Original Article

Morphometric Assessment of the Piriform Aperture and Its Clinical and Forensic Applications

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Abstract

Background: The piriform aperture (PA) is a midface structure that forms the anterior skeletal boundary of the nose. It is highly variant due to its physiological adaptations to the climate. Its variations are useful in forensic identification and reconstructive surgeries of the face. This study aimed at determining the PA's dimensions and their accuracy in sex determination. **Materials and Methods:** The PA's dimensions were retrospectively examined using 336 (199 males and 137 females) adult cranial computed tomography images in the database of the radiology unit of a university teaching hospital in Delta State, Nigeria, following institutional authorization. The aperture's index was calculated as a ratio of height to width. The data were analyzed using Statistical Package for the Social Sciences Version 23. The sexual dimorphism in the parameters was assessed using an independent *t*-test. Association among the continuous variables was analyzed by Pearson's correlation test. $P = 0.05$ was considered statistically significant. The percentage accuracy for correct sex prediction was assessed using the discriminant function analysis. **Results:** A significant relationship between dimensions with sex was observed ($P < 0.05$). The width of the aperture was the best sex-discriminating parameter (70.2%). The overall accuracy for sex discrimination using the aperture's dimensions was 75.0%. **Conclusion:** This study provides the standard ranges for the PA's width and height, valuable for surgical planning. These dimensions were sexually dimorphic and demonstrated an acceptable overall accuracy of correct sex allocation (75%). Consequently, this aperture may be utilized as a supplementary tool in conjunction with other methods for sex determination within studied population.

Keywords: Height, index, piriform aperture, sex determination, width

Introduction

The piriform aperture (PA) is a pear-shaped structure on the midface region that limits the skeletal portion of the nose anteriorly.[1] It is bounded by the maxillary bone's frontal process on the lateral aspect, while its upper portion is formed by the nasal bones. The PA is bordered inferiorly by the palatine processes of the maxilla and the anterior nasal spine.[2,3] The PA is an integral component of the upper respiratory passage which conditions the inspired air through warming, filtration, and moistening.[4] Its morphology and morphometry are influenced by the climate and are fundamental in ensuring good-quality nasal breathing.[5] The morphology of the PA varies based on environmental, climatic and geographical factors due to its adaptations to the physiological needs of respiration. This is responsible for the racial and regional discrepancies in the dimensions of the PA.[6]

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The embryonic development of the PA is usually completed by the 8th week of gestation following a sequence of morphological changes. Initially, nasal placodes form nasal grooves which transform into nasal pits that later deepen to form primitive posterior nares.[7] The anterior nares form from the fusion of the maxillary process with both medial and lateral nasal processes. Between the 8th and 24th week, the epithelial plug fills the nostrils, and later on, it is reabsorbed.[8] The PA continues to develop during childhood and into adulthood, mainly by doubling its width. This growth proceeds further even after 20 years of age.[1,2]

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The identification of an unknown individual is important in forensic investigations. Anthropometric parameters are useful in estimating the biological profile of an individual and this includes the sex, age, stature and ethnicity.[9] Face measurements contribute to high accuracy of human identification in mass disasters.[10] The PA's size and morphological shape vary according to age, gender, race, and ethnic groups, thus defining the anthropological features of a given population.[2,5,6] Sex determination is fundamental in creating a reliable biological profile during forensic investigations.[9,11] The PA is a more reliable and classic sex indicator compared to the nasal bone due to the latter's high propensity for fractures.[9]

Besides anthropology and forensic science, the PA's dimensions are significant in rhinoplasty, pulmonology, neurosurgery, plastic and reconstructive surgery, otorhinolaryngology, and osteotomies.[1,2] The bones bordering the PA may fracture, hence affecting the esthetics of the face due to the central location of PA.[3,12] Moreover, the morphometric data serve as a reference for estimation during rhinoplasty.[13] Preoperative assessment of the aperture is imperative to improve surgical outcomes of these reconstructive procedures.[6,8] Surgical or traumatic alterations of the nasal aperture change the respiratory mechanics.[7] Skull base tumors in the anterior and middle cranial fossae may require the widening of the anterior nasal opening in subcranial, transsphenoidal, and transnasal approaches.[13] The radiologic assessment of PA morphometry is, therefore, paramount for appropriate surgical planning.

Computed tomography (CT) is the gold standard technique for the diagnosis of nasal cavity pathologies. In addition, it provides objective and accurate osteological evaluation of the nasal cavity and PA, thus being useful in forensic anthropology.[5,14] The use of CT helps forensic experts avoid maceration procedures which may be time-consuming and, subsequently, slowing down the identification process. Currently, the availability of a large dataset from the recent CT samples acquired from the living subjects has made CT useful in forensic investigations.[9] There is a paucity of data regarding the metric parameters of the PA and their validity in sex determination in Delta State, Nigeria. This study was designed to assess dimensions of the PA using CT images and evaluate the accuracy of using this aperture in predicting sex.

Materials and Methods

We conducted this research by adopting the descriptive cross-sectional design. Employing a retrospective approach, we assessed the PA on brain CT images from the radiologic database of a referral center in Delta State, Nigeria. Following the review and approval of the research protocol by the hospital's ethical board (EREC/PAN/2020/030/0371), we purposively sampled 336 images from the databank in the Picture Archiving and Communication System software. These brain CT images were acquired using a CT scanner (64-slice Toshiba Aquilon) manufactured in Japan (2009). The protocol for brain imaging at the study center involved 3-mm thick axial slices taken from the base of the skull to the vertex with the machine set at 120 kV tube potential and a current of 300 mA.

Inclusion criteria

We included brain CT images of both male and female patients, aged ≥20 years. The images were of good quality, with symmetry of structures and continuity of bony outline. We included images taken within a span of 5 years (2015–2020).

Exclusion criteria

The CT images with artifacts, patient rotation, and evidence of sinonasal pathologies, craniofacial tumors, trauma, congenital anomalies, or previous surgery were barred from this study. Moreover, brain images of patients <20 years were not included.

Using bone window, we identified the PA on coronal reconstructed images of the skull. The dimensions of the PA were measured in cm using a linear digital rule. Only one investigator measured the parameters in all the images assessed to avoid interobserver errors. The PA's height (length) was the maximum vertical distance between the rhinion superiorly to the anterior nasal spine inferiorly, while its width was defined as the widest transverse distance between the left and the right lateral piriform boundaries [Figure 1].[1,15] The measurements were taken three times and the average values were recorded. The PA index was calculated as the ratio of PA height to width.[1]

The data were grouped in 10 years' age groups and analyzed using IBM® Statistical Package for the Social Sciences (SPSS) Version 23 (Armonk, New York). The metric parameters were summarized in means and standard deviations. The sex variations and differences in the age groups were evaluated using an independent t-test and analysis of variance, respectively. Pearson's correlation test was used to probe for any relationship between age and the PA dimensions. The statistical significance level was pegged at $P < 0.05$.

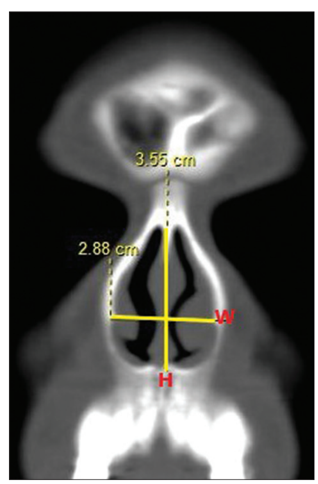

Figure 1: Reformatted coronal computed tomography image showing the measurement of height and width of the Piriform aperture. H: Height and W: Width

The average PA parameters were utilized in discriminant function analysis (DFA) to assess their accuracy in sex prediction. One parameter was employed to establish the discriminant equation for sex prediction in the univariate analysis, while the multivariate analysis involved a combination of the PA variables for sex determination.

The calculated coefficients and constants were integrated into the discriminate equations determining the discriminant functional scores: Discriminant functional score (D) = Constant+Y1P1+Y2P2 where Y1 Y2 represented coefficients and P1 P2 denoted the PA metric variables (P1- PA width and P2- PA height). The average of the two centroids was calculated as the sectioning point (SP) for sex discrimination. The PA variables scoring above the SP were categorized as male, while those below the SP were classified as female. Parameters with high validity in discrimination were identified by low Wilks' lambda and high eigenvalue.[16]

Results

The average age of the 336 patients whose images were evaluated was 53.29 ± 18.18 years (range, 20–99 years).

Table 1: Sex and gender distribution of the computed tomography images

	Frequency	Percentage	Cumulative percent
Gender			
Female	137	40.8	40.8
Male	199	59.2	100.0
Total	336	100.0	
Age-groups			
20–29	40	11.9	11.9
30–39	50	14.9	26.8
40–49	52	15.5	42.3
50–59	67	19.9	62.2
60–69	55	16.4	78.6
70–79	46	13.7	92.3
80–89	19	5.7	97.9
90–100	7	2.1	100.0
Total	336	100.0	

Table 2: Descriptive statistics for the dimensions of the piriform aperture

Sex	Variables	Minimum	Maximum	Mean±SD
Males	Breadth (cm)	2.48	3.73	3.017±0.246
	Height (cm)	1.74	6.25	4.435±0.556
	Index	0.54	2.21	1.471±0.224
Females	Breadth (cm)	2.09	3.69	2.857±0.351
	Height (cm)	3.57	5.87	4.063±0.578
	Index	1.19	2.00	1.424±0.193
Average	Breadth (cm)	2.09	3.73	2.938±0.303
	Height (cm)	1.74	6.25	4.249±0.565
	Index	0.54	2.21	1.447±0.213

SD: Standard deviation

The categorization of the patients according to sex and 10 years' age groups is shown in Table 1. The mean PA height was 4.249 ± 0.565 cm, while the mean breadth was 2.938 ± 0.303 cm. The ratio of PA height to breadth (PA index) was 1.447 ± 0.213. The minimum and maximum values for the variables assessed are summarized in Table 2. These values provide the cutoff points of the parameters in each sex group. The variables were significantly larger in the male PAs than those of females ($P < 0.05$) [Table 3]. The measurements of the PA in various study populations are summarized in Table 4. The PA parameters in the current study significantly varied in the 10 years' age groups ($P < 0.05$) [Table 5]. The height and breadth showed a significant weak positive correlation with each other ($P = 0.001$). However, their association with age did not show any statistical significance ($P > 0.05$). The PA index showed a significantly weak positive relationship with PA height and a significantly weak negative association with PA width and age [Table 6].

The following equations were derived from the univariate DFA to establish the discriminant function score using the PA width and height:

D=-10.074 + 3.413* PA breadth

D = -7.795 + 1.769* PA Height

The PA width had a higher accuracy in sex discrimination (236, 70.2%) compared to the PA height (222, 66.1%) [Table 7]. The Wilks' lambda for the PA breadth and height was 0.426 and 0.518, respectively, while their calculated eigenvalues were 2.014 and 1.987, respectively.

The discriminant score in the multivariate discriminate analysis was as follows:

D = -9.783 + 3.463* PA breadth – 0.100* PA Height

From this multivariate analysis, the accuracy for correct sex allocation was 75% (males: 79.4%, females: 68.6%) [Table 7]. The Wilks' lambda and eigenvalues obtained were 0.259 and 2.384, respectively.

Discussion

The PA's vertical and transverse dimensions were larger than those documented in Egyptian and Turkish CT studies[5,12,15,17,18] [Table 3]. The PA height and width measured directly on dry skulls of Indian and Brazilian subjects revealed smaller dimensions than the findings in this study.[2,6] Similarly, a previous Nigerian study by Jaiyeoba-Ojigho *et al*.[19] documented lower PA metric variables in the dry skulls they evaluated. Conversely, Abba *et al*.[14] in Nigeria reported larger PA dimensions than our findings. This discrepancy may be attributed to their study being conducted in a different geographic and climatic zone (Kano) involving the Hausa–Fulani ethnic group, predominant in Northern Nigeria. Moreover, they measured the PA dimensions on scanograms which are limited by the superimposition of structures.

Using three-dimensional CT images in Egypt, Abdelaleem *et al*.[9] reported lower height and larger width in males in comparison to the Nigerian males in this study. In addition, the females in their study had a shorter PA width compared to the females evaluated in the current study. Kabakci *et al*.[1] recorded larger PA height and smaller width than the observed PA dimensions in our study. Understanding the PA size is crucial for otorhinolaryngologists, as a narrow PA can limit the success of septoplasty and inferior turbinate reduction; therefore, failure of this procedure warrants PA widening.[1]

The PA index in this study (1.477) was different from the index documented in two Turkish populations evaluated by Yüzbaşioğlu *et al*.[17] (1.36) and Kabakci *et al*.[1] (1.84). The indices by Asghar *et al*.[6] and Abba *et al*.[14] were different from ours because they calculated the index as a percentage of width divided by height. According to Asghar *et al*.,[6] the PA index in males was 79.91% and that of females was 77.0%. These were higher than 67.20% and 66.36%, respectively, documented by Abba *et al*.[14] The normal ranges of the aperture's dimensions and index obtained in this study are valuable for surgeons in endoscopic sinus surgeries and neurosurgical procedures. Furthermore, the maxillofacial surgeons in the study center will utilize these findings during plastic and reconstructive surgeries of the face.

Table 3: Association between the piriform aperture metric variables and sex

Variables	Males	Females	*P*
Breadth (cm)	3.017±0.246	2.857±0.351	0.001*
Height (cm)	4.435±0.556	4.063±0.578	0.021*
Index	1.471±0.224	1.424±0.193	0.013*

**P* considered significant at <0.05

Table 4: The height and width of the piriform aperture in different studies

Author	Mode	Country	*n*	Sex	Unit	Height	Width
Kabakci *et al*.[1]	CT	Turkey	200	Male	mm	45.19±2.91	24.94±2.85
				Female		42.84±2.88	23.46±2.15
Araujo *et al*.[2]	Dry skull	Brazil	64	Male	mm	31.4±3.3	25.7±1.9
				Female		29.4±3.9	25.7±2.5
				Average		30.6±3.6	25.7±2.2
Kaplanoglu *et al*.[5]	CT	Anatolian, Turkey	363	Male	mm	37.45±7.25	23.54±2.96
				Female		35.92±6.74	23.24±2.29
				Average		36.76±7.06	23.41±2.68
Asghar *et al*.[6]	Dry skull	India	40	Male	mm	31.16±3.58	24.9±1.59
				Female		29.57±3.28	22.77±1.57
				Average		30.6±3.48	24.16±1.86
Abdelaleem *et al*.[9]	CT	Egypt	250	Male	mm	38.24±7.82	30.53±6.68
				Female		35.12±6.05	27.08±2.88
Abba *et al*.[14]	CT	Nigeria, Kano	153	Male	mm	54.39±2.53	36.48±2.78
				Female		54.28±2.54	35.00±2.64
El-Farouny *et al*.[15]	CT	Egypt	89	Male	mm	34.17±4.4	24.31±1.52
				Female		28.51±2.7	22.78±1.53
Yüzbaşioğlu *et al*.[17]	CT	Turkey	120	Male	cm	3.34±0.29	2.46±0.21
				Female		3.01±0.30	2.33±0.20
				Average		3.17±0.34	2.39±0.22
Yegin[18]	CT	Turkey	138	Male	cm	3.5±0.4	2.4±0.2
		Anatolian		Female		3.0±0.3	2.3±0.2
				Average		3.12±0.43	2.29±0.20
Current study	CT	Nigeria	336	Male	cm	4.435±0.556	3.017±0.246
				Female		4.063±0.578	2.857±0.351
				Average		4.249±0.565	2.938±0.303

CT: Computed tomography

Table 5: The association between the morphometric parameters of the piriform aperture and age groups

Parameters	Age-groups (years)								*P*
	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	
Breath (cm)	2.740	2.968	3.067	3.046	2.997	2.854	2.988	3.000	0.001*
Height (cm)	4.138	4.412	4.405	4.327	4.261	4.053	4.216	4.177	0.001*
Index	1.510	1.487	1.436	1.421	1.422	1.420	1.411	1.372	0.001*

**P* considered significant at <0.05

The racial and population variations in the PA morphometry are primarily due to congenital anatomic variations besides adaptation to the different geographical, environmental, and climatic conditions.[9,11] Climatic variations alter nasal morphology, the orientation of the nasal bone, and the mucosal lining of the internal passages, consequently affecting the PA anatomy.[7] Cold and dry climates, such as those in Europe, are associated with longer, larger, and more prominent external noses and narrow PAs. In contrast, warmer and humid regions like Africa are linked to broader, flatter external noses and wider PA indicating greater nasal respiration in Africans compared to Europeans.[1,4] Extreme hot, dry and cold climates require larger surface area and volume of the nasal passages. To adapt to these climatic conditions, the PA becomes longer and narrower to facilitate the turbulence of airflow by soft tissue. This enhances the conditioning of inspired air through filtration, warming and humidification.[1,2,4] Excessive soft tissue requires a wider and circular PA as observed in Indians.[6] Discrepancies in PA dimensions documented in literature could also be attributed to differences in populations, sample size, age and sex composition of study samples, and the technique of measurement – whether directly on dry skull or through radiological means.[5]

Corresponding to several previous studies, this study reports sexual dimorphism in the PA dimensions.[1,6,9,14,17] This contradicts the report by Araujo *et al*.[2] The dimensions in males are larger than those in females on account of the hormonal effects on postnatal bone growth. In the preadolescent stage, bone growth occurs at an equal rate in both sexes. At puberty, estrogen in females inhibits osteoblastic activity at the growing ends of bones reducing the growth rate compared to males.[14] The androgens in males enhance periosteal formation, leading to bone thickening and robust bone features.[11,20] Besides hormonal influence, sexual dimorphism in bone has been associated with biomechanical load, nutrition, and socioeconomic status.[11]

Table 6: Correlation between the piriform aperture dimensions with age

	Age	Breath	Height	Index
Age				
r	1	0.104	0.179	−0.489*
P		0.092	0.148	0.004
Breath				
r	0.104	1	0.292*	−0.124*
P	0.092		0.001	0.025
Height				
r	0.179	0.292*	1	0.376*
P	0.148	0.001		0.038
Index				
r	−0.489*	−0.124*	0.376*	1
P	0.004	0.022	0.038	

**P* considered significant at <0.05. *r*: Pearson's correlation coefficient

The PA width was the most discriminating variable for sex, with an accuracy of 70.2%. Using both PA width and height, the general accuracy for correct sex allocation was 75.0% with slightly higher accuracy of grouping males (79.4%) than females (68.6%). Abdulaleem *et al*.[9] reported a similar finding, with PA width being the best variable in sex prediction (75.4%), followed by height (71.8%). The multivariate DFA by these authors revealed an overall accuracy of 68.3%, slightly lower than our findings. However, caution should be exercised when using discriminate equations for determining sex, as noted by Abdulaleem *et al*.[9] Alves *et al*.[11] found that the PA height had a good sex-predicting potential. They also emphasized the importance of combining multiple variables for increased accuracy and precision in sex determination, as observed in the present study. Discrepancies in the accuracies could be caused by differences in sample size, the statistical tool used (DFA vs. linear regression), and PA parameters included in sex prediction.

Consistent with Kabakci *et al*.,[1] the PA vertical and transverse dimensions significantly increased with age until 50 years, differed in the various age groups, and the index reduced with advancing age. However, in the present study, the association of these parameters with age was not significant. Previous studies report an increase in PA dimensions with age.[1,2,21] A double increase in the width from infancy into adulthood, continuing even after the second decade, has been reported.[1,2] Bigger apertures are associated with more physical capacity, which declines with aging, resulting in a proportionate reduction in PA diameters with age.[1] Aging causes the resorption of facial bones such as the midface skeleton comprising the PA leading to an increase in its dimensions.[9]

Table 7: Discriminant function analysis using the piriform aperture dimensions

PA variable	Coefficient	Constant	Centroid		SP	Accuracy (%)		
			Male	Female		Males	Females	Overall
Multivariate analysis								
Width	3.463	−9.783	0.223	−0.323	−0.05	158 (79.4)	94 (68.6)	252 (75.0)
Height	−0.100							
Univariate analysis								
Width	3.413	−10.074	0.207	−0.301	−0.047	150 (75.4)	86 (62.8)	236 (70.2)
Height	1.769	−7.795	0.052	−0.076	−0.012	143 (71.9)	79 (57.7)	222 (66.1)

Wilks' Lambda 0.259, Eigenvalue 2.384. SP: Sectioning point, PA: Piriform aperture

The PA height herein showed a positive relationship with the width and PA index, while the breadth showed a negative association with PA index. These were statistically significant, implying that the PA width and height directly influence each other, while the PA index could be estimated directly from the height and inversely using the PA width. These significant associations have implications for planning of transnasal approaches to tumors at the skull base and reconstructive surgeries.

Conclusion

The standard PA dimensions established in this study can be used in the planning of reconstructive surgeries and neurosurgical procedures which require transnasal approaches. The dimensions showcased sexual dimorphism with an overall accuracy of 75% in correctly allocating sex. Consequently, the PA can be used in our population to supplement other known sex determination methods.

Strength of the study

The utilization of CT images for PA morphometry ensures precise measurements, as this imaging modality accurately delineates bony structures, particularly effective for assessing skull bones.

Limitation of the study

The retrospective design, purposive sampling technique, and the reliance on a single radiological unit limited the sample size used.

Future research directions

Future research endeavors should involve multiple centers in Delta State to enhance the sample size. The PA measurements can be correlated with other craniometrics variables. In addition, considering various ethnic groups could evaluate whether the PA dimensions contribute to estimating ethnicity. Further investigations may explore the accuracy of combining PA dimensions with other craniometrics parameters for enhanced sex determination.

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Conflicts of interest

There are no conflicts of interest.

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