

MORPHOMETRIC ANALYSIS OF LARGER OPENINGS OF THE GREATER WING OF THE HUMAN SPHENOID BONE

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Analysis of the anatomical characteristics of openings in the greater wing of the sphenoid bone (round, oval and spinous opening – FR, FO and FS) has a clinical significance in surgical and diagnostic procedures. The aim of the study was to examine the morphological and morphometric characteristics of the round, oval and spinous openings in the human skulls. The research was conducted on 20 skulls housed at the Institute of Anatomy of the Faculty of Medicine in Niš. The skulls were numerated, and the openings were photographed against the ruler with a Canon A470 camera. Photo processing and morphometric analysis (measuring the length and width of the FR, FO and FS) were performed using ImageJ software. The average length of the FR on the right was 3.14 ± 0.77 mm and 3.44 ± 0.65 mm on the left, width on the right was 2.38 ± 0.58 mm, 2.61 ± 0.55 mm on the left; length of the FO on the right was 5.88 ± 0.88 mm, 5.50 ± 1.06 mm on the left, width on the right was 2.70 ± 0.58 mm, 2.82 ± 0.68 mm on the left; length of the FS on the right was 1.65 ± 0.27 mm, 1.73 ± 0.49 mm on the left, width on the right was 1.32 ± 0.32 mm, and 1.20 ± 0.39 mm on the left. The t-test of independent samples determined no statistically significant difference neither between the parameters on both sides, nor between the measured parameters of the same openings. A moderate positive correlation existed between FS length and width on the left, FR length and width on the right and between FS widths on both sides; a negligible positive correlation between the length and width of FO on the right and between lengths of the FS on both sides; a weak positive correlation existed between other measured parameters.

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Key words: round opening, oval opening, spinous opening, greater wing of the sphenoid bone

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Introduction

The greater wing (*ala major*) is a paired extension of the sphenoid bone. Its inner surface forms most of the floor of the middle cranial fossa (1, 2, 3). The greater wing originates from the lateral surface of the body of the sphenoid bone by three roots: front, middle and back root. It contains openings for the passage of vital neurovascular elements. Variants of these openings have been des-

cribed in the anatomical and radiological literature, which is important both for understanding complex regional neurovascular anatomy and for differentiating normal from potentially abnormal structures (4). Between the front and middle roots of the greater wing, there is the foramen rotundum (FR), a communication between the middle cranial fossa and the pterygopalatine fossa. The maxillary nerve leaves the skull through this opening along with the venous plexus that surrounds it. The cavernous sinus, which lies in the skull, and the pterygoid plexus, which is outside the skull, are connected via the foramen rotundum (5, 6). The opening can communicate with the superior orbital fissure and its contents since it is located below and behind its inner part (2, 7). In a small percentage of cases a lateral rotundal canal, opened to the infratemporal fossa, may be present laterally from the FR. Although the nature of this canal has not been fully elucidated, it is thought that an emissary vein passes through it (8). Between the middle and posterior roots of the greater wing, posterolaterally from the FR and outside from the foramen lacerum, there is the foramen ovale (FO). It is a communication between the middle cranial fossa and the infratemporal fossa

through which the mandibular nerve and occasionally the lesser petrosal nerve exit the skull, while the accessory branch of the maxillary artery enters it (5, 9, 10, 11). Located in the transition zone between intracranial and extra cranial structures, the FO has great clinical significance as an approach during surgical, radiological and radiotherapy treatments (like in trigeminal neuralgia), as well as in various diagnostic procedures (11, 12). In neurosurgery, it is important in terms of micro vascular decompression of the trigeminal nerve (trigeminal rhizotomy). Knowledge of the topography and variation of the FO can be of great importance in the prevention of damage of the trigeminal nerve during mentioned interventions. Knowing the position of this opening is also important in a percutaneous biopsy of cavernous sinus tumors (13). Also, the oval opening is the most common site of the nasopharyngeal cancer spread (11). In addition to the FO, a venous opening (foramen Vesalius) or several small openings for the passage of venous blood vessels may be present (6). If absent, small veins pass through the oval foramen (7). In the outer part of the posterior margin of the greater wing, on the spine of the sphenoid bone, there is the foramen spinosum (FS), placed posterolaterally of the oval opening. It is a communication between the middle cranial fossa and the infratemporal fossa (2, 3, 8). Through the FS, the middle cerebral artery and the meningeal branch of the mandibular nerve enter the

skull (4, 5). Proximity of the FS to the FO can make the middle cerebral artery susceptible to iatrogenic injury during percutaneous trigeminal rhizotomy and anesthesia of the mandibular nerve and increase the risk of developing extradural hematomas (14, 15).

Knowing the variability of the size of the mentioned openings, as well as their mutual relations can greatly facilitate numerous diagnostic interventions, and at the same time prevent complications. That's why the aim of the research was to examine the morphological and morphometric characteristics of the FR, FO and FS and to contribute to the knowledge of their representation and possible variations.

Materials and methods

The research was conducted on 20 dried adult human skulls obtained from the Institute of Anatomy, Faculty of Medicine in Niš. All the skulls were numerated. The FR, FO and FS were photographed next to the ruler with a Canon A470 7 Mpix camera. The obtained photographs were processed in the "ImageJ" program for processing and analysis of photographs. Morphometric analysis was performed in the same program (Figures 1, 2 and 3). The values of the length and the width of the FR, FO and FS were processed with the graph-analytical and tabular data processing program "Microsoft Office Excel".

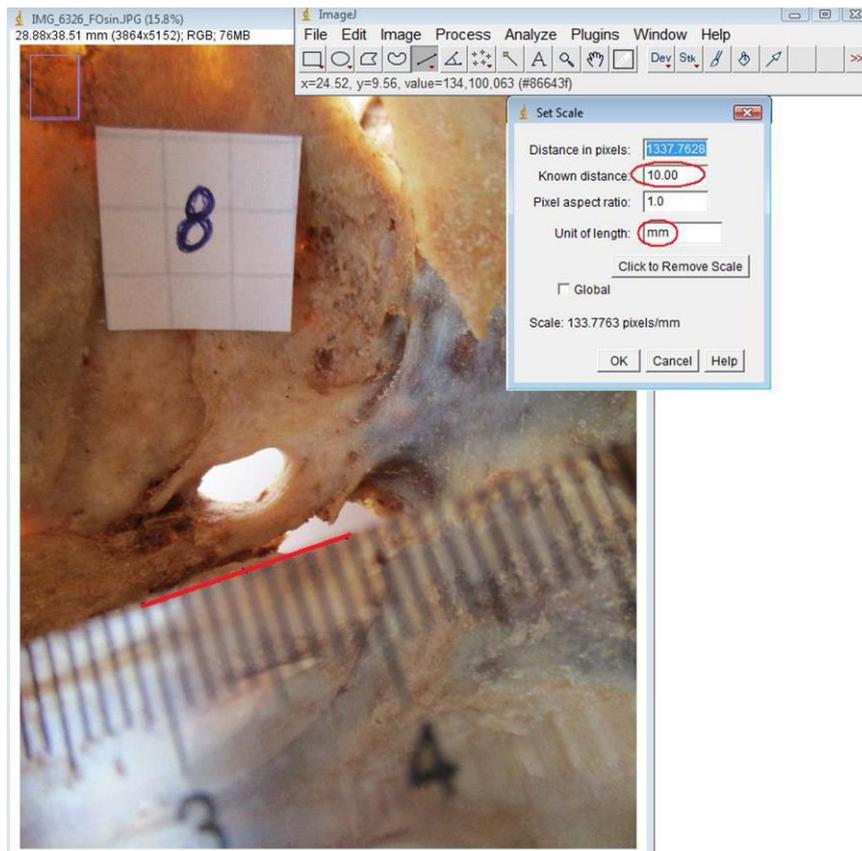


Figure 1. Setting the unit of measurement using ImageJ software

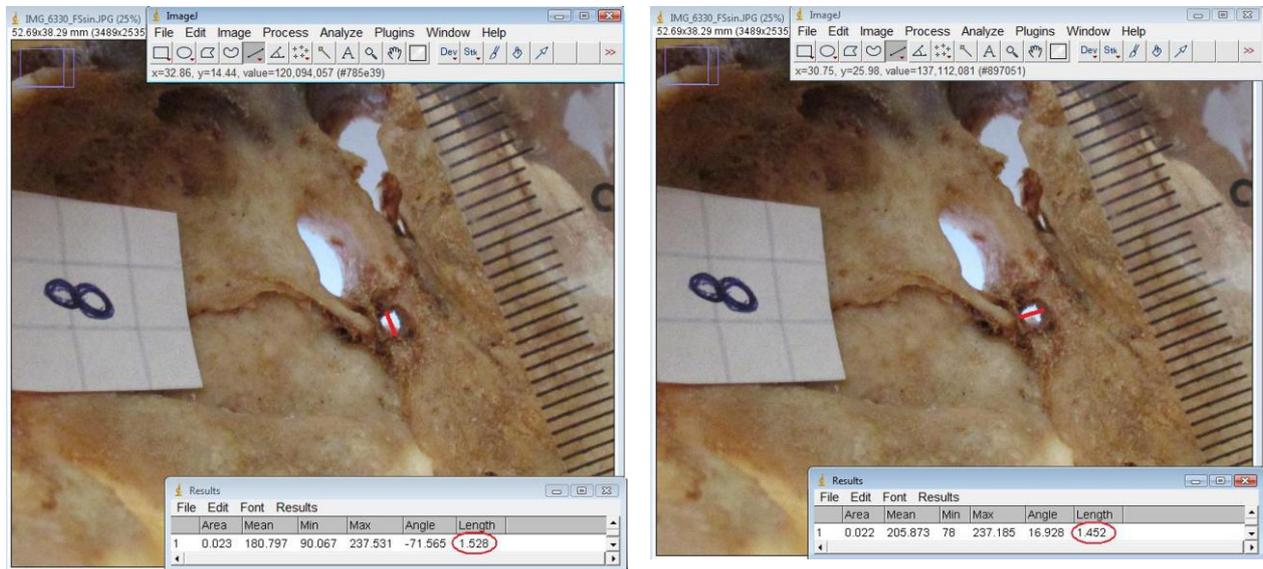


Figure 2. Procedure for measuring the length and width of the foramen spinosum

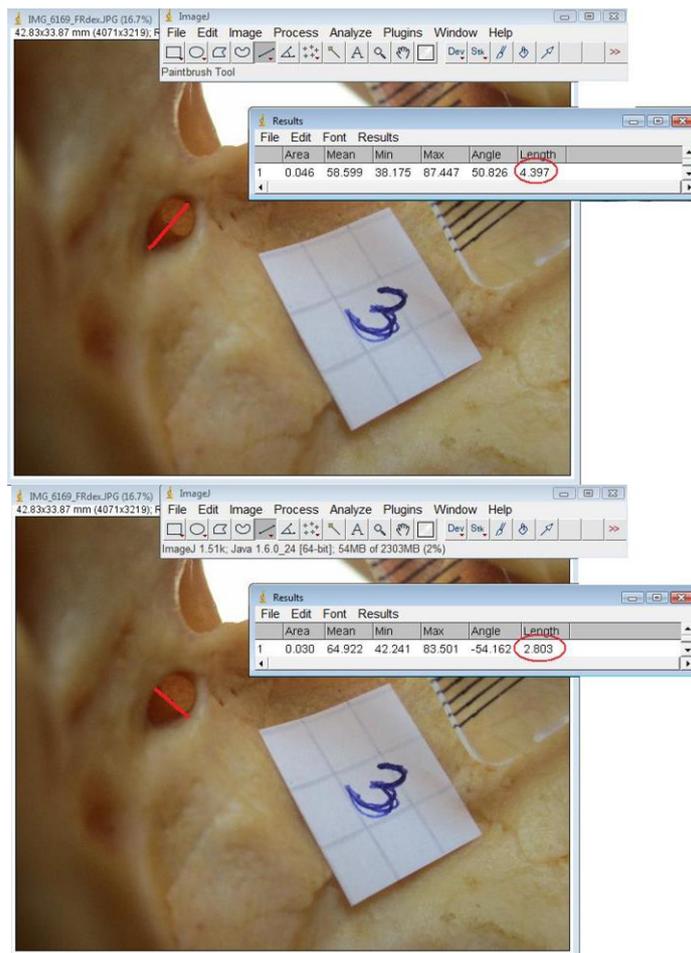


Figure 3. Procedure for measuring the length and width of the foramen rotundum

Results

In our study, the FR, FO and FS were present in all cases and on both sides. The values of the measured parameters and their mean values ($\bar{X} \pm SD$) are shown in the Tables 1 and 2. Statistically significantly reduced or increased values were marked in the tables: all values less than $\bar{X} - SD$ in blue and the ones greater than $\bar{X} + SD$, in red.

The average length of the FR on the left side was 3.44 mm, the maximal length was 4.41 mm, the minimal 2.29 mm. On the right side, the average length was 3.14 mm, the maximal 4.49 mm and the minimal 1.90 mm. The average FR width on the left was 2.61 mm, the maximal 3.63 mm and the minimal 1.48 mm. The average width of the FR on the right side was 2.38 mm, the maximal 3.43 mm and the minimal 1.51 mm. In 75% of cases, the FR was slightly oval in shape, in the rest almost round, with the dimensions which differed just in the decimals of mm. In most cases (65%), the FR was longer on the left, wider on the right (55% of cases).

The average length of the FO on the left side was 5.50 mm, the maximal 7.54 mm and the

minimal 3.25 mm. On the right, the average length of the FO was 5.88 mm, the maximal being 8.30 mm and a minimal 4.52 mm. In terms of width, the average value on the left was 2.82 mm, the maximal 4.36 mm and the minimal 1.54 mm. The average width of the FO on the right was 2.70 mm, the maximal 3.72 mm and a minimal 1.42 mm. The right FO were longer in 70% of cases while the left ones were wider in the 75% of cases.

The average length of the FS on the left side was 1.73 mm, the maximal 2.79 mm and the minimal 0.84 mm. On the right, the average length of the FS was 1.65 mm, the maximal 2.27 mm and a minimal of 0.81 mm. The average width of the FS on the left side was 1.20 mm, the maximal 1.92 mm and a minimal 0.54 mm. On the right side, the average width of the FS was 1.32 mm, the maximal 2.07 mm and a minimal 0.78 mm. In 25%, FS were almost round, differing in the decimals of the mm only, while in the rest 75% of cases they were slightly oval in shape. The lengths of FS were equally large on both sides, the widths larger on the right in 65% of cases.

Table 1. Values of measured parameters (mm) on the left side and their mean values ($\bar{X} \pm SD$)

No.	Left side					
	FR length	FR width	FO length	FO width	FS length	FS width
1	4.41	2.57	4.66	2.35	1.40	1.08
2	2.49	2.11	5.10	1.54	1.76	1.10
3	3.66	2.58	5.24	2.78	1.96	1.09
4	2.41	2.17	4.89	2.67	1.53	0.74
5	3.88	2.60	4.09	2.87	1.14	0.78
6	3.79	2.66	5.45	2.27	0.84	0.56
7	3.98	2.39	5.64	2.90	1.07	0.54
8	2.71	1.48	6.14	2.16	1.97	1.33
9	3.33	3.61	3.84	2.43	1.79	1.71
10	4.12	2.92	6.27	4.36	1.67	1.14
11	4.32	3.03	6.91	3.15	1.65	1.43
12	2.29	2.14	3.25	1.91	1.85	1.74
13	3.34	3.09	5.59	3.07	1.84	1.51
14	3.12	1.92	4.91	2.13	1.34	1.00
15	3.15	2.09	6.04	3.53	1.49	0.98
16	3.24	2.33	5.71	3.27	2.25	1.58
17	3.78	2.78	5.81	3.09	2.42	1.12
18	3.68	3.63	7.54	3.20	2.79	1.49
19	2.90	2.93	6.11	3.93	2.49	1.92
20	4.17	3.10	6.90	2.85	1.41	1.17
\bar{X}	3.44	2.61	5.50	2.82	1.73	1.20
SD	0.65	0.55	1.06	0.68	0.49	0.39
$\bar{X} + SD$	4.08	3.16	6.56	3.50	2.23	1.59
$\bar{X} - SD$	2.79	2.06	4.44	2.14	1.24	0.81

Table 2. Values of measured parameters [mm] on the right side and their mean values ($\bar{X} \pm SD$)

No.	Right side					
	FR length	FR width	FO length	FO width	FS length	FS width
1	3.90	2.70	6.11	1.58	1.64	0.82
2	2.67	1.87	4.82	1.42	1.64	1.27
3	4.37	3.43	6.21	2.20	1.55	1.40
4	2.68	2.18	4.52	2.14	1.67	0.78
5	2.87	1.93	5.31	2.83	1.97	1.28
6	2.21	1.51	6.33	3.01	0.81	0.85
7	3.34	2.12	5.52	2.61	1.89	1.19
8	1.90	1.62	6.46	2.79	1.79	1.41
9	3.27	2.23	4.96	3.26	1.82	1.24
10	2.26	3.02	6.44	2.52	1.62	1.53
11	3.04	1.68	8.30	3.41	1.69	1.39
12	3.47	2.35	4.54	3.19	1.57	1.56
13	4.49	3.26	6.59	2.81	1.55	1.84
14	2.54	1.95	5.62	2.57	1.71	1.48
15	3.10	2.27	6.21	3.44	1.60	1.41
16	2.64	2.36	6.27	3.72	1.67	1.53
17	4.24	3.42	6.10	2.74	1.40	1.00
18	2.91	2.71	5.09	2.82	1.52	1.11
19	2.56	2.12	6.06	2.64	2.27	2.07
20	4.26	2.79	6.24	2.28	1.60	1.19
\bar{X}	3.14	2.38	5.88	2.70	1.65	1.32
SD	0.77	0.58	0.88	0.58	0.27	0.32
$\bar{X}+SD$	3.90	2.96	6.76	3.28	1.92	1.64
$\bar{X}-SD$	2.37	1.79	5.01	2.11	1.38	0.99

Table 3 shows the numbers of skulls with statistically significantly increased ($> \bar{X} + SD$), or statistically significantly reduced ($< \bar{X} - SD$) values.

T-test for independent samples revealed absence of statistically significant difference of the corresponding parameters on the right and left sides. These results are shown in the Table 4.

The results of the correlation analysis between the measured parameters of the same openings are shown in the Table 5. A moderate positive correlation existed between the length and width of the FS on the left and between the length and width

of the FR on the right side. There was a negligible positive correlation between the length and width of the FO on the right side. Among all other measured parameters, a weak positive correlation was noted.

The results of the correlation analysis among the same measured parameters on different sides are shown in the Table 6. There was a positive correlation between all parameters, but it was of negligible strength for the length of FS between left and right sides, moderate for the width of FS between left and right sides, and also weak for all other parameters of the measured openings.

Table 3. Number of skulls with significantly increased or decreased values of measured parameters (l – length; w – width)

	Left side						Right side					
	F R l	F R w	F O l	F O w	F S l	FS w	F R l	F R w	F O l	F O w	F S l	F S w
$> \bar{X}+SD$	4	3	3	3	4	4	4	4	1	3	2	2
$< \bar{X}-SD$	4	2	3	3	3	4	3	3	4	2	1	4

Table 4. Comparison of measured parameters on the right and left side

Measured parameter		$\bar{X} \pm SD$	p
Left side	FR length [mm]	3.44 ± 0.65	0.187
Right side	FR length [mm]	3.14 ± 0.77	
Left side	FR width [mm]	2.61 ± 0.55	0.204
Right side	FR width [mm]	2.38 ± 0.58	
Left side	FO length [mm]	5.50 ± 1.06	0.223
Right side	FO length [mm]	5.89 ± 0.88	
Left side	FO width [mm]	2.82 ± 0.68	0.540
Right side	FO width [mm]	2.70 ± 0.59	
Left side	FS length [mm]	1.73 ± 0.50	0.510
Right side	FS length [mm]	1.65 ± 0.27	
Left side	FS width [mm]	1.2 ± 0.39	0.301
Right side	FS width [mm]	1.32 ± 0.32	

Table 5. The correlation coefficient between measured parameters of the same openings (l – length; w – width)

Side	Compared parameters	r
Left side	FR l : FR w	0.516
	FO l : FO w	0.539
	FS l : FS w	0.729
Right side	FR l : FR w	0.741
	FO l : FO w	0.288
	FS l : FS w	0.505

Table 6. The correlation coefficient between measured parameters of the same openings on both sides (l – length; w – width)

Parameter	Compared sides	r
FR l	Left side: Right side	0.323
FR w	Left side: Right side	0.387
FO l	Left side: Right side	0.566
FO w	Left side: Right side	0.319
FS l	Left side: Right side	0.226
FS w	Left side: Right side	0.639

Discussion

The greater wing of the sphenoid bone contains several openings. The FR, FO and FS are permanent and connect the middle cranial fossa with the pterygopalatine fossa (FR) and the infra temporal fossa (FO and FS) and convey significant neurovascular elements (16). The studies of the size and shapes of these foramina have not only anatomical

but also clinical importance during evaluation of radiologic images, then a profound surgical importance such as in percutaneous trigeminal rhizotomy and transfacial fine-needle aspiration and also a diagnostic importance in tumors and in electroencephalographic analysis of seizures in some types of epilepsy (17). Only scattered reports of the size and variations of these foramina are available in the literature.

The foramen rotundum is located in the root of the greater wing of the sphenoid bone, lateral to the lower part of the superior orbital fissure. It serves as a passage for the maxillary nerve and also contains venous plexus which surrounds the nerve and links the cavernous sinus with the pterygoid plexus lying outside the skull.

In our investigation, the FR was always present and its morphology did not show essential variability. Although its name indicates a round shape, it was most often (in 75% cases) slightly oval in shape. The average dimensions of the FR on the left were 3.44x2.61 mm, while on the right they were 3.14x2.38 mm. According to the average dimensions, the left FR were larger than the right ones. The left FR were longer in 65.00% of cases while the right ones were wider in 55.00% of cases. We did not determine the existence of statistically significant difference between the measured parameters on the left and right side. There was a weak positive correlation between the parameters of the different sides. Other authors have reached similar dimensions in their researches. Thus, Shapiro and Robinson (7) found the dimensions of FR ranging from 3x3 mm to 4x5 mm, Sepahdari and Mong (18) 3.00 mm and Kumar et al. (16) 3.11 mm. There was no statistically significant difference between the parameters of the left and right side, neither in the investigations of the mentioned authors nor in the research of Kocaogullar et al. (19) and Reymond et al. (6). Some researchers have described rare variations in the shape and position of the FR. Double FR was described by Sepahdari and Mong (18), and occurred in cases of double maxillary nerve. Rusu (20) observed a canal lateral to the foramen rotundum that could not clearly be linked to it in 8% of patients. He proposed calling it the lateral rotundal canal. Uncommon congenital asymmetry, enlarged FR was also observed. It is expected in a lesion or a tumor of the maxillary nerve. Anomalous enlargement of the foramen may be distinguished from pathologic erosion by the presence of well-defined margins (7).

The foramen ovale is the largest opening located in the root of the greater wing of the sphenoid bone. It conveys mandibular nerve and the accessory meningeal artery, occasionally lesser petrosal nerve and an emissary vein. The foramen ovale is situated at the transition zone between the intracranial and the extracranial structures, therefore, it is used as a passageway to the intracranial structures during the invasive surgical or diagnostic procedures (12, 17). Variations of the size and shape of the FO could affect transcutaneous needle placement into it or distort anatomic relationships during approaches to the cranial base. Therefore, knowledge of the exact topography, shape and size of this opening is of great clinical importance.

In our study, the average sizes of the FO on the left and right sides were 5.50x2.82 mm and 5.88x2.70 mm, respectively. The length of the opening, in most cases, was larger on the right side (70.00%), and the width was larger on the left side in 75.00% of cases. We did not find statistically significant difference between the measured parameters on the right and left side. The lengths of the FO

were greater than the width in all cases, so they were clearly elongated in shape. There was a positive correlation and it was of medium strength for the length of the FO and for the width of this opening, too. Mean FO dimensions in our cases were similar to those in the studies of Reymond et al. (6) and Sepahdari and Mong (18), while in the studies of Ray et al. (12), Osunwoke et al. (21), Nirupma and Anju (22), Patil et al. (13), Murugan and Saheb (23) and Kuppasad et al. (24), they were larger. There was not statistically significant difference between the measured parameters on the right and left side in the researches of Reymond et al. (6), Osunwoke et al. (21), Patil et al. (13) and Kuppasad et al. (24). In contrast, Murugan and Saheb (23) obtained statistically significant differences between the measured values of the FO on the right and left sides. The difference between the length of the FO in the opposite sexes was not statistically significant (6, 12, 23) while the mean width in male skulls was slightly larger than in females. According to the results of one study, FO is narrower on the right than on the left side. The narrow FO can cause pressure on the mandibular nerve which may cause trigeminal neuralgia. In this study, the incidence of trigeminal neuralgia on the right side was shown to be higher (25). Researchers in the USA found statistically significant difference in the length of FO as well as between the average area and perimeter of the FO on both sides (27). Others, comparing the dimensions of FO and FS in newborns and adults, came to the conclusion that the diameter of the FO and FS changes during the growth and development of the child (21).

Variations in the shape of FO were evidenced by a number of investigators with slight differences. Most openings were oval shaped; followed by almond, round and slit like ones. In a small number of cases, the edges of the FO were uneven, with nodules or smaller or larger spines that incompletely divided the opening into sections (11, 12, 17, 22, 23, 24, 26). Variations in the shape of the FO were due to developmental reasons (24) as well as a consequence of the venous blood vessel passing through it (7). The contents of the FO can be partially separated by bony spikes in the cases of doubled foramen ovale (12) or multiple foramen ovale (6). Some other variations as merged FO and FS and crescent-shaped FO were also described (10).

Knowledge of the topography and position variabilities of FO and FR enables avoidance of complications in the cases of surgical procedures with the access through these openings, like during cavernous sinus surgery (28), or in the setting of tumor in the masticator space (13, 18).

The foramen spinosum is a small opening located in the posteromedial part of the root of the greater wing. It transmits the middle meningeal artery and the nervus spinosus. In terms of surgical and anesthetic exploratory maneuvers in the base of the skull, this opening is of great importance, so some researchers have studied its incidence, shape, morphometric details, relations with the FO, as well as the presence of possible anomalies (17, 29).

In our study, FS was present on all skulls, and was single, as in the results of a study by Raymond et al. (6). During morphometry of the FS, we found that its average dimensions on the left and right side were 1.73x1.20 mm, and 1.65x1.32 mm, respectively. The differences between the measured parameters on the right and left side were not statistically significant. Neither Ginsberg et al. (8) nor Osunwoke et al. (21) obtained statistical significance when comparing these parameters. The FS was sometimes absent in a small number of cases, 3.2% (8), 0.8% (6), 4% (10). This happened in the cases when the middle cerebral artery originated from the ophthalmic or internal carotid artery instead of the maxillary artery. The foramen spinosum showed numerous asymmetries and variations in shape and size in the studies. These variations were caused either by incomplete osteogenesis or by aberrant formation of the middle cerebral artery. In our study, the FS was slightly oval in shape in 70.00% of cases, in the study of Saheb et al. (4) it was round in 58% of cases, oval in 38%, and irregular in 4%. The FS may also be incompletely separated from the FO or completely connected to it (7). Double FS has been also seen, in cases when the middle cerebral artery branches before passing through it (10, 17, 30).

Many authors state that variations present on skull-based openings may be the result of an evolutionary process and that it may turn out that the presence of a particular variation is actually

normal or frequent in a particular geographic population or ethnic group (31). Perhaps this may explain the differences in the dimensions of FR, FO and FS in our study, as well as in the studies of other researchers.

Knowing of morphological characteristics as well as variations of size and shapes of FR, FO and FS can be of great importance in neurosurgery in terms of planning and performing of diagnostic or surgical interventions such as tumor detection, biopsy and resection, micro vascular decompression of the trigeminal nerve and other transcutaneous methods of treating trigeminal neuralgia.

Conclusion

In this study dimensions (lengths and widths) of the FR, FO and FS were determined. Difference between the lengths and widths of the left and right FR, FO and FS exists but is not statistically significant. Also, correlation between measured dimensions is either moderate or weak.

Acknowledgments

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doi:10.5633/amm.2021.0202**MORFOMETRIJSKA ANALIZA VEĆIH OTVORA VELIKOG KRILA
KLINASTE KOSTI ČOVEKA***Miljana Pavlović¹, Ivan Jovanović¹, Milena Trandafilović¹, Vesna Stojanović¹, Milorad Antić¹,
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U korenu velikog krila klinaste kosti nalaze se otvori za prolaz krvnih sudova i živaca (okrugli – FR, ovalni – FO i spinozni – FS otvor). Analiza anatomskih karakteristika i dimenzija ovih otvora ima klinički značaj, zbog njihove pozicije između intrakranijalnih i ekstrakranijalnih struktura i hirurških i dijagnostičkih procedura. Cilj istraživanja bio je da se ispituju morfološke i morfometrijske karakteristike okruglog, ovalnog i spinoznog otvora na humanim lobanjama. Istraživanje je sprovedeno na 20 lobanja na Institutu za anatomiju Medicinskog fakulteta u Nišu. Lobanje su numerisane, a otvori fotografisani pored lenjira fotoaparatom marke Canon, model A470. Obrada fotografija i morfometrijska analiza (merenje dužine i širine okruglog, ovalnog i spinoznog otvora) izvršene su u programu "ImageJ". Prosečna dužina okruglog otvora desno iznosila je 3,14 mm ± 0,77 mm, levo 3,44 mm ± 0,65 mm; širina okruglog otvora desno iznosila je 2,38 mm ± 0,58 mm, levo 2,61 mm ± 0,55 mm; dužina ovalnog otvora desno 5,88 mm ± 0,88 mm, levo 5,50 mm ± 1,06 mm; širina ovalnog otvora desno 2,70 mm ± 0,58 mm, levo 2,82 mm ± 0,68 mm; dužina spinoznog otvora desno 1,65 mm ± 0,27 mm, levo 1,73 mm ± 0,49 mm; širina spinoznog otvora desno 1,32 mm ± 0,32 mm, levo 1,20 mm ± 0,39 mm. T-testom nezavisnih uzoraka, utvrđeno je da ne postoji statistički značajna razlika među parametrima na desnoj i levoj strani, ni između merenih parametara istih otvora. Srednja pozitivna korelacija postoji između dužine i širine FS na levoj, dužine i širine FR na desnoj strani i između širine FS na desnoj i levoj strani; zanemarljiva pozitivna korelacija postoji između dužine i širine FO na desnoj strani i između dužine FS na desnoj i levoj strani, dok između ostalih merenih parametara postoji slaba korelacija.

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