GENDER DIMORPHISM OF THE RELATIONSHIPS BETWEEN THE CRANIAL AND FACIAL SKULL SECTIONS IN MATURE HUMAN INDIVIDUALS

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ABSTRACT

Background. To date, the range of individual anatomical variability of the cranial profile type in mature adults, depending on gender and skull structure type has not yet been adequately established.

Aim. To study gender-specific ratios of the cranial and facial parts of the skull in mature adults.

Materials and Methods. The materials of our study consisted of 115 skulls of mature adults of both sexes, including 35 dry bone specimens of whole or fragmented skulls. For each parameter, the following metrics were calculated: The following parameters were used in the statistical analysis: $\bar{x}$ (arithmetic mean), σ (standard deviation), and $m_{\bar{x}}$ (standard error of the mean).

Results. It was found that in men the skull length is $\bar{x}$=181.36 with σ=3.31 and $m_{\bar{x}}$=0.46, while in women it does not exceed $\bar{x}$=176.57 with σ=3.28 and $m_{\bar{x}}$=0.47; the skull width in men reaches $\bar{x}$=141.17 with σ=2.62 and $m_{\bar{x}}$=0.34, and in women, it does not exceed $\bar{x}$=134.94 with σ=2.50 and $m_{\bar{x}}$=0.33; the height parameter of the skull in men also reaches maximum values at the level of $\bar{x}$=141.38 with σ=3.75 and $m_{\bar{x}}$=0.52, while in women, it is somewhat lower at $\bar{x}$=137.24 with σ=3.15 and $m_{\bar{x}}$=0.55. In mature men, the upper facial width is $\bar{x}$=94.17 with σ=3.87 and $m_{\bar{x}}$=0.50, while in women, this parameter averages $\bar{x}$=90.71 with σ=4.05 and $m_{\bar{x}}$=0.54; the middle width in men reaches $\bar{x}$=128.93 with σ=1.53 and $m_{\bar{x}}$=0.20, while in women, it does not exceed $\bar{x}$=122.49 with σ=1.44 and $m_{\bar{x}}$=0.19; the maximum indicators of angular width are established in men, averaging $\bar{x}$=99.64 with σ=4.15 and $m_{\bar{x}}$=0.54, while in women, they do not exceed $\bar{x}$=92.27 with σ=3.78 and $m_{\bar{x}}$=0.51.

Conclusions. The study identified significant gender-specific differences in the cranial and facial dimensions of middle-aged individuals. Men demonstrated larger average values for skull length, width, and height, as well as upper face width, bizygomatic width, and angular width, compared to women. These findings highlight distinct morphological characteristics between genders.

Keywords: *computed tomography, cranial index, face width, face length, face height.*

Introduction

To date, the full range of individual anatomical variability in the cranial profile of mature adults, depending on gender and skull type, has not been adequately established. The bony structure of the human skull shows immense diversity in its sections, bones, apertures, and channels, with insufficiently studied variability ranges according to age, gender, and individual head shape.

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Building on the classic works of renowned scientists [1; 2], new perspectives and morphological aspects are emerging to refine cranial metrics [3–5]. The goal of cranial metric research is to determine the position of the jaws relative to the plane of the anterior part of the skull base, identify facial types, and detect deviations from the average sizes characteristic of normal occlusion for the same type [6; 7].

With the rapid advancements in maxillofacial surgery, surgical and orthodontic dentistry, reconstructive surgery, and modern prosthetic methods, there is a growing need for more detailed cranio- and morphometric data. Such research is essential to justify and develop optimal diagnostic methods for treating individuals with craniofacial pathology. The study of cranial structures in the facial

and brain sections of individuals of different genders is particularly pressing.

The number of studies on gender-specific features of the facial and cranial sections, especially using computed tomography, remains insufficient despite the relevance of the topic. Currently, notable works by both domestic and foreign authors exist on this subject. The results of a pilot study by Milella M. et al. [8] are of interest, confirming sexual dimorphism in cranial structure, albeit on a small sample size.

A significant contribution to the field is the work by Toneva D. et al. [9], which shows that dimensions, rather than the form, of the facial skull exhibit the greatest variability by sex. Their study also demonstrated significant sexual dimorphism in the nasal region of the facial skull. Furthermore, these authors showed age-related variations in the structure of the lower jaw section of the skull. Their findings established sexual dimorphism in the structure of the mastoid process area [10].

Works by Ukrainian scientists are also well-recognized. The studies of Vovk Y.M. [11] regarding skull structure have become foundational to modern cranial metric studies and constitute a cornerstone of human anatomy research. The works of Speransky A.D. [12] and Sinelnikov R.D. [13] have retained their relevance, supplemented by results from studies using advanced diagnostic methods, particularly computed tomography [14].

Therefore, despite the importance of the topic, many questions about gender dimorphism in the structure of the facial and cranial skulls remain unanswered and require further investigation.

Considering all the above, the **aim** of our work is to study the gender-specific features of the relationships between the cranial and facial sections of the skull in mature adults.

Materials and Methods

The material for our study consisted of 115 skulls from mature adults of both genders. This included 35 dry bone specimens of complete or fragmented skulls from the museum collection of the Department of Human Anatomy, Clinical Anatomy, and Operative Surgery at Kharkiv National Medical University (KhNMU). Additionally, 80 human head Computed Tomography (CT) scan results, free of bone tissue pathology, were collected from diagnostic centers based on cooperation agreements with the Department of Human Anatomy, Clinical Anatomy, and Operative Surgery at the KhNMU. The distribution of the specimens by gender is presented in *Table 1*.

Table 1. The distribution of the specimens by gender

Material of the study	Person by gender	
	Male	Female
Complete skull bone specimens	8	7
Fragmented skull bone specimens	11	9
Computed tomography images	40	40
Total	59	56

Our research was carried out following the recommendations on "Compliance with ethical and legislative norms and requirements in conducting scientific morphological research". These conclusions indicate that the materials presented for examination are scientifically substantiated, the research methods described in the study were used in compliance with human rights according to the current legislation in Ukraine, meet international ethical requirements, and do not violate ethical standards in science and biomedical research.

For the study, mature adult representatives of both genders were selected: men aged 22 to 60 years; women aged 21 to 55 years (according to the classification of age periodization of human life recommended by the Ministry of Health of Ukraine (Letter No.08.01-22/2472 dated December 9, 2008)).

Moreover, the material for our research had an almost equal gender distribution: 59 male skulls and 56 female skulls, which allowed for the establishment of certain patterns and reliable differences among the parameters studied depending on gender.

Cranial metric studies of CT scan results were conducted using measurement blocks of computer programs used for tomogram analysis and 3D reconstructions. Licensed versions of such programs are always available on the tomograph and allow for the precise measurement of the bony structure of the head. In our cranial metric studies, the following programs were used:

1. Ez3D Plus 3D, version 1.2.0.5 (E-WOO Technology Co., South Korea) – the 3D imaging and analysis software for precise tomogram measurement and visualization;

2. DICOM Vidar Dicom Viewer version 4.2 (VIDAR Systems Corporation, USA) – a medical image viewer designed for detailed evaluation of DICOM-format files;

3. eFilmLite, version 3.4 (Merge Healthcare, USA) – the lightweight diagnostic imaging software for reviewing and analyzing medical images in the DICOM format.

All anatomical structures, being three-dimensional objects, have three main dimensions: length, width, and height, corresponding to the three basic anatomical planes (sagittal, frontal, and horizontal). For the entire skull, length is the distance between the glabella (gl) and opisthocranion (op) points; width is the dimension between the right and left euryon (eu) points; height is the measurement between the bregma (b) and basion (ba) points.

For the facial part of the skull, two height calculations can be distinguished: overall height, the dimension between the nasion (n) and gnathion (gn) points; upper part height, the distance from the nasion (n) to the prosthion (pr). For the width dimensions of the face, the most appropriate measurements are: upper face width, the distance between the right and left frontomalar-temporal points (fmt-fmt); zygomatic diameter, the distance between the right and left zygion (zy-zy) points; and mandibular width, the distance between the right and left gonion (go-go) points.

In our study, the statistical processing of the obtained results was carried out using the computer programs Statistica 13.5.0.17 (TIBCO, USA) for Excel 365 (Microsoft, USA). For each parameter obtained, calculations were performed for the arithmetic mean ($\bar{x}$), standard deviation (σ), and the error of the arithmetic mean ($m_{\bar{x}}$). All obtained and described indicator values were considered reliable at $p<0.05$, and Pearson correlation analysis was performed for a series of samples.

Results and Discussion

Our research established the characteristics of the profile cranio-metric features of the facial section of the skull. The diverse dimensions that address this question, combined with the close interaction between different sections of the skull, necessitate, first and foremost, the study of the existing relationships between the cranial and facial sections of the bony structure of the head. The existing range of indicators for the main linear dimensions of the skull has been established, with the results presented in *Table 2*.

For mature men, the skull length ranged from 169 mm to 192 mm, while for women, this parameter is within 162 mm to 187 mm. In turn, the skull width for men varied from 128 mm to 152 mm, and for women, it ranges from 122 mm to 144 mm. The skull height for men was between 129 mm and 151 mm, while for women, it was between 127 mm and 147 mm.

Table 2. The main linear dimensions of the skull (mm)

Size \ Gender	Male	Female
Skull length (g-op)	169–192	162–187
Skull width (eu-eu)	128–152	122–144
Skull height (b-ba)	129–51	127–147

Notes:

g-op – skull length (distance from the glabella to the opisthocranion);

eu-eu – skull width (maximum cranial breadth, measured between the most lateral points of the parietal bones);

b-ba – skull height (distance from the basion to the bregma).

Thus, there was a slight but clearly defined trend indicating that the main linear dimensions were generally larger in males. To confirm this observation, a statistical analysis of the obtained data was conducted, with the results presented in *Table 3*.

It was established that in men the skull length was $\bar{x}=181.36$ mm with $\sigma=3.31$ and $m_{\bar{x}}=0.46$, while in women it did not exceed $\bar{x}=176.57$ mm with $\sigma=3.28$ and $m_{\bar{x}}=0.47$. The skull width in men reached $\bar{x}=141.17$ mm with $\sigma=2.62$ and $m_{\bar{x}}=0.34$, and for women, it was not more than $\bar{x}=134.94$ mm with $\sigma=2.50$ and $m_{\bar{x}}=0.33$. The height parameter of the skull in males also reached maximum values at $\bar{x}=141.38$ mm with $\sigma=3.75$ and $m_{\bar{x}}=0.52$, while in females it was somewhat smaller at $\bar{x}=137.24$ mm with $\sigma=3.15$ and $m_{\bar{x}}=0.55$.

Analysis of the statistically substantiated data leads to the conclusion that the main linear parameters of the skull are clearly dependent on gender. The longitudinal and transverse parameters are significantly larger in men. with a difference in averages up to 5-6 mm, while the height parameter does not show such a significant difference, although it is still larger in men by more than 4 mm.

To visually demonstrate the observed features of the shapes and sizes, our study used comparisons of 3D models of skull structures built with tomographic computer programs used during examinations. For instance, the established difference in the main linear dimensions of the skull in mature adults depending on gender is illustrated in *Figure 1*.

Table 3. Statistical indicators of the skull size of a mature person

Size \ Statistical indicator	Male			Female		
	$\bar{x}$	σ	$m_{\bar{x}}$	$\bar{x}$	σ	$m_{\bar{x}}$
Skull length (g-op)	181.36	3.31	0.46	176.57	3.28	0.47
Skull width (eu-eu)	141.17	2.62	0.34	134.94	2.50	0.33
Skull height (b-ba)	141.38	3.75	0.52	137.24	3.15	0.55

Notes:
g-op – skull length (distance from the glabella to the opisthocranion);
eu-eu – skull width (maximum cranial breadth, measured between the most lateral points of the parietal bones);
b-ba – skull height (distance from the basion to the bregma);
$\bar{x}$ – arithmetic mean (average of the measurements);
σ – standard deviation (indicating the variability of the data);
$m_{\bar{x}}$ – standard error of the mean (representing the precision of the mean estimate).

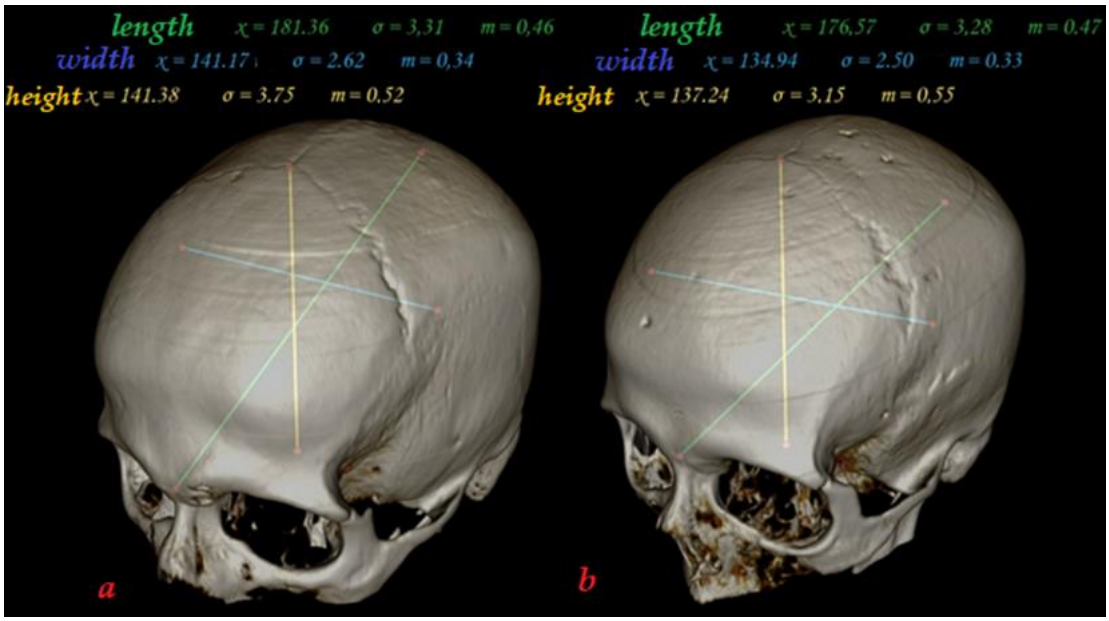

Fig. 1. Gender characteristics of the main linear dimensions of the skull of a mature person: *a* – male. *b* – female (CT No.1875-16; CT No.957-16)

Transverse dimensions play a significant role in understanding the relationships between different sections of the skull. For such a comparison the width of the skull (eu-eu) was taken from the cranial section. Three dimensions were taken from the facial section: upper facial width (fmt-fmt), middle or overall facial width (zy-zy), and lower mandibular width. also known in craniology as the gonial width (go-go). The number of transverse facial dimensions is due to the main objective of our study. The obtained range of these dimensions is presented in *Table 4*.

Table 4. Main transverse dimensions of the human skull in mature adults (mm)

Size \ Gender	Male	Female
eu-eu	128–152	122–144
fmt-fmt	85–102	81–97
zy-zy	110–142	104–135
go-go	87–113	84–102

According to our data, the upper facial width ranges from 85 mm to 102 mm in men, while in

women it ranges from 81 mm to 97 mm. The overall facial width also showed maximum values in men, ranging from 110 mm to 142 mm compared to the range of 104 mm to 135 mm in women.

The lower mandibular width in men varied from 87 mm to 113 mm, whereas in women, it ranged from 84 mm to 102 mm.

Compared to the previously described width of the cranial section, it can be asserted that the transverse dimensions of both sections tend to be larger in males. This thesis was confirmed by the results of the statistical analysis of the obtained data (*Table 5*). A visual representation of this established feature is presented in *Figure 2*.

Table 5. Statistical indicators of the transverse dimensions of the skull

Size \ Gender		Male	Female
eu-eu	$\bar{x}$	141.17	134.94
	σ	2.62	2.50
	$m_{\bar{x}}$	0.34	0.33
fmt-fmt	$\bar{x}$	94.17	90.71
	σ	3.87	4.05
	$m_{\bar{x}}$	0.50	0.54
zy-zy	$\bar{x}$	128.93	122.49
	σ	1.53	1.44
	$m_{\bar{x}}$	0.20	0.19
go-go	$\bar{x}$	99.64	92.27
	σ	4.15	3.78
	$m_{\bar{x}}$	0.54	0.51

Notes:
eu-eu – maximum cranial breadth (measured between the most lateral points of the parietal bones);
fmt-fmt – minimum frontal breadth (measured between the most lateral points of the frontal bones);
zy-zy – bizygomatic breadth (distance between the most lateral points of the zygomatic arches);
go-go – bigonial breadth (distance between the most lateral points of the mandibular angles);
$\bar{x}$ – arithmetic mean (average of the measurements);
σ – standard deviation (measure of data variability);
$m_{\bar{x}}$ – standard error of the mean (indicates the precision of the mean estimate).

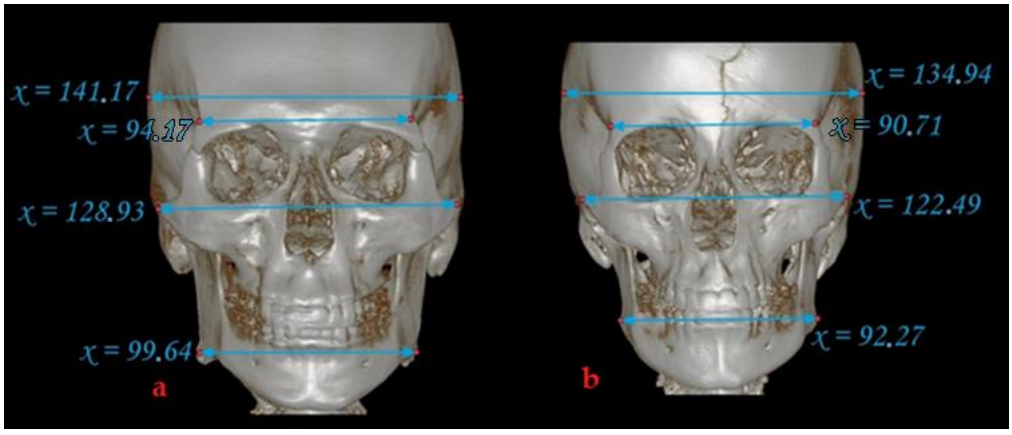

Fig. 2. Gender features of the main cross-sectional dimensions of a mature skull:
a – male, *b* – female (CT No.630700; CT No.650423)

It has been determined that in middle-aged men. the upper face width is $\bar{x}$=94.17 with σ=3.87 and $m_{\bar{x}}$=0.50, while in women this parameter has an average value of $\bar{x}$=90.71 with σ=4.05 and $m_{\bar{x}}$=0.54. The average width in men reaches $\bar{x}$=128.93 with σ=1.53 and $m_{\bar{x}}$=0.20, whereas in women it does not exceed $\bar{x}$=122.49 with σ=1.44 and $m_{\bar{x}}$=0.19. The maximum angular width indicators are found in males averaging $\bar{x}$=99.64 with σ=4.15 and $m_{\bar{x}}$=0.54, while in females they do not exceed $\bar{x}$=92.27 with σ=3.78 and $m_{\bar{x}}$=0.51. Similar trends were observed for the overall skull width.

Based on the obtained numerical characteristics it can be stated that regardless of the part of the skull. transverse dimensions are significantly dependent on gender, with all sizes in this direction predominantly larger in men, with average variations ranging from 4 to 7 mm.

Our research provides one of the first comprehensive studies of gender-specific differences in the relationship between the cranial and facial sections of the human skull in mature adults. We compared the findings obtained from dry bone specimens of whole or fragmented skulls from the museum collection of the Department of Human Anatomy, Clinical Anatomy, and Operative Surgery with those derived from CT scans. Previous studies have typically focused either on bone specimens [15] or on CT imaging results [16]. The unique value of combining these methods lies in the ability to compare the results and suggest that CT results might approach the accuracy of measurements obtained from native skull specimens.

Our findings suggest that CT scans can provide measurements of cranial structure that are nearly as accurate as those obtained from traditional bone specimens. With the widespread adoption of advanced diagnostic techniques and the integration of 3D modeling into routine medical practice, our study could serve as a foundational resource for developing 3D models of the human skull that account for gender-specific differences. Such 3D models could be valuable educational tools for teaching anatomy to students and interns. Additionally, 3D models that account for gender differences in skull structure could be used to prepare specialists (neurosurgeons, ophthalmologists, otolaryngologists, etc.) for surgical procedures, aiding in the selection of surgical approaches and planning of operational stages.

The identified gender dimorphism in cranial and facial structure can be beneficial for surgical planning in these areas. Furthermore, our research results could be valuable in forensic medicine for identifying individuals. Additionally, these findings not only enhance our understanding of human anatomy but also have potential applications in anthropology for refining knowledge about human origin, gender, and racial characteristics.

Conclusions

As a result of the conducted study, data were obtained on the gender-specific characteristics of the cranial and facial regions of the skull in middle-aged individuals. It was found that in men, the skull length is $\bar{x}$=181.36 with σ=3.31 and $m_{\bar{x}}$= =0.46, while in women, it does not exceed $\bar{x}$= =176.57 with σ=3.28 and $m_{\bar{x}}$=0.47. The skull width in men reaches $\bar{x}$=141.17 with σ=2.62 and $m_{\bar{x}}$=0.34, while in women, it is no more than $\bar{x}$= =134.94 with σ=2.50 and $m_{\bar{x}}$=0.33. The height parameter of the skull in men also reaches maximum values at $\bar{x}$=141.38 with σ=3.75 and $m_{\bar{x}}$=0.52, while in women, it is somewhat lower at $\bar{x}$=137.24 with σ=3.15 and $m_{\bar{x}}$=0.55.

In middle-aged men, the upper face width is $\bar{x}$=94.17 with σ=3.87 and $m_{\bar{x}}$=0.50, while in women, this parameter has an average value of $\bar{x}$= =90.71 with σ=4.05 and $m_{\bar{x}}$=0.54. The average width in men reaches $\bar{x}$=128.93 with σ=1.53 and $m_{\bar{x}}$=0.20, whereas in women it does not exceed $\bar{x}$=122.49 with σ=1.44 and $m_{\bar{x}}$=0.19. The maximum angular width indicators are found in males, averaging $\bar{x}$=99.64 with σ=4.15 and $m_{\bar{x}}$=0.54, while in females they do not exceed $\bar{x}$=92.27 with σ=3.78 and $m_{\bar{x}}$=0.51.

DECLARATIONS:

Disclosure Statement

The authors have no potential conflicts of interest to disclosure, including specific financial interests, relationships, and/or affiliations relevant to the subject matter or materials included.

Statement of Ethics

The authors have no ethical conflicts to disclosure.

Data Transparency

The data can be requested from the authors.

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Consent for publication

All authors give their consent to publication.

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