J Phys Anthropol.* 2018;166(2):459–72.
- Fernée C, Zakrzewski S, Robson Brown K. Dimorphism in dental tissues: sex differences in archaeological individuals for multiple tooth types. *Am J Phys Anthropol.* 2021;175(1):106–27.
- Sorenti M, Martínón-Torres M, Martín-Frances L, Perea-Pérez B. Sexual dimorphism of dental tissues in modern human mandibular molars. *Am J Phys Anthropol.* 2019;169(2):332–40.
- De Angelis D, Gibelli D, Gaudio D, Cipriani Noce F, Guercini N, Varvara G, et al. Sexual dimorphism of canine volume: a pilot study. *Leg Med (Tokyo).* 2015;17(3):163–6.
- Kazzazi SM, Kranjoti EF. A novel method for sex estimation using 3D computed tomography models of tooth roots: a volumetric analysis. *Arch Oral Biol.* 2017;83:202–8.
- Ateş M, Karaman F, Işcan MY, Erdem TL. Sexual differences in Turkish dentition. *Leg Med (Tokyo).* 2006;8(5):288–92.
- Goksuluk D, Korkmaz S, Zararsiz G, Karaagaoglu AE. easyROC: an interactive web-tool for ROC curve analysis using R language environment. *R J.* 2016;8(2):213.
- Perinetti G, StaTips Part IV. Selection, interpretation and reporting of the intraclass correlation coefficient. *South Eur J Orthod Dentofac Res.* 2018;5(1):3–5.
- Garn SM, Lewis AB, Swindler DR, Kerewsky RS. Genetic control of sexual dimorphism in tooth size. *J Dent Res.* 1967;46(5):963–72.
- Alvesalo L. Sex chromosomes and human growth. A dental approach. *Hum Genet.* 1997;101(1):1–5.
- Lau EC, Mohandas TK, Shapiro LJ, Slavkin HC, Snead ML. Human and mouse amelogenin gene loci are on the sex chromosomes. *Genomics.* 1989;4(2):162–8.
- Guatelli-Steinberg D, Sciulli PW, Betsinger TK. Dental crown size and sex hormone concentrations: another look at the development of sexual dimorphism. *Am J Phys Anthropol.* 2008;137(3):324–33.
- Brook AH, Griffin RC, Townsend G, Levisianos Y, Russell J, Smith RN. Variability and patterning in permanent tooth size of four human ethnic groups. *Arch Oral Biol.* 2009;54(Suppl 1):79–85.
- Brace CL, Ryan AS. Sexual dimorphism and human tooth size differences. *J Hum Evol.* 1980;9(5):417–35.
- Schwartz GT, Dean MC. Sexual dimorphism in modern human permanent teeth. *Am J Phys Anthropol.* 2005;128(2):312–7.
- Işcan MY, Kedici PS. Sexual variation in bucco-lingual dimensions in Turkish dentition. *Forensic Sci Int.* 2003;137(2–3):160–4.
- Pilloud M, Scott G. Dentition in the estimation of sex. In: Klaes AR, editor. Sex estimation of the human skeleton. Academic Press; 2020. pp. 149–69.
- Acharya AB, Mainali S. Univariate sex dimorphism in the Nepalese dentition and the use of discriminant functions in gender assessment. *Forensic Sci Int.* 2007;173(1):47–56.
- Filipovic G, Kanjevac T, Cetenovic B, Ajdukovic Z, Petrovic N. Sexual dimorphism in the dimensions of Teeth in Serbian Population. *Coll Antropol.* 2016;40(1):23–8.
- Viciano J, Lopez-Lazaro S, Aleman I. Sex estimation based on deciduous and permanent dentition in a contemporary Spanish population. *Am J Phys Anthropol.* 2013;152(1):31–43.
- Yılancı HÖ, Özeren Keşkek C, Akçiçek G. Volumetric evaluation of dental tissues for sex estimation: a pilot study. 4th Int Congress Oral Diagnosis Maxillofacial Radiol Soc, 2022. 19–23 October 2022, Izmir:p.164.
- Alam MK, Khamis MF, Malik SN. Sex determination based on mesiodistal tooth width in Bangladeshi population. *Int Med J.* 2015;22:181–3.
- Ebeling CF, Ingervall B, Hede-gård B, Lewin T. Secular changes in tooth size in Swedish men. *Acta Odontol Scand.* 1973;31(3):141–7.
- Garn SM, Lewis AB, Walenga A. Evidence for a secular trend in tooth size over two generations. *J Dent Res.* 1968;47(3):503.
- Boushell LW, Sturdevant JR. Clinical significance of Dental anatomy, histology, physiology, and occlusion. In: Ritter AV, Boushell LW, Walter R, editors. Sturdevant's art and science of Operative Dentistry. St. Louis: Elsevier; 2019. pp. 1–39.
- Williams BA, Rogers T. Evaluating the accuracy and precision of cranial morphological traits for sex determination. *J Forensic Sci.* 2006;51(4):729–35.
- Swets JA. Measuring the Accuracy of Diagnostic systems. *Science.* 1988;240(4857):1285–93.

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