Original Article

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Sex Estimation Based on Paranasal Sinus Dimensions: A CT Study in Turkish Adults

Paranazal Sinüs Boyutlarıyla Cinsiyet Tayini: Yetişkin Türk Popülasyonu Örneğinde BT Çalışması

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ABSTRACT

Objective: This study investigates sex differences by assessing the frontal sinus (FS), maxillary sinus (MS), and sphenoid sinuses (SS) on paranasal sinus computed tomography (CT) images to evaluate their comparative discriminatory power for sex estimation.

Methods: A total of 419 individuals (206 males and 213 females) aged 20-49 years who underwent paranasal sinus CT were retrospectively included in the study. Linear measurements of the FS (height, width, depth, and the distance between the most superior points), MS (height, width, depth, anteroposterior width at the midpoint, and the intermedial wall distance), and sphenoid sinus (height, width, depth) were obtained. Statistical analyses were performed using R software. Intra- and interobserver reliability were assessed using intraclass correlation coefficients. Descriptive statistics were calculated for all variables. The discriminatory power of each measurement for sex estimation was evaluated using receiver operating characteristic curve analysis. Additionally, multivariate logistic regression analysis incorporating all parameters was conducted to assess their combined predictive value. A significance threshold of $p<0.05$ was applied for all analyses.

Results: Of the 22 paranasal sinus dimensions measured, 19 were larger in males than in females. The most accurate measurements were left (74%) and right FS (73%) depth. The

ÖZ

Amaç: Paranazal sinüs bilgisayarlı tomografisi (BT) görüntülerinde frontal sinüs (FS), maksillar sinüs (MS) ve sfenoid sinüs (SS) ölçümleri yapılarak cinsiyetler arası farklılıkların araştırılması, cinsiyet tayini açısından paranazal sinüs boyutlarının ayırt edicilik güçlerinin birbirleriyle karşılaştırılması amaçlanmıştır.

Yöntemler: Çalışmaya paranazal sinüs BT çekilen 20-49 yaş arası olgular dahil edilmiştir. Her bir olgunun sağ ve sol FS yüksekliği, derinliği, genişliği, her iki FS tepe noktalarının birbirine olan uzaklığı, her iki MS yüksekliği, derinliği, genişliği, orta nokta genişliği, intermaksillar mesafe, her iki SS yüksekliği, derinliği ve genişliği ölçülmüştür. Verilerin istatistiksel analizinde R yazılımı kullanılmıştır. Gözlemler ve gözlemciler arası kararlılığı test etmek için inter/intra class korelasyon testi uygulanmıştır. Tanımlayıcı istatistikler frekans, yüzde, ortalama, medyan ve standart sapma değerleri ile sunulmuştur. Cinsiyet tayininde sinüs değerlerinin her biri alıcı işletim karakteristik eğrisi analizi ile incelenmiştir. Çoklu değişkenli analizde, tüm sinüs parametreleri kullanılarak lojistik regresyon analizi yapılmıştır. Tüm testlerde istatistiksel anlamlılık olarak $p<0,05$ değeri kriter kabul edilmiştir.

Bulgular: Yirmi iki ölçümden 19'unun erkeklerde kadınlardan daha büyük olduğu görülmüştür. Cinsiyet tayininde en yüksek doğruluk oranına sahip olan ölçümler sol FS derinliği (%74) ve sağ FS derinliği (%73) olarak saptanmıştır. Lojistik regresyon

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ABSTRACT

formula derived from the logistic regression analysis of right FS depth, left FS depth, left FS width, right MS height, right MS depth, right MS width, left MS depth, left MS midpoint width, and left SS height demonstrated 76% accuracy.

Conclusion: The formula produced by multiple logistic regression analyses estimated sex with accuracy of 76%. The findings support the use of paranasal sinus dimensions can be utilized for sex estimation. National scale studies are needed.

Keywords: Forensic medicine, forensic anthropology, identification, sex estimation, paranasal sinus, computed tomography

ÖZ

sonucunda; sağ FS derinlik, sol FS derinlik, sol FS genişlik, sağ MS yükseklik, sağ MS derinlik, sağ MS genişlik, sol MS derinlik, sol MS orta noktasının genişliği ve sol SS yükseklik parametreleri kullanılarak oluşturulan formül ile %76 oranında cinsiyet tayini yapılabilmiştir.

Sonuç: Çalışmada üç paranazal sinüsün boyutları kullanılarak yapılan çoklu lojistik regresyon analizleri ile üretilen formül kullanılarak %76 oranında doğru cinsiyet tayini yapılabilmesi, paranazal sinüs boyutlarının cinsiyet tayininde kullanılabileceğini göstermiştir. Gündelik uygulamada kullanımı için konuyla ilgili çok merkezli, ulusal çapta çalışmalar gereklidir.

Anahtar Kelimeler: Adli tıp, adli antropoloji, kimliklendirme, cinsiyet tayini, paranazal sinüs, bilgisayarlı tomografi

Introduction

One of the most significant problems in creating a biological profile during the identification of human remains is that bones cannot always be found intact (1-3). The paranasal sinuses, situated in a protected region of the skull and composed of robust and compact bone, demonstrate high resistance to external forces, facilitating more accurate morphometric assessment (4-7). Computed tomography (CT) and magnetic resonance imaging are the most commonly used modalities for the evaluation of the paranasal sinuses (3-6,8,9). Due to its affordability, practicality, and accuracy, CT is considered the gold standard for morphometric measurements (3-6,10). This study aimed to assess sex-related differences in the dimensions of the frontal sinus (FS), maxillary sinus (MS), and sphenoid sinuses (SS) using paranasal sinus CT scans acquired for clinical purposes between 2019 and 2022, and to compare the discriminatory potential of these parameters in sex estimation.

Methods

Permission to use the data was obtained from the chief physician, and ethical approval was granted by the Clinical Research Ethics Committee of Bolu Abant İzzet Baysal University (approval number: 2022/224, date: 09.08.2022). This study was carried out in compliance with the ethical principles outlined in the Declaration of Helsinki as revised in 2024.

Paranasal sinus CT scans of patients aged 20-49 years who were admitted to the hospital between January 1, 2019, and September 20, 2022, were retrospectively analyzed. All images were obtained using a multi-detector CT scanner (Revolution EVO, GE Healthcare, Waukesha, WI, USA). The images were acquired in a high-resolution bone window with a slice thickness of 1.25 mm, a reconstruction interval of 0.625 mm, a pitch value of 0.984, and a gantry rotation time of 0.6 s, at 100 kVp and 80 mA, with an exposure time of 2.8 s. The DICOM images were reviewed on a computer equipped with an Intel® Core™ i5-9400 CPU @ 2.90 GHz, 8.00 GB RAM, 64-bit x64-based processor, using a 1920×1080 resolution monitor and Kardelen PACS Viewer software (v.3.1.9.316). Observers were allowed to magnify the CT images and adjust image contrast and screen brightness during the measurements. Patients with a history of trauma, surgery, congenital or acquired facial anomalies, paranasal sinus pathology (e.g., acute or chronic inflammation, infection, bleeding, wall thickening, tumors), or any condition affecting bone density were excluded from the study. The height, width, depth of the FS were measured in accordance with the methods described by Akhlaghi et al. (11) and Sherif et al. (12). The distance between the most superior points of the FSs was measured following the protocol reported by Chowdhuri et al. (8) (Figure 1). Measurements of the MS, including the height, width, depth, the anteroposterior width at the midpoint, and the distance between the medial walls, were performed as described by Sherif et al. (12) (Figure 2). The height, width, and depth of both SSs were measured according to the methodology outlined by Ramos et al. (3) (Figure 3).

Statistical Analysis

Fifteen days after the initial measurement by the first operator, 25 randomly selected subjects were measured again by the same operator. The same 25 subjects were also measured twice, 15 days apart, by a second operator. To reduce bias in the results, the intraclass correlation coefficient (ICC) was computed to assess inter-intraobserver consistency.

Statistical analyses were conducted using R version 4.2.2 (2022) (R Core Team, R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria; available at https://www.R-project.org). Data for continuous variables are expressed as mean ± standard deviation, while categorical data are

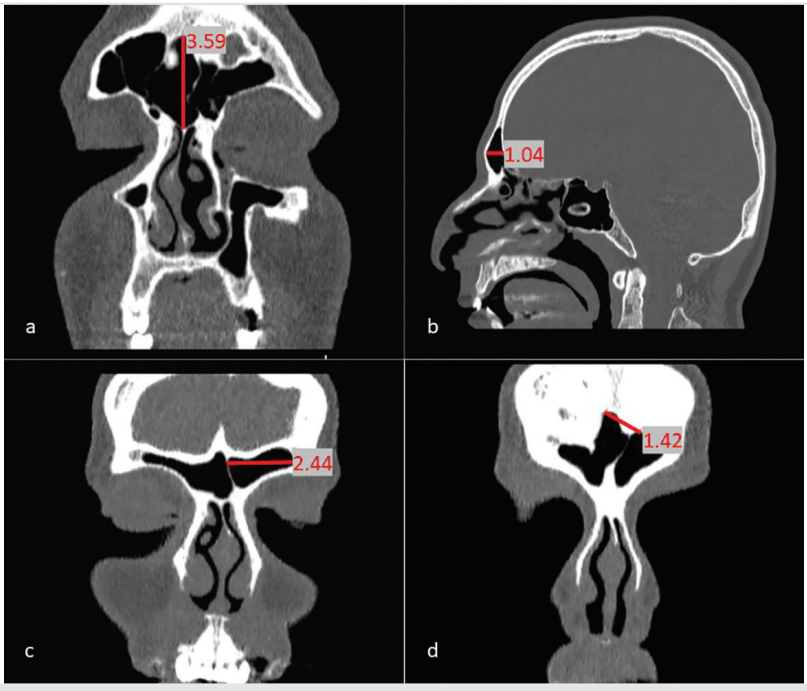

Figure 1. Measurements of frontal sinus (FS). a) FS height measurement, b) FS depth measurement, c) FS width measurement, d) distance between the apex points of FS

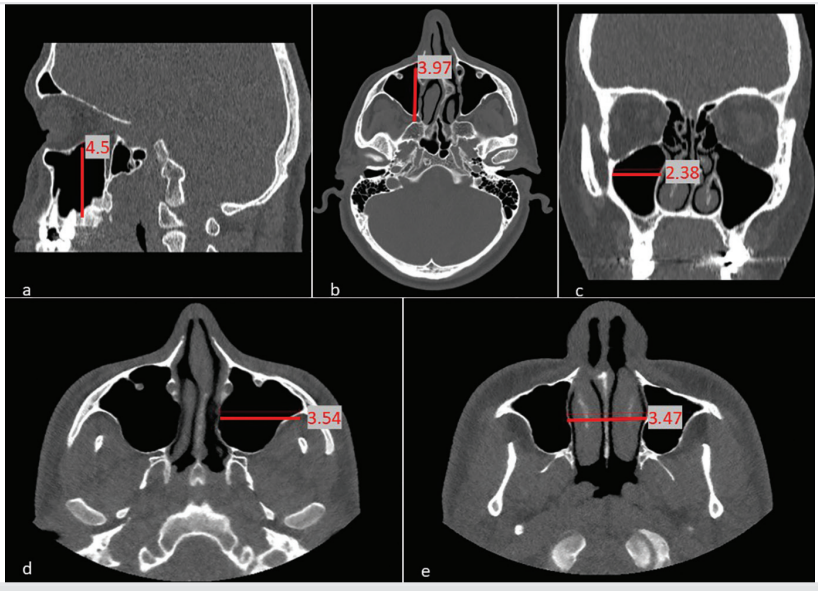

Figure 2. Measurements of maxillary sinus (MS). a) MS height, b) MS depth, c) MS width, d) width at the midpoint of the MS, e) distance between the medial walls of both MS

expressed as frequencies and percentages. Normality was evaluated both visually, with histograms, and analytically, with the Shapiro-Wilk and Kolmogorov-Smirnov tests. For normally distributed data, parametric tests were employed, and for non-normally distributed data, non-parametric tests were used. Differences between sexes were assessed using the Mann-Whitney U test. Receiver operating characteristic (ROC) curve analysis was used for each sinus measurement in sex estimation, with calculation of specificity, sensitivity, cut-off value, positive and negative predictive values, and accuracy. Logistic regression was performed with all sinus parameters; non-significant variables were removed stepwise until significant independent predictors were identified. Model fit was assessed by the Hosmer-Lemeshow test. A significance threshold of $p<0.05$ was adopted for all analyses.

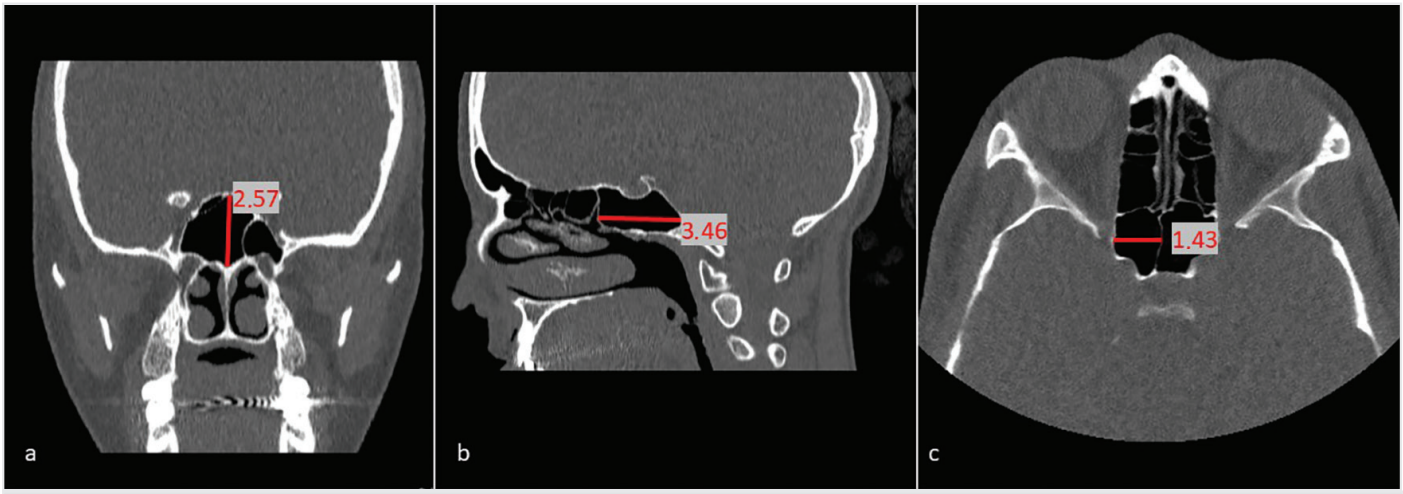

Figure 3. Measurements of sphenoid sinus (SS). a) SS height, b) SS depth, c) SS width

Results

The study included 206 male and 213 female subjects. The mean age was 30.85±9.06 years for males (min: 20, max: 49) and 32.84±8.74 years for females (min: 20, max: 49). The ICC in this study ranged from 0.99 to 1.00 (p<0.0001).

All measurements, except the left maxillary midpoint, the right SS depth and width, were larger in males. A comparison of sinus dimensions by sex is presented in Table 1.

The sensitivity, specificity, positive predictive value, negative predictive value, cut-off value, and accuracy for sex estimation were calculated (Table 2), and ROC curves were

Table 1. Comparison of sinus sizes by sex (all measurements are in cm)

	Male			Female			p-value
	Median	25th percentile	75th percentile	Median	25th percentile	75th percentile	
Right FS height	2.73	2.33	3.31	2.27	1.76	3.04	<0.001
Right FS depth	1.35	1.14	1.64	1.00	0.84	1.22	<0.001
Right FS width	3.11	2.48	3.68	2.69	1.90	3.32	<0.001
Left FS height	2.94	2.40	3.55	2.39	1.88	2.93	<0.001
Left FS depth	1.39	1.15	1.64	1.03	0.86	1.23	<0.001
Left FS width	3.25	2.58	3.77	2.81	2.22	3.41	<0.001
FS peaks distance	1.74	1.28	2.3	1.55	1.09	2.07	<0.01
Right MS height	4.26	3.82	4.60	3.96	3.51	4.20	<0.001
Right MS depth	4.01	3.79	4.26	3.96	3.67	4.16	<0.05
Right MS width	2.86	2.46	3.16	2.63	2.30	2.95	<0.001
Right MS midpoint width	2.57	2.15	2.89	2.42	2.12	2.66	<0.01
Left MS height	4.13	3.81	4.54	3.92	3.53	4.23	<0.001
Left MS depth	4.02	3.75	4.21	3.92	3.70	4.12	<0.01
Left MS width	2.78	2.38	3.17	2.67	2.37	2.96	<0.05
Left MS midpoint width	2.47	2.09	2.80	2.38	2.10	2.70	0.275
Intermaxillary distance	3.48	3.25	3.73	3.37	3.41	3.65	<0.01
Right SS height	2.34	2.06	2.57	2.09	1.78	2.36	<0.001
Right SS depth	2.77	2.19	3.24	2.68	1.97	3.17	0.080
Right SS width	2.01	1.60	2.43	1.88	1.55	2.47	0.167
Left SS height	2.30	2.04	2.62	2.03	1.79	2.28	<0.001
Left SS depth	2.88	2.30	3.24	2.54	2.03	3.12	<0.001
Left SS width	2.06	1.69	2.59	1.81	1.51	2.28	<0.001

FS: Frontal sinus, MS: Maxillary sinus, SS: Sphenoid sinus

Table 2. Sensitivity, specificity, positive/negative predictive values, accuracy, and AUC values of sinus measurements in estimating sex

	Sex prediction								
	Female (n=213)	**Male (n=206)**	**Sensivite**	**Spesifite**	**Cut-off**	**PPV**	**NPV**	**Accuracy**	**AUC (95% Cl)**
Right FS height	109	160	77.6%	51.2%	2.13	60.6%	70.3%	64.2%	0.64 (0.59-0.69)
Right FS depth	156	151	73.3%	73.2%	1.17	73.2%	73.9%	73.2%	0.77 (0.72-0.82)
Right FS width	107	143	69.4%	50.2%	2.70	57.4%	62.9%	59.6%	0.63 (0.58-0.69)
Left FS height	125	145	70.3%	58.6%	2.56	62.2%	67.2%	64.4%	0.66 (0.61-0.72)
Left FS depth	157	151	73.3%	73.7%	1.18	72.9%	74.0%	73.5%	0.77 (0.73-0.82)
Left FS width	148	107	51.9%	69.4%	3.23	62.2%	59.9%	60.9%	0.63 (0.57-0.68)
FS peaks distance	94	151	73.3%	44.1%	1.39	55.9%	63.1%	58.5%	0.58 (0.52-0.63)
Right MS height	165	106	51.5%	77.5%	4.24	68.8%	62.3%	64.7%	0.67 (0.62-0.72)
Right MS depth	166	69	33.3%	77.9%	4.19	59.4%	54.8%	56.1%	0.57 (0.51-0.62)
Right MS width	178	78	37.9%	83.5%	3.04	69.0%	58.2%	61.1%	0.62 (0.57-0.68)
Right MS midpoint width	169	83	40.0%	79.3%	2.71	65.3%	57.8%	60.1%	0.57 (0.52-0.63)
Left MS height	124	133	64.6%	58.2%	4.00	59.9%	62.9%	61.3%	0.65 (0.60-0.70)
Left MS depth	120	125	60.6%	56.3%	3.97	57.3%	59.7%	58.5%	0.58 (0.53-0.64)
Left MS width	195	50	24.3%	91.5%	3.18	73.5%	55.5%	58.5%	0.56 (0.50-0.61)
Left MS midpoint width	149	83	40.3%	70%	2.62	56.5%	54.8%	55.4%	0.53 (0.47-0.58)
Intermaxillary distance	53	183	88.8%	24.9%	3.15	53.4%	69.7%	56.3%	0.57 (0.52-0.63)
Right SS height	150	119	57.7%	70.4%	2.29	65.3%	63.3%	64.2%	0.65 (0.60-0.70)
Right SS depth	58	170	82.5%	27.2%	2.03	52.3%	61.7%	54.4%	0.55 (0.49-0.60)
Right SS width	88	142	68.9%	41.3%	1.74	53.1%	57.8%	54.9%	0.54 (0.48-0.59)
Left SS height	160	110	53.4%	75.1%	2.29	67.4%	62.5%	64.4%	0.68 (0.63-0.74)
Left SS depth	138	109	52.9%	64.8%	2.84	59.2%	58.7%	58.9%	0.60 (0.47-0.65)
Left SS width	121	131	63.6%	56.8%	1.89	58.7%	61.7%	60.1%	0.60 (0.55-0.66)

FS: Frontal sinus, MS: Maxillary sinus, SS: Sphenoid sinus, AUC: Area under the curve, CI: Confidence interval, PPV: Positive predictive value, NPV: Negative predictive value

generated. The left FS depth (74%), right FS depth (73%), and the right MS height (65%) were the measurements with the highest accuracy (Figure 4).

To determine the suitability of paranasal sinus measurements for sex estimation, logistic regression analysis was performed. The analysis identified the following parameters as significant predictors: right FS depth, left FS depth, left FS width, right MS height, right MS depth, right MS width, left MS depth, width of anteroposterior midpoint of left MS, and left SS height (Table 3). The dependent variable was coded as male=0 and female=1. The fitted model estimated the probability of being female and was expressed as:

logit[P(female)]=8.557 +(-1.115 x right FS depth)+(-2.155 x left FS depth)+(0.549 x left FS width)+(-1.132 x right MS height)+(1.947 x right MS depth)+(-1.08 x right MS width)+(-1.723 x left MS depth)+(1.626 x left MS midpoint width)+(-1.636 x left SS height).

The predicted probability of being female was calculated as P(female)=exp(logit)/[1 + exp(logit)]. A predicted probability ≥0.50 was classified as female, whereas a predicted probability <0.50 was classified as male. The discriminatory performance of the logistic regression model was assessed using ROC curve analysis. The model demonstrated good discriminative ability, with an area under the curve of 0.84 (95% confidence interval: 0.81-0.88).

Using this formula, males were predicted with 72% accuracy, females with 80% accuracy, and the overall accuracy was 76% (Table 4).

Discussion

Numerous studies have demonstrated the potential of FSs for identification (8,10,13,14). Consistent with these, this study found all FS measurements to be greater in males. Research from the Czech Republic and Egypt, along with Chalkoo et al. (9), corroborates that FS dimensions are larger in males (10,14).

In this study, the height, depth, and width of both MS, as well as the width of anteroposterior midpoint of left MS and the distance between medial walls of MS, were found to be greater in males. These findings support previous studies on MSs conducted in various populations, including those by De Mendonça et al. (13), Teixeira et al. (14), Ekizoglu et

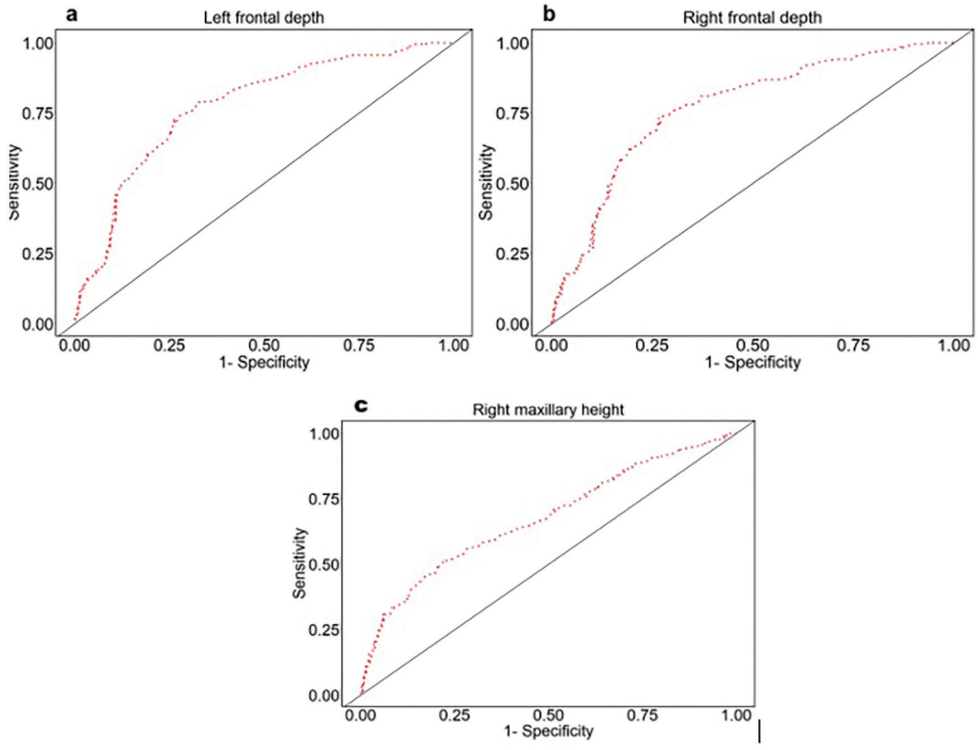

Figure 4. ROC curves of a) left FS depth, b) right FS depth, c) right MS height
ROC: Receiver operating characteristic, FS: Frontal sinus, MS: Maxillary sinus

Table 3. OR and consequences of logistic regression analysis

Measures	OR (%95 CI)*	p-value
Right FS depth	0.33 (0.12-0.86)	0.024
Left FS depth	0.11 (0.03-0.40)	0.001
Left FS width	1.73 (1.20-2.49)	0.003
Right MS height	0.32 (0.17-0.58)	<0.001
Right MS depth	7.01 (1.94-25.31)	0.003
Right MS width	0.34 (0.13-0.83)	0.019
Left MS depth	0.17 (0.05-0.61)	0.006
Left MS midpoint width	5.08 (2.25-11.45)	<0.001
Left SS height	0.19 (0.10-0.36)	<0.001

*: Estimated relative risk as represented by odds ratio and 95% confidence interval, FS: Frontal sinus, MS: Maxillary sinus, SS: Sphenoid sinus, OR: Odds ratio

Table 4. Comparison of the predicted sexes with the formula and the actual sexes

		Predicted group		
		Male, n (%)	Female, n (%)	Total
Original group	Male	148 (71.8%)	58 (28.2%)	206 (100%)
	Female	43 (20.2%)	170 (79.8%)	213 (100%)
Overall percentage of male + female		318 (75.9%)		

al. (15), and studies from Egypt (16), Sri Lanka (17), Brazil (18), and India (19-21).

The height, depth, and width of left SS, as well as the height of right SS, were significantly greater in males; however, no sex difference was found in the depth and width of right SS. In their study, Sherif et al. (12) reported that right SS depth and width measurements were greater in males, while Ramos et al. (3) found SS volume to be greater in males, with no differences in other measurements. The weak sex differences observed in SSs may be attributed to anatomical variation and ethnic diversity.

In this study, right and left FS depths were found to be the parameters with the highest accuracy (74% and 73%) in sex estimation. In a study of 100 cases in Egypt, right FS depth was found to be the most discriminatory measurement (22), while in the study of Akhlaghi et al. (11), left FS height and in Chalkoo et al. (9), left FS depth and width were reported as the strongest sex-discriminatory parameters.

The logistic regression formula obtained in this study yielded 72% accuracy in males, 80% in females, and 76% overall. Sherif et al. (12) achieved 77% accuracy with all three sinus measurements, while Ibrahim et al. (16) achieved 72% accuracy with FS measurements, Ekizoglu et al. (15) achieved 77% accuracy with MS measurements, and Teixeira et al. (14) achieved 74% accuracy with MS

measurements. The results support the use of all three paranasal sinus measurements in sex estimation.

Study Limitations

The generalizability of this study is limited by its retrospective design and single-center nature, which reduce population diversity. It is important to consider that anthropological measurements may vary across different ethnic groups. However, our sample size is larger than those of similar studies.

As the study was designed retrospectively, reliable data on stature and other body measurements of the cases were unavailable, it was also not possible to evaluate the measured cases in terms of body dimensions.

Conclusion

The findings showed that males exhibited larger values in 19 of the 22 paranasal sinus measurements. Using a formula generated by multiple logistic regression analysis that incorporated dimensions from all three paranasal sinuses, sex determination was achieved with 76% accuracy. These results are consistent with the literature and suggest that paranasal sinus dimensions can aid sex determination in cases where other methods are inconclusive. Future national multicenter studies may facilitate the practical application of paranasal sinus measurements in forensic identification.

Ethics

Ethics Committee Approval: Ethical approval was granted by the Clinical Research Ethics Committee of Bolu Abant İzzet Baysal University (approval number: 2022/224, date: 09.08.2022).

Informed Consent: Retrospective study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: B.K.Y., M.H., Concept: B.K.Y., E.H., Design: B.K.Y., E.H., Z.Z.E., Data Collection or Processing: B.K.Y., M.H., Analysis or Interpretation: B.K.Y., E.H., Z.Z.E., S.A.K., Literature Search: B.K.Y., Writing: B.K.Y., E.H.

Conflict of Interest: No conflict of interest was declared by the authors.

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