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Exploiting maxillary sinus dimensions for sexual determination in the Bosnian and Herzegovinian population

Коришћење димензија максиларног синуса за одређивање пола у босанскохерцеговачкој популацији

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SUMMARY

Introduction/Objective This study aimed to evaluate sex assessment using cone-beam computed tomography (CBCT) images by analyzing the dimensions and volume of the maxillary sinus. Additionally, the study aimed to develop prediction formulas for sex assessment and assess their accuracy for the population of Bosnia and Herzegovina.

Methods A total of 150 CBCT images were analyzed, comprising 73 males and 77 females, aged 20 to 69 years. The dimensions of the maxillary sinuses—specifically, the mediolateral, superoinferior, and anteroposterior measurements—along with their volumes, were assessed using Romexis software. Measurements were taken from both axial and coronal projections. To develop gender prediction formulas, multiple regression analysis was employed. The accuracy of sex prediction was evaluated using discriminant functional analysis.

Results Significant differences ($p < 0.05$) in sinus dimensions and volume were observed between sexes. Males had larger maxillary sinuses: left sinus volume was 27.60 ± 6.87 cm^3 in males versus 22.10 ± 5.77 cm^3 in females and right sinus volume was 27.48 ± 7.02 cm^3 in males versus 21.65 ± 5.42 cm^3 in females. The right maxillary sinus provided the highest accuracy for sex prediction (75%), followed by the left sinus (71%).

Conclusion The dimensions and volume of the maxillary sinus vary significantly between sexes, with males typically having larger sinuses. A gender prediction formula based on the right maxillary sinus offers the highest accuracy for sex prediction, achieving 75%. This formula could be a valuable tool in forensic applications specific to the Bosnian population when other methods are not available.

Keywords: maxillary sinus; sex determination; forensic identification; CBCT; sexual dimorphism

САЖЕТАК

Увод/Циљ Циљ овог истраживања био је да се оцени процена пола на основу снимака соне - беам компјутерској томографији (CBCT) анализом димензија и волумена максиларног синуса, те да се развију формуле за предвиђање пола, уз одређивање њихове тачности за популацију Босне и Херцеговине.

Методе Анализирано је укупно 150 CBCT снимака (73 мушкарца, 77 жена) у доби од 20 до 69 година. Димензије (медиолатералне, супероиферирне и антеропостериорне) и волумен максиларних синуса мерене су коришћењем Romexis софтвера, при чему су мерења извршена на аксијалним и коронарним пројекцијама. Формуле за предвиђање пола генерисане су коришћењем мултипле регресије. Дискриминантна функционална анализа коришћена је за процену тачности предвиђања пола.

Резултати Уочене су значајне разлике ($p < 0.05$) у димензијама синуса и волумену између полова. Мушкарци су имали веће максиларне синусе: волумен левог синуса био је 27.60 ± 6.87 cm^3 код мушкараца наспрем 22.1 ± 5.77 cm^3 код жена, док је волумен десног синуса био 27.48 ± 7.02 cm^3 код мушкараца наспрем 21.65 ± 5.42 cm^3 код жена. Десни максиларни синус пружио је највишу тачност у предвиђању пола (75%), док је леви синус имао тачност од 71%.

Закључак Димензије и волумен максиларног синуса значајно се разликују између полова, при чему мушкарци имају веће синусе. Формула за предвиђање пола заснована на десном максиларном синусу пружа најтачнију процену пола (75%) и може бити користан алат у форензичким применама за популацију Босне и Херцеговине када други методи нису доступни.

Кључне речи: максиларни синус; одређивање пола; форензичка идентификација; *CBCT*; сексуални диморфизам

INTRODUCTION

The maxillary sinus is a pneumatized hollow space located in the central portion of the upper jaw. Its size varies among individuals and can be influenced by factors such as age, sex, the

level of pneumatization, and early tooth loss. The exact function of the maxillary sinus is still not fully understood, but there are several theories regarding its role. It is thought to help minimize the weight of the head, contribute to voice resonance, and prepare air intake by heating and humidifying the air [1].

This research examines the maxillary sinus as a valuable anatomical feature for assessing sex based on its dimensions. Sex assessment is a crucial area in dental forensics, playing a significant role in identifying unknown individuals who may be victims of bomb explosions, natural disasters, or other types of accidents. It also contributes to establishing a person's identity when identity information is lacking. In addition to forensic applications, sex assessment is also relevant in archaeological, biological, and anthropological studies. [2, 3]. Forensic experts face significant challenges in sex assessment when only skeletal fragments of individuals are available. The most critical aspect of anthropological examination is accurately determining sex. Due to the knowledge of gender, half of the possibilities are eliminated, as sex is a two-option framework, meaning it can be either male or female. Accurate sex assessment is essential because it significantly influences factors such as age and physical constitution. This information is valuable for researchers across various fields, including medical sciences, anthropology (particularly in the examination of skeletal remains), criminology (for identifying undocumented individuals, such as in major accidents where identification is challenging), forensic medicine, archaeology, and others [4, 5, 6].

There are several methods for assessing the sex of unidentified individuals based on skeletal remains and their anatomical features. These methods include measuring the length and height of the head, the distance between the basion and the prosthion, and the circumference of the head. Other measurements involve the length of the supraorbital edge, the size of the mastoid process and the mandibular ramus, the shape and length of the palate, and the circumference

of the occipital condyle, among others. [3]. Unlike other anatomical features used for sex assessment, the maxillary sinus of individuals exposed to fire or other disasters invariably remains intact. This characteristic establishes the maxillary sinus as a crucial element in forensic dentistry [4, 5].

The aim of this study was to evaluate sex differences using cone-beam computed tomography (CBCT) images to determine the dimensions and volume of the maxillary sinus. Additionally, the study aimed to develop formulas for sex prediction and assess their accuracy for the population of Bosnia and Herzegovina.

METHODS

The study was designed to measure the mediolateral (ML), superoinferior (SI) and anteroposterior (AP) linear dimensions and the volume of both right and left maxillary sinuses using CBCT images. A total of 150 CBCT images including 73 males and 77 females aged 20 to 69 from the existing database of the Specialist Center "Dental Clinic", Faculty of Medicine, University of Banja Luka were observed in this study. CBCT images were taken using Planmeca Viso® G7 plus following exposure parameter settings 90kW, 4-10mA,14s and images acquisition at 0.2 mm voxel size. CBCT images were selected based on strict inclusion and exclusion criteria. The inclusion criteria ensured that only images of individuals with intact maxillary sinuses were included. Exclusion criteria included individuals under 20 years of age, as maxillary sinus development is typically completed by the age of 18-20 years [7]. Additionally, images were excluded if any pathological conditions were present, such as maxillary sinus pathology, facial deformities involving the maxilla, deep caries, periapical abscesses, odontogenic cysts, tumors, or significant bone loss due to periodontal disease. These

criteria were applied to ensure the selection of healthy, anatomically intact cases, thus minimizing the impact of potential factors that could compromise the research results. Considering the retrospective design of the study, the CBCT images were originally acquired for various clinical purposes. The subjects' written consent was obtained, according to the Declaration of Helsinki, and the study has been approved by the local ethics committee (Ethics Committee for Research on Humans and Biological Materials, Faculty of Medicine, University of Banja Luka, under approval number No.18/4. 227/24).

Performed measurements were operated in the software Romexis 6.0 (Planmeca Oy, Finland). The ML and AP dimensions of right and left maxillary sinuses were measured on axial projection while the SI dimensions of right and left maxillary sinuses were measured on coronal projection. On the axial and coronal projections, the slices of CBCT image whose ML, AP and SI dimensions had the greatest dimensions of the left and right maxillary sinus, were chosen as the reference for measurements.

The ML dimension was defined as the longest distance perpendicular from the medial wall of the sinus to the most lateral wall of the lateral process of the maxillary sinus in the axial projection (Figure 1). The AP was defined as the longest distance from the most anterior point to the most posterior point of the medial wall in the axial projection (Figure 2). The SI was defined as the longest distance from the lowest point of the sinus floor to the highest point of the sinus roof in the coronal projection (Figure 3). The measurements were performed by two trained examiners, who calibrated and cross-verified their results to ensure accuracy and consistency.

The volume of each maxillary sinus was calculated using the following equation [4]:

$$\text{Volume} = (\text{ML} \times \text{AP} \times \text{SI} \times 0.5)$$

The data collected were entered into Microsoft Excel 2017 (Microsoft Corporation, USA) and statistically analyzed using IBM SPSS Statistics for Windows, Version 22.0. (IBM Corp., Armonk, NY, USA). The mean values of all obtained dimensions, standard deviations, and statistical significance ($p < 0.05$) were calculated. Multiple regression formulas were created to predict sex based on the measured dimensions. If the result of the formula was positive, the predicted sex was male; if negative, female. The accuracy of sex prediction was assessed using discriminant functional analysis, with results expressed as percentages and displayed in tabular form. Statistical significance was set at $p < 0.05$ for standard significance, $p < 0.001$ for highly significant results, and $p > 0.05$ was considered non-significant.

RESULTS

The mean values and standard deviations of the dimensions of the left and right maxillary sinuses revealed statistically significant differences between males and females. A statistically significant difference ($p < 0.001$) was observed in all dimensions of both maxillary sinuses between males and females, except for the anteroposterior dimension of the left maxillary sinus (APL) (Table 1).

It was noted in comparison between the right and left maxillary sinus that the all dimensions of left maxillary sinus were marginally larger than the right maxillary sinus in females. On the contrary, in males, the right maxillary sinus was marginally larger in dimensions than the left maxillary sinus, apart from the ML dimensions. The ML dimension of the right maxillary sinus was less than ML dimension of the left maxillary sinus in males. However, these all-dimensions differences were statistically insignificant (Table 2).

It was observed that the volume of the left maxillary sinus (VL) was marginally larger than the

volume of the right maxillary sinus (VR) in males, while in females, the VL was smaller than the VR. Conversely, the VR was marginally larger than the VL in females, and smaller than the VL in males. However, these differences in volume were statistically insignificant. When comparing between genders, the volume of both maxillary sinuses was larger in males than in females, and this difference was statistically significant (Table 3).

Gender prediction formulas (*Formula 1*, *Formula 2*, *Formula 3*) were developed using multiple regression analysis, based on the dimensions and volume of both the right and left maxillary sinuses.

Formula 1. Sex prediction formula based on dimensions and volume of the left maxillary sinus.

Predicted Sex = 6.44 – 0.55 × SIL – 1.60 × MLL – 1.33 × APL + 0.24 × VL

Where:

- SIL = Superoinferior dimension of the left maxillary sinus
- MLL = Mediolateral dimension of the left maxillary sinus
- APL = Anteroposterior dimension of the left maxillary sinus
- VL = Volume of the left maxillary sinus

Formula 2. Sex prediction formula based on dimensions and volume of the right maxillary sinus.

Predicted Sex = 5.66 – 0.67 × SIR – 1.28 × MLR – 1.16 × APR + 0.22 × VR

Where:

- SIR = Superoinferior dimension of the right maxillary sinus
- MLR = Mediolateral dimension of the right maxillary sinus
- APR = Anteroposterior dimension of the right maxillary sinus
- VR = Volume of the right maxillary sinus

Formula 3. Sex prediction formula based on dimensions and volume of both maxillary sinuses.

Predicted Sex = 7.16 – 0.03 × SIL – 1.25 ×MLL – 0.81 × APL + 0.13 × VL – 0.69 × SIR – 0.14 × MLR – 0.62 × APR + 0.13 × VR

Where:

- SIL = Superoinferior dimension of the left maxillary sinus
- MLL = Mediolateral dimension of the left maxillary sinus
- APL = Anteroposterior dimension of the left maxillary sinus
- VL = Volume of the left maxillary sinus
- SIR = Superoinferior dimension of the right maxillary sinus
- MLR = Mediolateral dimension of the right maxillary sinus
- APR = Anteroposterior dimension of the right maxillary sinus
- VR = Volume of the right maxillary sinus

The sex prediction based on the dimensions and volume of the maxillary sinuses, as shown in Table 4, ranged from a minimum accuracy of 64% for males in the left maxillary sinus to a maximum of 83% for females using both sinuses combined.

DISCUSSION

In dental forensics, sex assessment is a critical step in the identification process, particularly when there is limited information available about the deceased. It is often the first priority for forensic experts in cases such as accidents, chemical and nuclear explosions, natural disasters, and similar situations [8]. The maxillary sinus serves as a valuable alternative for sex assessment when other methods are impractical or impossible to use. Skeletal analysis, particularly of pelvic morphology, is widely considered the gold standard for determining sex due to its high accuracy. However, in cases where remains are fragmented or incomplete, the pelvis or other skeletal markers may not be available or suitable for analysis. Since the maxillary sinus is well-protected within the craniofacial skeleton, it is often preserved even in instances of significant trauma or decomposition, making it an important option for assessment. [9, 10, 11].

Dental structures, particularly teeth, are often used for sex assessment due to their durability and availability. However, prolonged exposure to environmental factors, diseases, or wear can lead to significant degradation of these dental elements. In contrast, the maxillary sinus remains largely unaffected by such conditions, making it a more reliable structure for analysis. Furthermore, advanced imaging techniques, such as CBCT, have facilitated precise measurements of maxillary sinus dimensions, enhancing its utility in forensic identification [12, 13, 14].

The results of this study indicate that the dimensions of the left and right maxillary sinuse (specifically MLL, SIL, APL, VL, MLR, SIR, APR, and VR) are larger in males than in females, with these differences being statistically significant. Previous studies by Gamba et al. [9], Ayyildiz and Akgunglu [10], Mathew and Jacob [11], Elbaz et al. [12], Rani et al. [13], and Jaideepa et al. [14] have also reported that male maxillary sinuses are significantly larger than those of females. These findings align with the results of this study and provide additional validation. Mathew and Jacob [11] utilized CBCT technology, which offers greater precision compared to the two-dimensional methods employed by Elbaz et al. [12]. Rani et al. noted the influence of age [13], while Elbaz et al. focused on an Egyptian population, suggesting potential ethnic variations [12]. Conversely, other studies by Barros et al. [15], Belgin et al. [16], Gulec et al. [17], and Saccucci et al. [18] did not find statistically significant differences in maxillary sinus dimensions between sexes. Barros et al. included subjects of varying ages and nutritional statuses, which could contribute to these inconsistent findings [15]. While Gulec et al. [17] used CBCT, their sample size was smaller. Belgin et al. [16], on the other hand, relied on traditional radiographic methods, which may have affected accuracy.

This study clearly demonstrates that the height of the maxillary sinus is the most reliable distinguishing factor between sexes, aligning with the findings of Teixeira et al. [19], Mathew and Jacob [11], Kannampurath et al. [20], and Paknahad et al. [21]. Teixeira et al. specifically noted that maxillary sinus height is the most effective parameter for sex assessment [19]. Similarly, the CBCT-based study by Mathew and Jacob closely aligns with our findings, underscoring the importance of maxillary sinus height [11]. Kannampurath et al. further validate maxillary sinus height as a reliable marker in Asian populations, highlighting the consistency of this observation across different groups [20]. Additionally, Paknahad et al. [21] confirmed the significance of maxillary sinus height while noting variability based on the population sample studied.

Studies by Aşantoğrol and Coşgunarslan [22] along with Dhandapany et al. [23] confirm statistically significant correlations between maxillary sinus volume and sex, which supports our findings. Aşantoğrol and Coşgunarslan highlighted the impact of anatomical variations on maxillary sinus volume, making this information relevant for the broader applicability of our results [22]. Dhandapany et al. [23] also emphasized the potential of artificial intelligence in analyzing maxillary sinus volumes, suggesting that it could improve both accuracy and applicability.

Our results indicate that the highest accuracy for sex prediction was achieved using the dimensions and volume of the right maxillary sinus, with an accuracy rate of 75%. This is followed by the dimensions and volume of both maxillary sinuses together at 74%, and lastly, the dimensions and volume of the left maxillary sinus, which showed an accuracy of 71%. These findings align with those of Teixeira et al. [19], Prabhat et al. [24], and Wanzeler et al. [25], but contrast with the results reported by Teke et al. [3]. Teixeira et al. found an overall accuracy rate of 73.6% for sex prediction based on similar parameters, including intersinus distance [19]. Prabhat et al. reported a higher accuracy for the right maxillary sinus at 80%, compared to 73.3% for the left maxillary sinus, which is consistent with our findings [24]. Wanzeler et al. demonstrated even greater accuracy for the right maxillary sinus, at 80.37%, and noted high accuracy when analyzing both maxillary sinuses together, at 84.66% [25].

Teke et al. [3] found lower overall accuracy for both maxillary sinuses combined (69,3%) likely due to their smaller sample size and older methodology.

Studies by Teixeira et al. [19], Prabhat et al. [24] and Wanzeler et al. [25] support similar accuracy rates across various populations, indicating the potential universality of these methods. However, variability in findings by Gamba et al [9] and Barros et al. [15] highlights the importance of further validation in different ethnic groups.

The limitation of this study is the exclusion of patients aged 19 years and younger, which may affect the accuracy of sex prediction using the formula created in this study when applied to a younger population.

CONCLUSION

The results of this study revealed significant differences in the dimensions and volume of the left and right maxillary sinuses between the sexes. Male sinuses were found to be larger than those of females, leading to the conclusion that maxillary sinus dimensions can be used for sex assessment. The highest accuracy in sex prediction was observed for the dimensions and volume of the right maxillary sinus, achieving an accuracy rate of 75%. The formulas developed for sex prediction suggest that this method may be beneficial for forensic sex assessment in the population of Bosnia and Herzegovina, especially in cases where other, more reliable methods are not applicable. Future research should aim to validate these formulas in various populations to evaluate their generalizability and accuracy across different demographic groups.

Conflict of interest: None declared.

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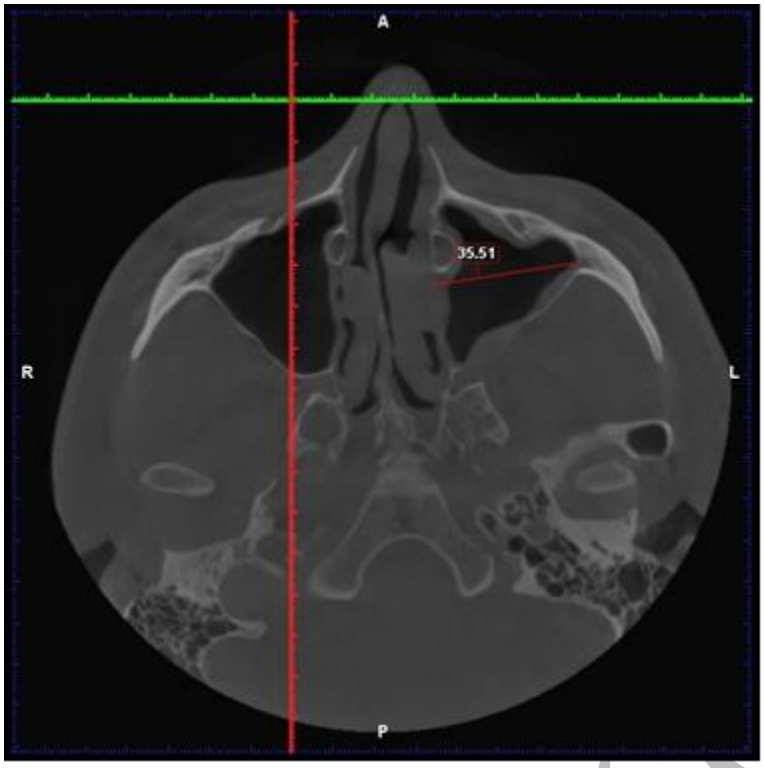

Figure 1. Mediolateral dimension of the maxillary sinus on axial projection of cone-beam computed tomography

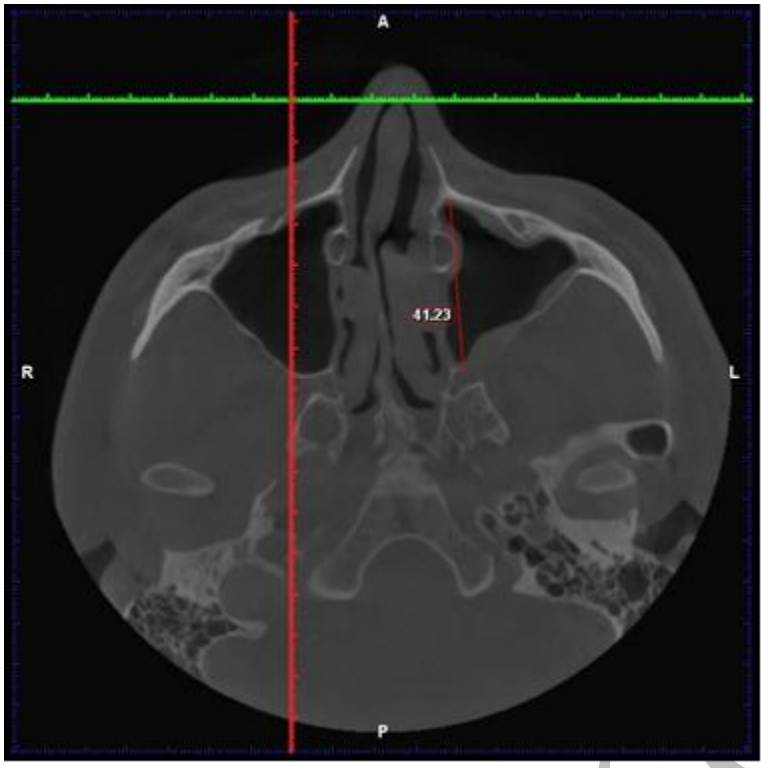

Figure 2. Anteroposterior dimension of the maxillary sinus on axial projection of cone-beam computed tomography

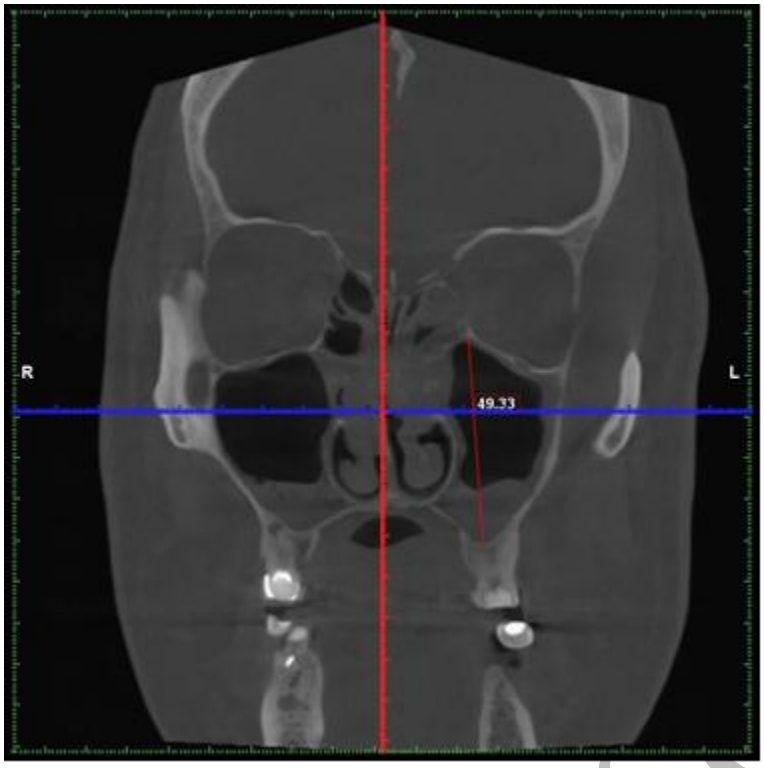

Figure 3. Superoinferior dimension of the maxillary sinus on coronal projection of cone-beam computed tomography

Table 1. Mean dimensions of maxillary sinus and their standard deviation (SD)

Dimensions	Male	Female	p-value
	Mean (mm) ± SD	Mean (mm) ± SD	
MLL	3.26 ± 0.42	3.01 ± 0.44	< 0.001
SIL	4.23 ± 0.45	3.84 ± 0.43	< 0.001
APL	3.93 ± 0.36	3.75 ± 0.32	< 0.002
MLR	3.24 ± 0.41	2.97 ± 0.43	< 0.001
SIR	4.23 ± 0.53	3.84 ± 0.42	< 0.001
APR	3.94 ± 0.35	3.74 ± 0.34	< 0.001

MLL – mediolateral dimension of the left maxillary sinus; SIL – superoinferior dimension of the left maxillary sinus; APL – anteroposterior dimension of the left maxillary sinus; MLR – mediolateral dimension of the right maxillary sinus; SIR – superoinferior dimension of the right maxillary sinus; APR – anteroposterior dimension of the right maxillary sinus

Table 2. Comparison of dimensions of the left and right maxillary sinuses between males and females

Sex	Dimensions	Mean (mm) ± SD**		p-value
		Right maxillary sinus dimensions	Left maxillary sinus dimensions	
Males	ML	3.24 ± 0.41	3.26 ± 0.42	> 0.05
	SI	4.23 ± 0.53	4.23 ± 0.45	> 0.05
	AP	3.94 ± 0.35	3.93 ± 0.36	> 0.05
Females	ML	2.97 ± 0.43	3.01 ± 0.44	> 0.05
	SI	3.84 ± 0.42	3.84 ± 0.43	> 0.05
	AP	3.74 ± 0.34	3.75 ± 0.32	> 0.05

ML – mediolateral dimension of the maxillary sinus on axial projection of cone-beam computed tomography (CBCT); SI – superoinferior dimension of the maxillary sinus on coronal projection of CBCT; AP – anteroposterior dimension of the maxillary sinus on axial projection of CBCT; SD – standard deviation

Table 3. Comparison of mean dimensions of volume of right and left maxillary sinuses with standard deviation (SD) between males and females

Sex	Mean (mm^3) + SD		p-value
	Right maxillary sinus volume	Left maxillary sinus volume	
Males	27.48 ± 7.02	27.60 ± 6.87	> 0.05
Females	21.65 ± 5.42	22.10 ± 5.77	> 0.05
p-value	< 0.001	< 0.001	

Table 4. Classification results of discriminant functional analysis of accuracy of sex predicted

Parameters	Sex predicted (%)		
	Male	Female	Both sexes
Dimensions and volume of right maxillary sinus	70	81	75
Dimensions and volume of left maxillary sinus	64	78	71
Dimensions and volume of both maxillary sinus	64	83	74

