https://doi.org/10.5272/jimab.2025314.6586
Journal of IMAB
ISSN: 1312-773X
https://www.journal-imab-bg.org
Journal of IMAB. 2025 Oct-Dec;31(4)
OPEN ACCESS
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Original article

THREE-DIMENSIONAL MSCT ANALYSIS OF SEXUAL DIMORPHISM IN FACIAL SKULL AND PIRIFORM APERTURE MORPHOLOGY IN SOUTH BULGARIA

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ABSTRACT

Purpose: Human skeleton exhibits varying degrees of sexual dimorphism – the pelvic bones, limbs long bones and the skull are the most frequently studied. Methods have been developed for the study of individual bones, and a high degree of sexual dimorphism is observed in measurements of the skull and, more specifically, of the facial skull in humans. Data on sexual dimorphism for the Bulgarian population are from direct measurements of skulls performed with conventional craniometric instruments. The aim of the study was to evaluate the sexual dimorphism of piriform aperture and facial skull dimensions obtained on 3D reconstructed MSCT scans in individuals of the South Bulgarian population.

Methods: The study included three-dimensional skull models rendered from computed tomography head scans with landmarks acquired on them.

Results: The results revealed that the mean values of all linear measurements of the piriform aperture and facial skull showed the presence of significant sexual dimorphism.

Conclusions: With the development of imaging diagnostics, conditions have been created for performing more precise craniometric studies of people. Therefore, this gives the opportunity to update and supplement the available database for the Bulgarian population. It provides essential information for facial reconstruction, preoperative examination, surgical procedures and postoperative controls.

Keywords: sexual dimorphism, piriform aperture, facial skull, MSCT, 3D reconstruction, South Bulgaria,

INTRODUCTION

Human skeletal remains exhibit varying degrees of sexual dimorphism, with the pelvic bones, long limb bones, and skull being the most extensively studied. Among these, the facial skull, in particular, shows marked sexual dimorphism. Research has developed methods to quantify both the size (quantitative) and shape (qualitative) of bones to account for these differences. Notably, the pelvis and skull demonstrate the highest accuracy in sex determination. According to Mays & Cox, sex determination from the pelvis achieves an accuracy of 98%, from the skull and mandible 90%, and from the skull without the mandible 80% [1]. Moreover, Toneva et al. reported an accuracy of 87% for mandible-based sex classification, due to its significant size differences between males and females [2].

Numerous anthropological studies have explored sexual dimorphism in individual bones as well as composite skeletal elements, aiming to establish their contribution to sex determination. In Bulgaria, early anthropometric studies of the skull were conducted by Kadanov and Mutafov [3], focusing exclusively on male skulls, which did not address inter-sex differences. Later, Yordanov [4] provided a generalized comparison of male and female skulls, and in 2010, Nikolova's dissertation examined cranial anatomical variations, including inter-sex and bilateral differences. Following these studies, Toneva and Nikolova performed craniometric analyses on 3D CT scans of Bulgarian individuals [5].

Studies of the soft tissues of the face, and specifically sexual dimorphism in facial dimensions, have also been conducted in Bulgaria by Pavlov et al. (1963), Petrov et al. (1963), and others. These studies, along with international research, have contributed to a significant database of facial anthropometric data for different ethnic groups [6, 7, 8, 9]. Recent research by Harizanova expanded the scope to include dental and interdental indices, providing further insights into variations that could assist in sex determination [10, 11].

In this study, we aimed to evaluate sexual dimorphism in the piriform aperture and facial skull dimensions using 3D reconstructed MSCT scans of individuals from the South Bulgarian population.

MATERIALS AND METHODS

The study included 120 three-dimensional skull models rendered from computed tomography head scans of individuals of Bulgarian origin (55 men and 65 women), aged 20 to 60 years. All subjects were consecutively admitted to the Medical Complex Saint Ivan Rilski Hospital, Department of Imaging Diagnostics, Plovdiv. The subjects were referred for objective clinical reasons by their physician for a computed tomography scan of the head. The participants in the study were distributed by gender due to the presence of sexual dimorphism in the studied anthropological dimensions.

Exclusion criteria:

• Non-Bulgarian ethnicity of any of the parents or grandparents;

• Presence or history of craniofacial trauma involving the facial skull and nose;

• History of trauma in the maxillofacial region;

• Surgical or plastic interventions in the maxillofacial region and nose;

• Endocrine diseases, metabolic diseases, disorders in the development of the skeletal system, growth retardation, or other diseases that are related to the development of the facial skull and nose.

The study was approved by the local Ethics Committee at the St George University Hospital. All subjects gave written informed consent to participate.

The study was conducted with a third-generation Siemens SOMATOM Sensation Cardiac 64 Multi-Slice Computed Tomography (MSCT) Scanner - a multi-detector, spiral 64-slice computed tomography scanner. The CT scans were performed using a Siemens scanner with a Windows-based operating system (SYNGO), offering advanced imaging capabilities. The scanning time was set to 0.46 seconds per slice, with slice thickness varying between 0.75 mm and 10 mm. The tilt angle was adjustable from +/- 30°, with 0.5° increments, ensuring precise anatomical alignment. Spiral scanning was conducted over a duration of 100 seconds.

This system allows for the acquisition of high-resolution images across all planes while minimizing ionizing radiation exposure and reducing "electronic noise" in the images. The imaging data were captured in DICOM format, and the 3D reconstruction of the skull and mandible was performed using the Volume Rendering (VR) tool in Radiant DICOM Viewer software. Craniometric points were placed on the reconstructed 3D model, and linear measurements were taken based on these anatomical landmarks.

For the study 16 anthropological dimensions were measured after placing the required craniometric landmarks on the skull images – piriform aperture height (PAH), nasal height (NH), nasal bone length (NBL), upper facial height (UFH), lower facial height (LFH), morphological facial height (MFH), superior width of PA (SWPA), inferior width of PA (IWPA), zygomatic width (ZW), bigonial width (BGW), bimental width (BMW), skull width (SW), biorbital width (BOW), interorbital width (IOW), orbital width (OW) and orbital height (OH) (fig. 1.) (fig. 2).

Fig. 1. Craniometric landmarks on a 3D facial skull image.

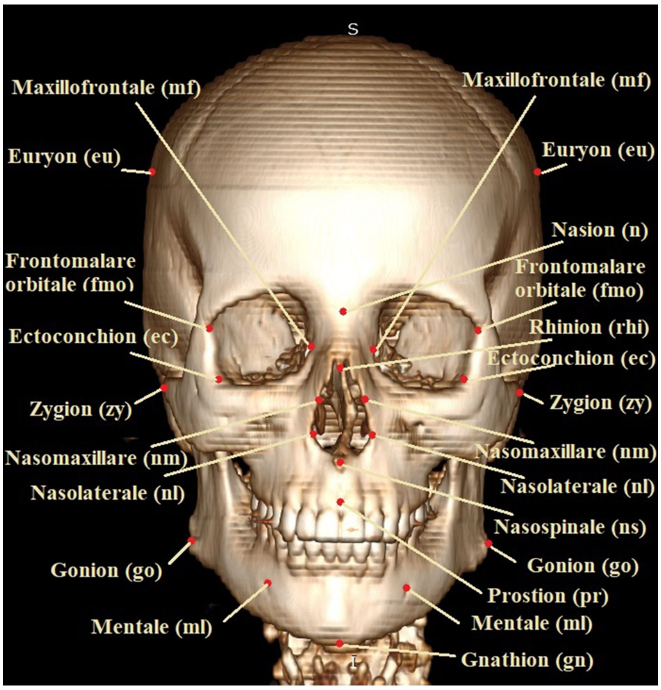
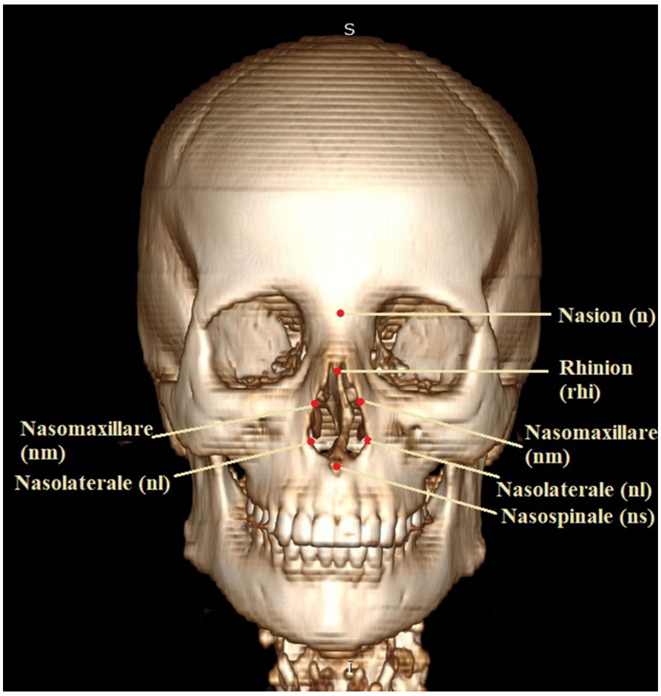


Fig. 2. Craniometric landmarks on a 3D image of the piriform aperture.



The data were statistically analyzed in SPSS 24.0. (Statistical Package for the Social Sciences 24.0), using the following analyses:

• Descriptive statistics: mean, standard deviation, minimum-maximum;

• Graphical analysis;

• Parametric analyses: Student's t-test (two-tailed).

The level of statistical significance was set at $P < 0.05$.

RESULTS

The comparison of craniofacial measurements between males (n=55) and females (n=65) revealed significant sexual dimorphism in most of the evaluated parameters (Table 1). Males demonstrated higher mean values than females for nearly all anthropometric dimensions.

Significant differences ($p < 0.05$) were observed in PA height, nasal height, upper and lower facial heights, morphological facial height, upper and lower widths of PA, zygomatic width, bigonial width, bimental width, skull width, biorbital width, interorbital width, and orbital width. Among these, the most pronounced differences were noted in zygomatic width ($t = 13.75$, $p < 0.001$), morphological facial height ($t = 9.27$, $p < 0.001$), and bigonial width ($t = 9.93$, $p < 0.001$), indicating that males had markedly broader and longer facial structures.

In contrast, nasal bone length ($t = 1.88$, $p = 0.063$) and orbital height ($t = 1.68$, $p = 0.095$) did not show statistically significant differences between sexes.

Overall, the findings demonstrate that males possess significantly greater facial and cranial dimensions in both height and breadth compared with females. The most pronounced sexual dimorphism was observed in zygomatic width, morphological facial height, bigonial width, and biorbital width. These results indicate that the male craniofacial complex is generally more robust and exhibits greater transverse and vertical dimensions than the female counterpart.

Table 1. Comparison of linear dimensions between men and women for anthropological assessment of the facial skull and piriform aperture in individuals from the Bulgarian population.

Anthropological dimensions	**Males (n=55)**		**Females (n=65)**		**Statistical significance**	
	Mean	**SD**	**Mean**	**SD**	**t**	**p**
PA height	3.1009	0.33	2.7845	0.32	5.302	**0**
nasal height	5.2476	0.33	4.8246	0.3	7.334	**0**
nasal bone length	2.1467	0.36	2.0402	0.24	1.88	0.063
upper facial height	6.9144	0.46	6.3106	0.4	7.578	**0**
lower facial height	5.1782	0.46	4.6682	0.38	6.602	**0**
morph. facial height	12.0925	0.7	10.9757	0.6	9.272	**0**
upper width of PA	1.648	0.22	1.5363	0.17	3.052	**0.003**
lower width of PA	2.4055	0.2	2.2894	0.18	3.287	**0.001**
zygomatic width	13.3116	0.37	12.3274	0.41	13.75	**0**
bigonial width	10.2533	0.49	9.3122	0.55	9.925	**0**
bimental width	4.6325	0.29	4.3851	0.25	4.924	**0**
skull width	13.3795	0.58	13.2057	0.57	4.51	**0**
biorbital width	9.938	0.4	9.3037	0.35	9.096	**0**
interorbital width	2.0349	0.22	1.8642	0.18	4.532	**0**
orbital width	3.9624	0.19	3.6978	0.2	7.344	**0**
orbital height	3.092	0.18	3.0288	0.23	1.683	0.095

DISCUSSION

Sexual dimorphism refers to systematic differences in shape, size, and structure between males and females of the same species. In the case of the piriform aperture and facial skull, the degree of sexual dimorphism varies across populations, influenced by genetic, environmental, dietary, and social factors. This variability underscores the importance of population-specific data in anthropological studies. While studies on sex determination using three-dimensional (3D) computed tomography (CT) reconstructions of the head in the Bulgarian population are limited, they represent a reliable and consistent source of anthropological data.

Craniometric analysis based on 3D CT reconstructions is an efficient and non-invasive method for obtaining precise cranial measurements. Unlike DNA analysis, which is time-consuming and requires specialized equipment and trained personnel, craniometry offers a faster, repeatable approach to studying maxillofacial morphology for sex determination. Given the growing need for accessible and accurate methods in forensic anthropology, craniometric data from 3D reconstructions can play a pivotal role in creating population-specific databases for sex estimation in modern populations.

Craniometric analysis has long been used to determine key biological characteristics such as sex, age, stature, and ethnicity across disciplines like anthropology, archaeology, and forensic medicine. It proves particularly useful in cases of incomplete or degraded skeletal remains and even for living individuals. Craniometric methods can be categorized into metric and non-metric approaches. Non-metric methods focus on descriptive or scopic features, such as the presence or absence of specific morphological traits, while metric methods involve precise anatomical measurements using defined craniometric points and indices.

In this study, 14 craniometric points were placed on 3D reconstructions of the cranial CT scans from individuals in the South Bulgarian population, with both median and bilateral locations. We measured 16 linear dimensions and calculated 6 facial indices. Our results demonstrated clear sexual dimorphism across most of these linear dimensions, with men showing consistently higher average values than women, except in a few cases. These findings align with previous studies, including those by Toneva D, et al. [2, 5], who were the first in Bulgarian literature to demonstrate the effectiveness of 3D cranial reconstructions from CT scans in sex determination. Additionally, international studies by Ekizoglu et al. (2016), Techataweewan et al. (2021), Swift et al. (2023), and Gillet et al. (2020) further support our results [12, 13, 14, 15].

Our research adds to the growing evidence supporting the usefulness of craniometric analysis of 3D CT data in sex estimation, especially for the South Bulgarian population. These results not only offer valuable insights into population-specific sexual dimorphism but also provide a dependable tool for forensic and anthropological use.

CONCLUSION

Our results revealed significant sexual dimorphism in most of the linear measurements of the piriform aperture, which can be useful for a wide range of fields. The study also confirmed that CT data, especially if rendered in 3D, can provide precise and accurate morphological information.

With the development of imaging diagnostics more precise craniometric studies of people have been performed. Therefore, this allows for the available database for the Bulgarian population to be updated and supplemented. It provides essential information for facial reconstruction, preoperative examination, surgical procedures and postoperative controls.

Abbreviation list:

CT – computer tomography
PA – piriform aperture
PAH - piriform aperture height
NH - nasal height
NBL - nasal bone length
UFH - upper facial height
LFH - lower facial height
MFH - morphological facial height
SWPA - superior width of PA
IWPA - inferior width of PA
ZW - zygomatic width
BGW - bigonial width
BMW - bimental width
SW - skull width
BOW - biorbital width
IOW - interorbital width
OW - orbital width
OH - orbital height

Acknowledgements

This study is supported by the Medical University of Plovdiv, Bulgaria. This article is part of a scientific project DPDP-09/2025 “Anthropological characteristics of facial skull and piriform aperture in Bulgarian population - 3D reconstructed MSCT scans measurements”, Medical University of Plovdiv, Bulgaria.

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Please cite this article as: Todorova Z, Popova F, Angelova I, Harizanova Z, Naydenova I, Tsvetanov T. Three-Dimensional MSCT Analysis of Sexual Dimorphism in Facial Skull and Piriform Aperture Morphology in South Bulgaria. *J of IMAB.* 2025 Oct-Dec;31(3):6586-6590. [Crossref - https://doi.org/10.5272/jimab.2025314.6586]

Received: 10/07/2025; Published online: 06/11/2025

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