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Original Articles

Correlation Between the Morphometric Characteristics of the Piriform Aperture and the Facial Skeleton: A CT-Based Study of a Bulgarian Population

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Advances in imaging diagnostics have enabled precise analysis of craniofacial structures. The piriform aperture, central to nasal morphology and facial aesthetics, is vital in respiration, growth, and craniofacial development. This study examines correlations between piriform aperture dimensions and facial skeletal measurements using computed tomography. A total of 120 adults of Bulgarian ethnic origin (55 males, 65 females), aged 20-60 years, were analyzed using 3D reconstructions from multi-slice CT scans. Significant positive correlations were found between piriform aperture height and nasal height, upper, and lower aperture widths. An inverse correlation was observed between aperture height and nasal bone length. Additional associations were noted between facial height and cranial width measurements. The findings underscore the relevance of piriform aperture morphology in clinical contexts and support its integration into surgical planning for reconstructive and aesthetic facial procedures.

Key words: piriform aperture, craniofacial morphology, computed tomography, 3D reconstruction

Introduction

In the early 21st century, significant progress has been made in craniofacial anthropological research, facilitated by the accumulation of large datasets derived from independent studies and the development of geometric morphometric methods [15, 17]. Traditional craniometric landmarks [3, 8, 9, 14] are gradually being complemented or replaced by 3D morphometric approaches that allow precise measurement of otherwise inaccessible skull regions [1, 4, 6, 19, 23, 24].

The nasal region plays a critical role in overall craniofacial growth. Prenatally, the nasal septum functions as a growth center, stimulating maxillary development and guiding facial elongation. Postnatally, the septum and nasal cavity continue to influence facial morphology as functional matrices [20]. The piriform aperture not only affects nasal airflow but also contributes significantly to the aesthetic perception of the human face.

This study seeks to evaluate the correlations between the linear dimensions of the piriform aperture and the facial skeleton in a representative Bulgarian population, with particular emphasis on applications in reconstructive and aesthetic facial surgery.

Material and Methods

Study sample

The study included 120 adult individuals (55 males and 65 females) aged 20–60 years, of Bulgarian ethnic origin, referred for head CT for non-craniofacial medical indications. Participants were recruited from St. Ivan Rilski Medical Complex, Plovdiv, following ethical approval from the local Ethics Committee at the St George University Hospital and written informed consent in accordance with the Helsinki Declaration.

Participants included in the study were required to be over 20 years of age and of Bulgarian ethnic origin, defined as having both parents and all grandparents of Bulgarian descent. Additionally, only individuals who were referred to a head computed tomography (CT) scan for reasons unrelated to facial trauma were considered eligible. Exclusion criteria included any non-Bulgarian ancestry, a personal history of craniofacial trauma, surgery, congenital malformations, endocrine, metabolic, or skeletal development disorders, as well as the presence of chronic obstructive pulmonary disease (COPD) and other chronic conditions leading to mouth breathing, as these influence craniofacial morphology.

All CT scans were performed using a Siemens SOMATOM Sensation Cardiac 64-slice CT scanner. The imaging protocol involved a tube voltage of 120 kV and a tube current of 250 mA. Scans were acquired with a slice thickness of 0.5 mm and reconstructed at 0.3 mm intervals. Images were processed using a 512 × 512 matrix and the H45s convolution kernel to ensure high-resolution image quality suitable for detailed anatomical assessment. Data were exported in DICOM format and processed with Radiant DICOM Viewer using 3D volume rendering (VR). Anatomical landmarks were marked, and linear measurements were taken in millimeters between standard craniometric points.

Measurements

A total of **14 cranial landmarks** (**Table 1**) were obtained and **16 linear measurements** were recorded.

Table 1. Cranial landmarks, obtained in the study.

Landmarks	Abbr.	Description:
Eurion	eu	The most lateral point on the lateral surface of the skull. /bilateral location/
Frontomalare orbitale	fmo	The point of intersection of the lateral orbital margin with the zygomaticofrontal suture. /bilateral location/
Maxillofrontale	mf	The point of intersection of the medial orbital margin with the frontomaxillary suture. /bilateral location/
Zygion	zy	The most lateral point on the zygomatic arch. /bilateral location/
Nasomaxillare	nm	The point located at the intersection of the piriform aperture with the nasomaxillary suture. /bilateral location/
Nasolaterale	nl	The most posterior point on the lateral margin of the piriform aperture. /bilateral location/
Gonion	go	Point on the mandibular angel where the outline of the mandible intersects with the line bisecting the angle formed by the line tangent to the posterior ramus border and the line tangent to the inferior border of the body. /bilateral location/
Mentale	ml	The most inferior point of the mental foramen. /bilateral location/
Ectoconchion	ec	The intersection point of the lateral orbital margin and the line originating from maxillofrontale and crossing the orbit parallel to the upper orbital margin. /bilateral location/
Nasion	n	The intersection point of the frontonasal suture and the midsagittal plane.
Rhinion	rhi	The point of intersection of the upper end of the piriform aperture and the internasal suture.
Nasospinale	ns	The point located on the intersection of the median plane with the line connecting the lower edge of the piriform aperture.
Prostion	pr	The most anterior point in the midline on the upper alveolar process.
Gnathion	gn	The most inferior point on the mandibular border in the midsagittal plane

Linear measurements calculated:

● **Piriform Aperture**: Height (rhi-ns), Upper width (nm-nm), Lower width (nl-nl);

● **Nasal Region**: Nasal height (n-ns), Nasal bone length (n-rhi);

● **Facial Skeleton**: Upper facial height (n-pr), Lower facial height (pr-gn), Morphological facial height (n-gn), Zygomatic width (zy-zy), Bigonial width (go-go), Bimental width (ml-ml), Cranial width (eu-eu), Bi-orbital width (fmo-fmo), Interorbital width (mf-mf), Orbital width (mf-ec), Orbital height (the greatest linear distance between the upper and lower orbital rims, perpendicular to the orbital width).

Statistical Analysis

Data were analyzed using SPSS 24.0 (Statistical Package for the Social Sciences 24.0). Pearson's correlation coefficient (r) was calculated to assess linear relationships between variables. The level of statistical significance was set at $P < 0.05$. Correlation strength was classified as follows: r - 0.01–0.30 – weak; r - 0.30–0.50 – moderate; r - 0.50–0.70 – strong; r - 0.70–0.90 – very strong; r - > 0.90 – near-perfect correlation.

Results

Piriform Aperture Correlations

Piriform aperture (PA) height (rhi-ns) demonstrated a positive correlation with several key nasal measurements, including nasal height (n-ns), upper PA width (nm-nm), and lower PA width (nl-nl) (**Table 2**). In contrast, PA height was negatively correlated with nasal bone length (n-rhi). Both the upper and lower PA widths were positively correlated not only with each other but also with PA height, indicating coordinated growth patterns in these regions. Notably, the lower PA width exhibited a significant inverse correlation with nasal bone length, suggesting a potential compensatory or structural relationship between these dimensions.

Table 2. Correlation relationships between the measured linear dimensions of the piriform aperture combined for both sexes in individuals from the Bulgarian population.

Total for both sexes (n=120)							
Anthropological dimensions		**rhi-ns**	**n-ns**	**n-rhi**	**nm-nm**	**nl-nl**
rhi-ns	Pearson	1	.663**	-.365**	.246**	.342**
	p		**.000**	**.000**	**.007**	**.000**
n-ns	Pearson	.663**	1	.455**	.118	.175
	p	**.000**		**.000**	.201	.056
n-rhi	Pearson	-.365**	.455**	1	-.147	-.189*
	p	**.000**	**.000**		.110	**.039**
nm-nm	Pearson	.246**	.118	-.147	1	.404**
	p	**.007**	.201	.110		**.000**
nl-nl	Pearson	.342**	.175	-.189*	.404**	1
	p	**.000**	.056	**.039**	**.000**	
**. Correlation is significant at the 0.01 level (2-tailed).						
*. Correlation is significant at the 0.05 level (2-tailed).						

Facial Skeleton Correlations

Measurements of upper, lower, and total morphological facial height were found to be strongly correlated with nearly all craniofacial width parameters (**Table 3**). Specifically, zygomatic, bigonial, and bi-orbital widths showed consistent positive correlations with various linear facial dimensions, underscoring the interconnected development of facial width and height. Orbital width was significantly correlated with most facial measurements, with the exception of interorbital width, which did not follow the same pattern. Additionally, orbital height demonstrated significant correlations with all measured variables, excluding cranial width, bimental width, and interorbital width. These findings highlight a robust relationship among vertical and horizontal skeletal components of the face.

Table 3. Correlation relationships between the measured linear dimensions of the facial skeleton, combined for both sexes in individuals from the Bulgarian population.

Total for both sexes (n=120)												
Anthropological dimensions		**n-pr**	**pr-gn**	**n-gn**	**zy-zy**	**go-go**	**ml-ml**	**eu-eu**	**fmo-fmo**	**mf-mf**	**mf-ec**	**Orbital height**
n-pr	Pearson	1	.436**	.861**	.534**	.497**	.236**	.303**	.480**	.216*	.517**	.508**
	p		**.000**	**.000**	**.000**	**.000**	**.010**	**.001**	**.000**	**.018**	**.000**	**.000**
pr-gn	Pearson	.436**	1	.833**	.497**	.470**	.409**	.375**	.486**	.210*	.489**	.191*
	p	**.000**		**.000**	**.000**	**.000**	**.000**	**.000**	**.000**	**.022**	**.000**	**.037**
n-gn	Pearson	.861**	.833**	1	.607**	.569**	.375**	.398**	.571**	.252**	.595**	.417**
	p	**.000**	**.000**		**.000**	**.000**	**.000**	**.000**	**.000**	**.005**	**.000**	**.000**
zy-zy	Pearson	.534**	.497**	.607**	1	.703**	.476**	.477**	.766**	.440**	.619**	.267**
	p	**.000**	**.000**	**.000**		**.000**	**.000**	**.000**	**.000**	**.000**	**.000**	**.003**
go-go	Pearson	.497**	.470**	.569**	.703**	1	.570**	.263**	.617**	.357**	.490**	.325**
	p	**.000**	**.000**	**.000**	**.000**		**.000**	**.004**	**.000**	**.000**	**.000**	**.000**
ml-ml	Pearson	.236**	.409**	.375**	.476**	.570**	1	.253**	.509**	.463**	.306**	.000
	p	**.010**	**.000**	**.000**	**.000**	**.000**		**.005**	**.000**	**.000**	**.001**	.999
eu-eu	Pearson	.303**	.375**	.398**	.477**	.263**	.253**	1	.349**	.302**	.221*	.027
	p	**.001**	**.000**	**.000**	**.000**	**.004**	**.005**		**.000**	**.001**	**.015**	.767
fmo-fmo	Pearson	.480**	.486**	.571**	.766**	.617**	.509**	.349**	1	.536**	.727**	.309**
	p	**.000**	**.000**	**.000**	**.000**	**.000**	**.000**	**.000**		**.000**	**.000**	**.001**
mf-mf	Pearson	.216*	.210*	.252**	.440**	.357**	.463**	.302**	.536**	1	.050	-.049
	p	**.018**	**.022**	**.005**	**.000**	**.000**	**.000**	**.001**	**.000**		.586	.592
mf-ec	Pearson	.517**	.489**	.595**	.619**	.490**	.306**	.221*	.727**	.050	1	.370**
	p	**.000**	**.000**	**.000**	**.000**	**.000**	**.001**	**.015**	**.000**	.586		**.000**
Orbital height	Pearson	.508**	.191*	.417**	.267**	.325**	.000	.027	.309**	-.049	.370**	1
	p	**.000**	**.037**	**.000**	**.003**	**.000**	.999	.767	**.001**	.592	**.000**	
**. Correlation is significant at the 0.01 level (2-tailed).												
*. Correlation is significant at the 0.05 level (2-tailed).												

Table 4. Correlation relationships between the measured linear dimensions of the piriform aperture and facial skeleton, combined for both sexes in individuals from the Bulgarian population.

Total for both sexes (n=120)												
Anthropological dimensions		**n-pr**	**pr-gn**	**n-gn**	**zy-zy**	**go-go**	**ml-ml**	**eu-eu**	**fmo-fmo**	**mf-mf**	**mf-ec**	**Orbital height**
rhi-ns	Pearson	.435**	.303**	.437**	.498**	.374**	.213*	.300**	.412**	.153	.442**	.160
	p	**.000**	**.001**	**.000**	**.000**	**.000**	**.020**	**.001**	**.000**	.095	**.000**	.081
n-ns	Pearson	.794**	.318**	.667**	.588**	.446**	.195*	.315**	.457**	.185*	.500**	.378**
	p	**.000**	**.000**	**.000**	**.000**	**.000**	**.033**	**.000**	**.000**	**.043**	**.000**	**.000**
n-rhi	Pearson	.471**	.035	.309**	.139	.110	-.011	.035	.077	.048	.095	.280**
	p	**.000**	.705	**.001**	.130	.233	.909	.702	.400	.604	.302	**.002**
nm-nm	Pearson	.188*	.230*	.248**	.267**	.219*	.275**	.166	.310**	.392**	.160	-.023
	p	**.040**	**.011**	**.006**	**.003**	**.016**	**.002**	.070	**.001**	**.000**	.081	.802
nl-nl	Pearson	.100	.232*	.195*	.389**	.232*	.237**	.075	.479**	.361**	.379**	.057
	p	.275	**.011**	**.033**	**.000**	**.011**	**.009**	.415	**.000**	**.000**	**.000**	.536
**. Correlation is significant at the 0.01 level (2-tailed).												
*. Correlation is significant at the 0.05 level (2-tailed).												

Correlations between piriform aperture and facial skeleton measurements

Piriform aperture (PA) height (rhi-ns) demonstrated a strong positive correlation with most of the measured linear craniofacial parameters, except for interorbital width (mf-mf) and orbital height (**Table 4**). Nasal height (n-ns) was found to be significantly correlated with all of the facial skeleton measurements. Meanwhile the length of the nasal bones (n-rhi) exhibited a consistent positive correlation only with upper and morphological facial heights and with orbital height. Upper width of PA (nm-nm) was strongly correlated with most of the craniofacial parameters except for cranial width and orbital width and height. Lower width of PA (nl-nl) also revealed significance in correlations with most of the craniofacial parameters excluding upper facial and orbital height and cranial width.

Discussion

This study confirms that the morphometric parameters of the piriform aperture are closely linked to those of the facial skeleton. The nasal region, particularly the PA, demonstrates complex correlations indicative of integrated craniofacial growth. The inverse relationship between PA height and nasal bone length may reflect compensatory growth dynamics or developmental constraints. The results are presented for both sexes in order to assess the overall correlations between the morphometric characteristics of the piriform aperture and the facial skeleton in the general population sample. Acknowledging the potential influence of sexual dimorphism and the value of sex-specific correlation analyses further research is needed.

The growth and development of the nasal cavity have a central place in the ontogeny of the facial skull. Prenatally the nasal septum acts as a growth site and induces maxillary pull, which directs facial growth in an anteroinferior direction and leads to a sevenfold increase in facial length between the 10th and 40th weeks after fertilization [7]. Postnatally the nasal septum and cavity act as functional matrices and continue to be one of the determining factors for the development of the facial growth pattern [7, 13].

The findings align with previous studies indicating the central role of the nasal septum and nasal cavity in facial ontogeny [5, 20, 22]. The strong correlations found across multiple facial dimensions suggest that morphometric parameters can be predictive of nasal architecture — with direct applications in aesthetic and reconstructive surgical planning. Facial plastic surgery must be tailored to the close relationship between the soft tissue facial profile and the underlying bone structure, as well as the gender, age, ethnicity and geographic location of the individual [2, 10, 16, 18]. The size and shape of the nose can be determined by combined analysis of soft tissue and morphometric indices of the individual's piriform aperture and nasal bones [11]. However, this data must also be considered in accordance with the anthropological standard for the respective population. Research has shown that morphometric data of the piriform aperture and the nasal bones is a reliable source of information for determining the shape and dimensions of the nose in reconstructive and aesthetic surgical interventions in the facial area [12, 21].

Conclusion

The dimensions of the piriform aperture correlate significantly with key anthropometric parameters of the facial skeleton. These correlations should be considered in clinical practice, particularly in plastic and craniofacial surgery, where understanding individual anatomical variation is essential for optimal outcomes.

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