Original Article

Dimensions of the Sphenoid and Ethmoid Sinuses on Computed Tomography: Clinical Implications and Role in Sex Determination

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Abstract

Background: The measurements of the sphenoid and ethmoid sinuses (ESs) are essential in forensic investigations and during endoscopic sinus and skull base surgeries. This study aimed at assessing the dimensions of these sinuses and elucidating their role in sex determination. **Materials and Methods:** This retrospective assessment was conducted using brain-computed tomographic images stored in the Department of Radiology in a Tertiary hospital in Delta State, Nigeria. After institutional ethical approval, images of 292 patients (115 females and 177 males) aged >20 years, were used to measure the dimensions of the ethmoid and sphenoid sinuses (SSs) bilaterally. These were analyzed and summarized using descriptive statistics. Their association with gender, side, or age was assessed using inferential statistics and considered statistically significant at $P < 0.05$. Discriminant function analysis of the sinus measurements was conducted to evaluate their accuracy in correct sex prediction. **Results:** Both sphenoid and ESs showed significant sexual dimorphism. The ESs showed significant asymmetry ($P < 0.05$). The anterior width of the left ES (79.8%) was the best sex-discriminating variable. The combination of the left sinus dimensions was more accurate (74.3%, 85.3%) than the right sinuses (72.6%, 81.2%) in sex allocation. Using the bilateral ES dimensions yielded a higher accuracy (89.0%) than using bilateral SS parameters (80.1%). **Conclusion:** The sphenoid and ESs may be used in predicting the sex of an unknown skull bone recovered within the studied population with acceptable accuracy levels.

Keywords: Dimensions, ethmoid, sex determination, sinus, sphenoid, surgery

Introduction

Paranasal sinuses (PNS) are mucosal-lined air cavities housed within the skull bones. They reduce the skull weight, humidify inspired air, enhance the resonance of voice and buffer intracranial structures against facial trauma.[1,2] The sphenoid sinus (SS) is found on the middle part of the skull base.[3] It has an intervening intersinus septum which divides it into right and left cavities.[4] Its ostium drains into the nasal cavity via the sphenoethmoidal recess.[5] The SS begins to develop in the 8th week of intrauterine life as bilateral invaginations from the posterior nasal capsule.[6,7] It is radiographically evident at 2–3 years and expands with the growth of the sphenoid bone.[8,9] It completes growing and achieves its adult size by 12–14 years.[8,10] The sinus size is maintained throughout adulthood; however, it may regress in older age.[9,11] The SS shows high individual, ethnic and geographical variability in its morphology, dimensions, and pneumatization patterns.[7] This affects its relationship with the vital neurovascular structures adjacent to it, such as the internal carotid artery and optic nerve.[1,12]

The ethmoid sinus (ES) comprises air cells within the ethmoidal labyrinth, which develop from the cartilaginous nasal capsule.[13] They are present at birth, and their development continues up to the age of 12 years.[2,14] The

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ES is bordered by the fovea ethmoidalis superiorly, lamina papyraecea laterally, and the lacrimal bone anteriorly.[13] It is the most complicated sinus structurally and has vital structures adjacent to it, including the orbital and skull base contents.[14,15] The posterior ethmoid air cells empty via the superior meatus, while the anterior and middle cells drain via the middle meatus into the nasal cavity.[13]

The unique anatomic individuality of the PNS can validly be applied in human identification.[3] Identification is crucial in medicolegal cases and in mass disasters.[10] Due to its deep structural location, the SS is well protected from trauma and degradation from external causes. Moreover, sinuses are perfectly examinable on any head computed tomography (CT); hence, their visual comparison can be made using anatomical concordance in personal identification.[3] The SS volume can be used for sex differentiation with varying accuracies in different populations.[8,9,16,17] The use of ES morphometry in human identification is scarce in the literature.

The advent of endoscopic sinus surgery (ESS) and its increasing popularity have increased the interest in the morphology of the PNS among radiologists and surgeons.[12,13] This surgical procedure is the preferred mode of treating chronic rhinosinusitis, which is not responsive to medical treatment.[2] Rhinosinusitis has a higher prevalence in developing than the developed countries, and it greatly influences the quality of life, increasing the economic burden.[18] Moreover, its etiology has been associated with the size of the sinuses.[15] The ESS and endoscopic endonasal transphenoidal approach to the pathologies around the base of the skull, such as the pituitary gland, provide a quicker, and safer surgery with better visualization and a short recovery period.[19] The variability of the shape and size of the SS and ES and their relationship with vital structures increase the risk to iatrogenic injury intraoperatively.[1,12] Assessment of their volumes helps to determine the surgical accessibility of the sinuses, and skull base structures as well as predict the risk of complications.[3,9]

CT is the best modality for both qualitative and quantitative analysis of the PNS.[7,20] Sinus volume can also be measured using vernier calipers and water displacement methods on cadavers or dry skulls.[20-22] The dimensions and volumes of the ES and SS vary in different populations.[8,15,18,21-24] A population-specific database for normal sinus dimensions and volume is important to provide a guideline for surgeons, and radiologists.[2,3,8,25] The data will also be useful to forensic scientists in the personal identification of unknown skull bones.[16] Accordingly, this study aimed at assessing the dimensions of the SS and ES using CT images of adult Nigerians. Furthermore, the study investigated the accuracy of using these metric parameters in sex differentiation.

Materials and Methods

The study adopted a retrospective descriptive cross-sectional design. The CT images of the brain used were obtained from the radiological database of a Tertiary Hospital in Delta State, Nigeria. These images were accessed in the picture archiving communications systems after the research framework was reviewed and approved by the institution's ethics board (Registration number; EREC/PAN/2020/030/0371). The study included brain CT images of patients aged 20 years and above who were referred for imaging between June 2015 and June 2020. This age was selected because the PNS have already achieved their adult size.[7,14] We excluded images with sinonasal pathologies such as infection, polyps, and tumors. Images with a history of the skull base or facial trauma, sinonasal surgery, and those with poor technical quality as evidenced by artifacts were also eliminated. These images were taken using a 64-slice CT scanner (Toshiba Aquilon, Japan, 2009) in 5 mm thick axial slices, taken at 120 kV and 300 mA exposure factors, with a scan rotation time of 0.5 s. This is the study center's standard procedure for the evaluation of skull base structures, the brain, and the PNS. Minute details are evaluated on thinner slices measuring 3 mm thick. Coronal and sagittal sections were reconstructed from the axial slices using 1.5 mm slice thickness and 1.5 mm table increment as the reconstruction parameters. The images were viewed on a bone window, and the linear dimensions of the ES and SS were measured bilaterally using a digital measuring tool.

The ES width and length were measured on axial images. The anterior width was measured at the level corresponding to the posterior limit of the nasal bone, whereas the sinus posterior width was measured at the intersection between the medial wall of the orbit and the anterior boundary of the SS. The length of the ES was measured from the midpoint of a horizontal line at the posterior border of ES to the midpoint of the anterior sinus wall. Using the most posterior coronal section that shows the orbits, middle turbinates, hard palate, and anterior skull base, the ES height was measured as a perpendicular distance from the midpoint of the roof of the ethmoid to a transverse line across the inferior attachment of the uncinate process (superior border of the inferior turbinate) which is considered to be a consistent landmark [Figure 1].[26]

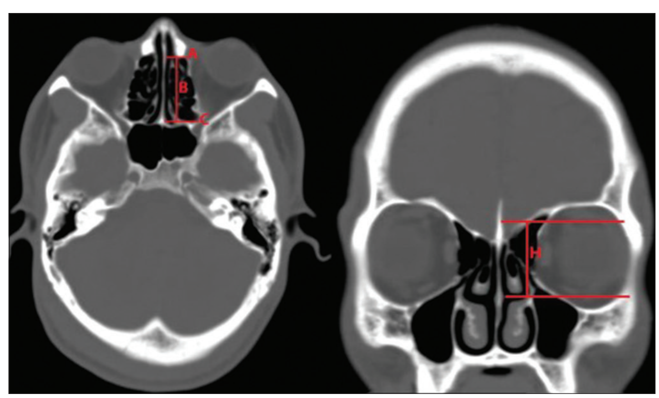

Figure 1: CT images showing the measurement of the ES dimensions; A: Anterior width, B: Length, C: Posterior width, H: Height (Original). CT: Computed tomography, ES: Ethmoid sinus

The SS depth (anteroposterior diameter) and width (transverse diameter) were measured on axial sections. The depth was defined as the longest distance between the anterior and posterior walls of the SS, while the width was measured as the greatest distance between the lateral wall and medial wall (intersinus septum) of the sinus. The SS height (craniocaudal distance) was measured as a vertical distance from the uppermost point of the sinus roof to the lowermost point of its floor on the coronal section [Figure 2].[22]

The volume of the SS was calculated using the simplified ellipsoid formula; Sinus Volume = $4/3 \times \pi \times A \times B \times C/2^3$, where A, B, and C are the ellipsoid diameters corresponding to depth, height, and width of the SS, respectively. Therefore, the SS volume was calculated as $\pi/6 \times$ depth $\times$ height $\times$ width.[24] A single observer measured the dimensions on 20 images, and these were repeated after a month to test for intraobserver agreement. Following this concordance test, all the measurements were carried out by a single investigator.

Analysis of the data based on the sex and age groups was performed using the Statistical Package for the Social Sciences (SPSS) software version 23 (IBM® Armonk, New York, USA). The quantitative variables were expressed in mean and standard deviations. The normality of data was assessed using the Kolmogorov–Smirnoff test. Gender and side differences in the measurements were evaluated using independent *t*-tests and paired *t*-tests, respectively. The metric differences between the age groups were analyzed using one-way analysis of variance. Pearson's test was employed to assess the association between the variables and age. Statistical significance was set at the level where P was < 0.05. The discriminant function analysis was used to calculate coefficients and constants. These were incorporated in the discriminate function equations generated for sex estimation. The equations were stated as; discriminant functional score (Y) = T0 + (T1 × S1) + (T2 × S2) + (T3 × S3). T0 was a constant, T1–T3 were coefficients and S1–S3 were the sinus metric variables. The means of the variables were incorporated into the equation to determine the centroids for the gender groups. These were averaged to obtain the sectioning points (Y0) which were used for sex discrimination. Using the sinus dimensions of each subject, Y values above Y0 were labeled males. Females were identified when the value of Y was below Y0. From these outcomes, the percentage accuracy for correct sex allocation was determined.

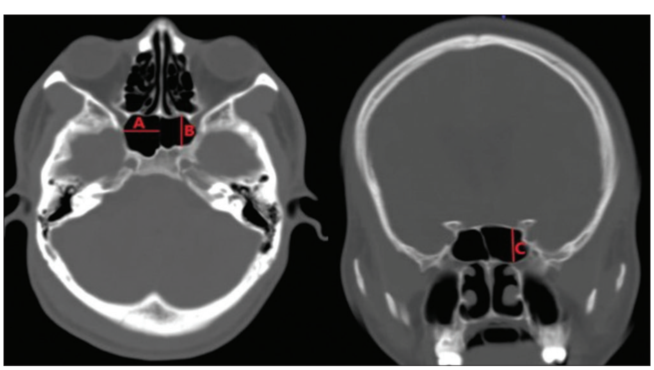

Figure 2: Computed Tomography images showing the measurement of the sphenoid sinus dimensions; A. Width, B. Depth, C. Height (Original)

Results

The sinus morphometry was assessed on brain CT images of 292 patients, including 177 (60.6%) males and 115 (39.4%) females, aged 20–99 years (average age 51.47 ± 17.22 years). The sample was categorized into 10 years' age-groups, and the distribution is shown in Table 1. From the Kolmogorov–Smirnov test, the variables measured had a normal distribution ($P = 0.095$). The intra-observer concordance test showed no statistically significant discrepancies between the measured parameters (SS depth $r = 0.573$, $P = 0.132$; SS width $r = 0.577$, $P = 0.234$; SS height $r = 0.521$, $P = 0.347$; ES length $r = 0.561$, $P = 0.421$; ES anterior width $r = 0.562$, $P = 0.178$; ES posterior width $r = 0.563$, $P = 0.149$; ES height $r = 0.584$, $P = 0.336$).

The average depth, width, and height of the SS were 2.57 ± 0.6 cm, 1.87 ± 0.50 cm, and 2.01 ± 0.47 cm, respectively. The average volume of the SS was 5.19 ± 2.52 cm^3. All these SS variables were significantly greater in males than in females ($P < 0.05$). However, they showed no significant side differences ($P > 0.05$) [Table 2]. The average width of the ES was 1.36 ± 0.27 cm anteriorly and 1.77 ± 0.33 cm posteriorly. Its mean length and height were 3.37 ± 0.51 cm and 3.02 ± 0.41 cm, respectively. These ES measurements were significantly higher in males than in females and on the right ES than the left ($P < 0.05$) [Table 1]. All the SS and ES dimensions did not show any significant variances between the age groups ($P > 0.05$) [Table 3].

The dimensions of the right SS and ES showed a significant positive correlation with the corresponding variables of the left sinuses. There was a significant positive association between the SS height and ES height, as well as the posterior width of ES and SS width ($0 < r < 0.5$, $P < 0.05$) [Table 4]. We also observed a significant weak positive correlation between the sinus dimensions ($0 < r < 0.5$, $P < 0.05$), although their association with age was not statistically significant [Table 5].

Table 1: Age distribution

Age group (years)	*n*
20-30	40
31-40	39
41-50	48
51-60	61
61-70	47
71-80	38
81-90	15
91-100	4
Total	292

Table 2: Gender and side comparisons in the sinus dimensions

Variables	Males	Females	*P*	Right	Left	*P*	Average
SS							
Depth (cm)	2.74±0.65	2.33±0.43	0.001*	2.58±0.60	2.57±0.62	0.898	2.57±0.61
Width (cm)	1.95±0.48	1.76±0.50	0.001*	1.87±0.48	1.88±0.53	0.748	1.87±0.50
Height (cm)	2.18±0.45	1.75±0.37	0.001*	2.02±0.47	2.00±0.46	0.328	2.01±0.47
Volume (cm^3)	6.53±3.39	3.85±1.68	0.001*	5.18±2.48	5.20±2.53	0.124	5.19±2.52
ES (cm)							
AW	1.46±0.26	1.21±0.20	0.001*	1.41±0.26	1.31±0.27	0.001*	1.36±0.27
PW	1.89±0.30	1.59±0.28	0.001*	1.78±0.30	1.75±0.35	0.001*	1.77±0.33
Length	3.52±0.56	3.15±0.30	0.001*	3.41±0.51	3.34±0.51	0.001*	3.37±0.51
Height	3.17±0.37	2.80±0.37	0.001*	3.06±0.44	2.99±0.39	0.001*	3.02±0.41

**P* value considered significant at <0.05. AW: Anterior width, PW: Posterior width, SS: Sphenoid sinus, ES: Ethmoid sinus

Table 3: Comparison of mean sinus dimensions in the various age groups (Original)

Age groups (Years)	*n*	Sphenoid sinus (cm)			Ethmoid sinus (cm)			
		AP	Width	Depth	AW	PW	Length	Height
20-30	80	2.41±0.52	1.92±0.45	2.00±0.42	1.23±0.21	1.86±0.35	3.64±0.58	3.03±0.34
31-40	78	2.77±0.66	1.90±0.50	2.03±0.43	1.47±0.32	1.69±0.20	3.49±0.53	3.15±0.34
41-50	96	2.58±0.56	1.91±0.55	1.98±0.56	1.33±0.28	1.72±0.26	3.52±0.64	2.93±0.45
51-60	122	2.71±0.62	1.83±0.47	2.02±0.44	1.48±0.28	1.76±0.36	3.32±0.38	3.13±0.53
61-70	94	2.53±0.58	1.91±0.51	2.04±0.34	1.33±0.20	1.83±0.29	3.14±0.46	2.92±0.26
71-80	76	2.61±0.63	1.83±0.53	2.04±0.50	1.36±0.18	1.76±0.40	3.25±0.32	3.09±0.25
81-90	30	2.09±0.42	1.78±0.47	1.88±0.64	1.19±0.32	1.76±0.44	3.11±0.26	2.82±0.44
91-100	8	2.28±0.62	1.81±0.55	1.71±0.48	1.21±0.10	1.70±0.18	3.51±0.16	2.34±0.56
P		0.201	0.425	0.340	0.201	0.082	0.501	0.321

AW: Anterior width, PW: Posterior width

Table 4: Correlation between metric variables of the sinuses

Variables	Pearson's correlation	*P*
Right and left SS		
Depth	0.388	0.001*
Width	0.018	0.042*
Height	0.688	0.001*
Right and left ES		
AW	0.589	0.001*
PW	0.447	0.001*
Length	0.825	0.001*
Height	0.760	0.001*
SS and ES		
SS height and ES height	0.328	0.001*
SS width and ES AW	0.035	0.397
SS width and ES PW	0.087	0.035*
SS depth and ES length	0.124	0.147

**P* value considered significant at <0.05. SS: Sphenoid sinus, ES: Ethmoid sinus, AW: Anterior width, PW: Posterior width

Univariate and multivariate discriminant analyses were used to calculate coefficients and constants used to derive discriminate function equations. The mean dimensions were incorporated in the equations to determine the centroids for each gender and calculate the sectioning points [Tables 6-8]. Among the SS and ES variables, the left SS width (76.4%; males 90.4% and females 54.8%) and the anterior width of the left ES (79.8%; males 86.4% and 69.6% females) were the best sex-discriminating variables, respectively [Table 9]. The accuracy of predicting sex using combined variables of the left SS (74.3%) and left ES (85.3%) was higher than the accuracy obtained using right SS (72.6%) and right ES (81.2%), respectively. The use of bilateral ES dimensions yielded higher accuracy (89.0%) compared to using all the dimensions of bilateral SS (80.1%) [Table 10].

Discussion

The mean SS dimensions and volume in this study were lower than findings from previous CT studies carried out in Nigeria (Sokoto), Poland, and India.[10,19,24] On the contrary, some CT studies documented higher SS volume.[1,6] Cadaveric measurements by Sareen *et al*.[27] revealed higher SS transverse and craniocaudal diameters compared to our findings. The ES in this study had higher widths and lower lengths than those documented by Oghenero *et al*.[26] in Usun state, Nigeria. The ES height in their study (30.1 mm) corresponded with our findings (3.02 cm). Analysis of CT images by Mousaviagdas *et al*.[15] revealed larger ES height and width than the observations herein.

The discrepancies in the sinus dimensions and volume may probably be due to differences in age, gender, race,

Table 5: Correlation between age and the sinus dimensions

Variables	Depth	Width	Height	Volume	Age
SS					
Depth					
r	1	0.400	0.238	0.367	0.132
P		0.001*	0.001*	0.021*	0.241
Width					
r	0.400	1	0.221	0.446	0.259
P	0.001*		0.001*	0.017*	0.097
Height					
r	0.238	0.221	1	0.301	0.357
P	0.001*	0.001*		0.042*	0.186
Volume					
r	0.367	0.446	0.301	1	0.105
P	0.021*	0.017*	0.042*		0.457

Variables	AW	PW	Length	Height	Age
ES					
AW					
r	1	0.215	0.379	0.268	0.430
P		0.001*	0.001*	0.001*	0.618
PW					
r	0.215	1	0.046	0.176	0.208
P	0.001*		0.001*	0.001*	0.154
Length					
r	0.379	0.046	1	0.208	0.326
P	0.001*	0.001*		0.001*	0.419
Height					
r	0.268	0.176	0.208	1	0.173
P	0.001*	0.001*	0.001*		0.091

*P value considered significant at <0.05. AW: Anterior width, PW: Posterior width, SS: Sphenoid sinus, ES: Ethmoid sinus

Table 6: Univariate discriminant function analysis

Variables	Wilk's Lambda	Coefficient	Constant	Centroid		Sectioning point
				Males	Females	
Right SS						
Height	0.431	2.472	−4.988	0.495	−0.762	−0.134
Width	0.436	2.169	−4.050	0.214	−0.329	−0.058
Depth	0.684	1.773	−4.571	0.295	−0.454	−0.080
Left SS						
Height	0.648	2.356	−4.704	0.345	−0.531	−0.093
Width	0.582	1.917	−3.605	0.112	−0.172	−0.030
Depth	0.689	1.717	−4.418	0.288	−0.443	−0.078
Right ES						
Height	0.600	2.562	−7.831	0.407	−0.626	−0.110
AW	0.634	2.964	−8.890	0.618	−0.951	−0.167
PW	0.611	2.641	−8.824	0.607	−0.934	−0.164
Length	0.621	2.051	−6.990	0.239	−0.368	−0.065
Left ES						
Height	0.596	2.864	−8.557	0.413	−0.636	−0.112
AW	0.674	3.141	−7.928	0.567	−0.873	−0.153
PW	0.635	2.179	−7.653	0.531	−0.814	−0.142
Length	0.710	2.165	−7.225	0.395	−0.608	−0.107

AW: Anterior width, PW: Posterior width, SS: Sphenoid sinus, ES: Ethmoid sinus

genetics, ethnicity, and environmental factors such as past infection.[10] Other causes of the variability include; observer biasness, methodology of measurements (radiological versus cadaveric or dry skull), devices (imaging equipment),

Table 7: Multivariate discriminant function analysis using the sphenoid sinus variables

	Unstandardized coefficient	Constant	Centroid		Sectioning point	Eigen	Wilk's Lambda
			Male	Female			
Right SS							
Depth	0.688	−6.492	0.554	−0.853	−0.1495	0.462	0.684
Height	0.330						
Width	2.033						
Left SS							
Depth	1.135	−5.973	0.436	−0.671	−0.118	0.286	0.678
Height	−0.277						
Width	1.789						
Both SSes							
Right depth	0.464	−7.453	0.602	−0.927	−0.163	0.546	0.647
Right width	0.390						
Right height	1.575						
Left depth	0.669						
Left width	−0.161						
Left height	0.469						

SS: Sphenoid sinus

Table 8: Multivariate discriminant function analysis using ethmoid sinus variables

	Unstandardized coefficient	Constant	Centroid		Sectioning point	Eigen	Wilk's Lambda
			Male	Female			
Right ES							
AW	1.922	−12.592	0.731	−1.125	−0.197	0.805	0.554
PW	2.460						
Length	0.732						
Height	0.982						
Left ES							
AW	1.846	−13.850	0.815	−1.254	−0.220	1.001	0.500
PW	1.867						
Length	0.837						
Height	1.796						
Both ESes							
Right AW	1.244	−14.485	0.945	−1.454	−0.255	1.345	0.427
Right PW	1.390						
Right length	−0.890						
Right height	0.467						
Left AW	0.831						
Left PW	1.259						
Left length	1.705						
Left height	0.962						

AW: Anterior width, PW: Posterior width, ES: Ethmoid sinus

imaging modality and technique/positioning, programs/software, landmarks used, the formula for calculating the volume, as well as variation in the samples size and composition.[5,8,9,22] The sinus metric parameters on CT are larger than cadaveric measurements because the former do not have to contend with mucosal thickness.[26] The type of pneumatization of the SS also significantly influences its dimensions, with previous studies documenting that the postsellar type is larger than the conchal, sellar, and presella.[5,28] The variant pneumatization of the ES is responsible for its irregular anatomy, which makes it difficult in establishing universally accepted boundaries hence, difficult to calculate its volume.[3] The volume of the ES was, therefore, not calculated in this study.

Consistent with several literature reports, we observed significantly larger SS variables in male patients than in females.[1,6,8,10,17] This has previously been ascribed to the impact of testosterone responsible for larger skull size, stature, and weight in males compared to their female counterparts.[2,18] On the contrary, some CT studies reported no significant gender differences in the SS dimensions and volume.[5,8,9,19,23]

Table 9: Percentage accuracy of gender discrimination using sinus dimensions

Variables	Correct prediction		
	Males, *n* (%)	Females, *n* (%)	Mean (%)
Right SS			
Height	151 (85.3)	67 (58.3)	218 (74.7)
Width	155 (87.6)	59 (51.3)	214 (73.3)
Depth	144 (81.4)	61 (53.0)	205 (70.2)
Left SS			
Height	153 (86.4)	65 (56.5)	218 (74.7)
Width	160 (90.4)	63 (54.8)	223 (76.4)
Depth	145 (81.9)	64 (55.7)	209 (71.6)
Right ES			
Height	141 (79.7)	61 (53.0)	202 (69.2)
AW	149 (84.2)	78 (67.8)	227 (77.7)
PW	145 (81.9)	64 (55.7)	209 (71.6)
Length	131 (74)	65 (56.5)	196 (67.1)
Left ES			
Height	137 (77.4)	61 (53.0)	198 (67.8)
AW	153 (86.4)	80 (69.6)	233 (79.8)
PW	144 (81.4)	61 (53.0)	205 (70.2)
Length	136 (76.8)	69 (60.0)	205 (70.2)

SS: Sphenoid sinus, ES: Ethmoid sinus

Table 10: Percentage accuracy of sex prediction using combined dimensions of the sinuses

Combined variables	Correct prediction		
	Males, *n* (%)	Females, *n* (%)	Mean (%)
Right SS	139 (78.5)	73 (63.5)	212 (72.6)
Left SS	142 (80.2)	75 (65.2)	217 (74.3)
Both SS	147 (83.1)	87 (75.7)	234 (80.1)
Right ES	148 (83.6)	89 (77.4)	237 (81.2)
Left ES	152 (85.9)	97 (84.3)	249 (85.3)
Both ES	158 (89.3)	102 (88.7)	260 (89.0)

SS: Sphenoid sinus, ES: Ethmoid sinus

Documented sexual dimorphism in a population may be influenced by the sample size, sample composition, and age range. Consistent with Wahyuni *et al*.[29] and El-Anwar *et al*.,[25] male patients had larger ES volume and dimensions than females. The smaller female ES widths inform surgeons to be more cognizant of the lamina papyracea, while the smaller heights increase the propensity to skull base injuries during ESS.[25]

The SS dimensions lacked significant association with laterality. Using cadaveric measurements, Kumar and Selvi[11] reported significantly larger left SS width and length than those of the right. In addition, Oliveira *et al*.[28] reported significantly larger left than right SS volume on CT images. This was contrary to other CT studies where side differences in the SS volume were not significant.[2,23] Significant SS asymmetry could be linked with the curved, irregular intersinus septum that is rarely at the midline.[4,28] Similarly, significant asymmetry of the ES could be attributed to the independent embryonic development of the PNS. Using CT images of normal ES, Mousaviagdas *et al*.[15] documented a significantly larger height of the left ES than that of the right. On the contrary, the bilateral posterior ES dimensions evaluated by El-Anwar *et al*.[25] lacked significant laterality.

Consistent with Oliveira *et al*.[28] and Schwerzmann *et al*.,[5] the SS and ES variables neither showed significant differences in the various age groups nor association with age. Therefore, the sinus dimensions may not be employed in the estimation of age in our population. On the contrary, Kuo and Liu[18] reported a significant negative relationship between the right SS volume and age. Jasso-Ramirez *et al*.[2] documented higher SS volume in the pediatric age groups due to the development of the facial part of the skull and teething. Furthermore, Karakas and Kavakli[30] documented an increase in the SS volume for up to 25 years and a reduction thereafter. After the fourth decade, the SS volume declines and reaches two-thirds of its maximum size in the 7th decade.[28]

The current study reports a significant positive association between all the measurements of a particular sinus and bilateral corresponding dimensions. Similarly, the height and width of the SS were significantly associated with those of the ES. This implies that these variables are in proportion with one another and can be used to approximate each other.[20] However, their weak association strongly suggests that their preoperative radiological assessment is mandatory for safe endoscopic surgical procedures. Similarly, Özer *et al*.[8] documented a significant positive correlation between the AP and transverse diameters of the SS and between the volumes of the right and left SS.

SS morphometry is significantly associated with protrusion and dehiscence of the ICA.[24] Larger SS volumes are associated with more intersinus septa and septa insertions onto the ICA canal, while smaller SS are linked with septa insertions onto the optic canal.[1] Therefore, radiological estimation of SS volume requires concurrent radiological identification of these septa and adjacent neurovascular structures to prevent fatal complications during endoscopic sinus and neurosurgical procedures.[1,4,12] ES is commonly involved in inflammatory processes and reoperations.[15] Its dimensions are important landmarks during ESS to avoid surgical injury to the skull base and orbital structures resulting in orbital hematoma, carotid artery-cavernous sinus fistula, or possible death.[14,25] According to Mousaviagdas *et al*.,[15] the awareness of the ES size may increase the efficacy of rhinosinusitis treatment and minimize surgical complications.

The left ES anterior width (79.8%) was the best sex-discriminating variable. The overall combination of variables in sex prediction revealed higher accuracies using the left SS and ES (74.3% and 85.3%) compared to the right sinuses (72.6% and 81.2%). The highest accuracy of sex allocation was observed when both ES dimensions were used (89.0%). The accuracy of sex prediction increased with the number of variables employed in the DFA. For instance, the ES variables used were more than those of the SS, hence yielding better prediction rates. Moreover, the combination of variables of two sinuses was more accurate than using those of a single sinus. Farazdaghi *et al*.[17] employed the receiver operating characteristic curve and found out that the SS volume was not appropriate for sex determination. Rad *et al*.[16] created discriminant function models for sex determination with the SS volume estimated by segmentation method using 469 cone beam CT images. They reported a high accuracy (90.2%) of correct sex prediction (86.0% males and 92.9% females). The accuracies vary in different populations, perhaps due to differences in race, sample size, sample composition statistical method, and radiological techniques.[16]

The use of a single study center limited the sample size used in the current study. The use of brain CT images is also a limitation of the current study. We recommend the use of PNS CT images with thinner axial cuts, which provide a better resolution for the evaluation of sinus morphometry.

Conclusion

This study provides a database of normal SS and ES dimensions in Delta State, Nigeria, which may help surgeons in the planning of safe endoscopic sinus and neurosurgical procedures. The accuracies obtained show that the SS and ES may be used for sex determination in forensic investigations.

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Conflicts of interest

There are no conflicts of interest.

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