ANATOMICAL VARIATIONS OF THE MASTOID FORAMEN: MORPHOMETRIC ANALYSIS USING EXIT HOLE MAPPING

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Abstract: The mastoid foramen is an anatomical structure critical for neurosurgical interventions due to its role in venous drainage via the mastoid emissary vein, which connects the sigmoid sinus to the external veins of the skull. This study aimed to investigate the morphometric parameters of the mastoid foramen by analyzing 28 dried human skulls from the Anatomy Department at Samarkand State Medical University. Measurements focused on the foramen's length, width, and shape, revealing that the average diameters for the right and left mastoid foramina were 0.13 cm and 0.1 cm, respectively. The predominant shapes identified were star-shaped and round, underscoring significant variability in anatomical features. Additionally, the exit shapes of the foramina were assessed, which further elucidated the potential anatomical variations that can influence surgical approaches. These findings are crucial for enhancing the understanding of the anatomical characteristics of the mastoid foramen and its clinical implications, particularly in reducing operative risks associated with neurosurgery. Future research could expand on these findings to clarify the anatomical variations and improve surgical strategies involving the mastoid region.

Keywords: Mastoid foramen, emissary vein, craniometry, anatomical variations, neurosurgery, exit shape

АНАТОМИЧЕСКИЕ ВАРИАЦИИ СОСЦЕВИДНОГО ОТВЕРСТИЯ: МОРФОМЕТРИЧЕСКИЙ АНАЛИЗ С ИСПОЛЬЗОВАНИЕМ КАРТИРОВАНИЯ ВЫХОДНОГО ОТВЕРСТИЯ

Аннотация: Сосцевидное отверстие является анатомической структурой, критически важной для нейрохирургических вмешательств из-за его роли в венозном дренаже через сосцевидную эмиссарную вену, которая соединяет сигмовидный синус с наружными венами черепа. Целью данного исследования было изучение морфометрических параметров сосцевидного отверстия путем анализа 28 высушенных человеческих черепов с кафедры анатомии Самаркандского государственного медицинского университета. Измерения были сосредоточены на длине, ширине и форме отверстия, что показало, что средние диаметры правого и левого сосцевидных отверстий составляли 0,13 см и 0,1 см соответственно. Преобладающими формами были звездообразная и круглая, что подчеркивает значительную изменчивость анатомических особенностей. Кроме того, были оценены формы выходных отверстий, что дополнительно прояснило потенциальные анатомические вариации, которые могут влиять на хирургические подходы. Эти результаты имеют решающее значение для улучшения понимания анатомических характеристик сосцевидного отверстия и его клинических последствий, особенно для снижения операционных рисков, связанных с нейрохирургией. Будущие исследования могут расширить эти результаты для уточнения анатомических

вариаций и улучшения хирургических стратегий, затрагивающих область сосцевидного отростка.

Ключевые слова: сосцевидное отверстие, эмиссарная вена, краниометрия, анатомические вариации, нейрохирургия, форма выхода

INTRODUCTION

The mastoid foramen plays a critical role in neurosurgical interventions in its vicinity. Given that this foramen accommodates a key component of venous drainage—the mastoid emissary vein, which connects the sigmoid sinus (a cranial venous sinus) to the external veins of the skull—knowledge of its position and variability significantly reduces operative risks. While existing studies have presented diverse craniometric data, including shape, diameter, and prevalence of the foramen, an essential aspect for understanding the nature of this structure lies in approximately predicting the vein's course from the foramen. Our initial goal was to define the morphometric parameters of the mastoid foramen and to create a model simulating the vein's approximate path, to enhance the understanding of its anatomical characteristics and potential clinical risks, accounting for variations in its location.

MATERIALS AND METHODS

The craniometric method was employed to measure the mastoid foramina, with evaluations of the foramen shape, exit shape, length, and width. Additionally, the vein’s course was estimated based on the exit shape.

The study material comprised 29 dried, intact human skulls without selection for sex or age, obtained from the Anatomy Department Laboratory at Samarkand State Medical University.

For craniometric measurement of foramen shape and diameter, a calibrated metal caliper was used—Set 3-D of drawing tools, manufactured by MINPRIBOR USSR, Rylsk, Model U-9, GOST 6100-68.

To compare measurements and convert them to centimeters, an electronic caliper was utilized—Matrix Digital Caliper, 150 mm, MTX, 316119.

For statistical analysis of the data, Microsoft Excel 2010 and appropriate calculation formulas were used.

RESULTS AND DISCUSSION

The average length-width of the right foramen is 0.29-0.24 cm, and for the left foramen, it is 0.22-0.19 cm. Applying the ellipse average diameter formula D=2*a*b/a+b (where «a» is an approximate length, and «b» is approximate width) we obtain the mean diameter of the foramina. The mean diameter of the right foramen is 0.13 cm, and for the left, it is 0.1 cm. Средний диаметр обоих отверстий 0.12 cm

No	Right foramina length	Right foramina width	Left foramina length	Left foramina width
1	0,22	0,22	0,18	0,19
2	0,09	0,06	0,08	0,08
3	0,46	0,26	0,23	0,25
4	**Absent**	**Absent**	**Absent**	**Absent**
5	0,16	0,21	0,2	0,2

6	**Absent**	**Absent**	0,25	0,2
7	0,4	0,37	0,23	0,27
8	0,2	0,27	0,2	0,25
9	0,24	0,22	0,24	0,17
10	0,21	0,19	0,31	0,25
11	**Absent**	**Absent**	0,33	0,26
12	0,22	0,2	0,25	0,24
13	**Absent**	**Absent**	0,19	0,14
14	0,22	0,22	0,21	0,22
15	0,21	0,18	0,26	0,21
16	0,18	0,14	0,25	0,16
17	**Absent**	**Absent**	0,27	0,19
18	0,18	0,17	0,19	0,13
19	**Absent**	**Absent**	0,12	0,1
20	0,33	0,32	0,19	0,18
21	0,11	0,9	0,14	0,14
22	0,21	0,13	0,18	0,16
23	0,14	0,17	0,31	0,3
24	0,28	0,38	**Absent**	**Absent**
25	0,22	0,21	0,16	0,17
26	0,26	0,25	0,33	0,3
27	0,24	0,14	0,26	0,15
28	0,24	0,16	0,24	0,15
29	**Absent**	**Absent**	**Absent**	**Absent**

Table 1. Measurement Results of Length and Width for the Right and Left Foramen

The most common shape of the mastoid foramen on the right side was star-shaped (9 cases or 32.1%) and round (5 cases or 17.8%). Similarly, on the left side, the most frequently observed shape of the mastoid foramen was also star-shaped (11 cases or 37.8%) and round (7 cases or 24.1%). The overall measurement data is presented in **Table 2.**

No	Right foramina shape	Left foramina shape
1	Ellipse	Stellate
2	Stellate	Round
3	Stellate	Stellate
4	**Absent**	**Absent**
5	Ovale	Round
6	**Absent**	Round
7	Round	Stellate
8	Stellate	Ovale
9	Ovale	Stellate

10	Stellate	Ovale
11	**Absent**	Ellipse
12	Round	Stellate
13	**Absent**	Ellipse
14	Triangle	Round
15	Stellate	Ellipse
16	Ellipse	Stellate
17	**Absent**	Stellate
18	Round	Ellipse
19	**Absent**	Stellate
20	Round	Stellate
21	Stellate	Stellate
22	Stellate	Round
23	Ellipse	Ellipse
24	Ellipse	**Absent**
25	Triangle	Ellipse
26	Round	Round
27	Stellate	Stellate
28	Stellate	Round
29	**Absent**	**Absent**

Table 2. Results of Shape Measurement of the Foramen on the Right and Left Sides

As an additional aspect in measuring the mastoid foramina of the skull, the "shape of the exit from the foramen" was also highlighted, indicating the presence of small grooves from the foramen both externally along the path and internally, thinning medially or, in rare cases, laterally (1 case, as indicated in **Table 3**). Graphic illustrations showing the variation of different exit shapes of the foramina are provided below in **Figures 1-5**

The following graphical representations illustrate the exit shapes of the foramina, highlighting the presence of grooves.:

- **Gray-filled oval** — Represents the foramen itself.
- **Light-colored area** — Indicates the groove around the foramen and its direction.
- **Blue color** — Symbolizes a schematic representation of the vessel, specifically the mastoid emissary vein, and its course through the foramen.

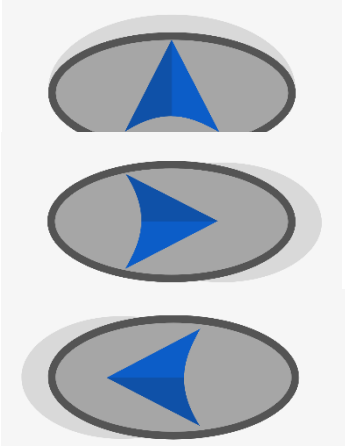

Fig. 1. Medially directed upward course

Fig. 2. Medially directed posterior course

Fig. 3 Medially directed ventral course

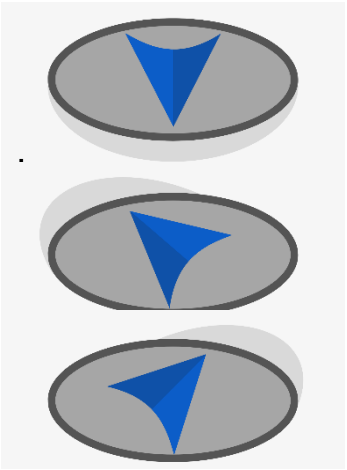

Fig. 4 Medially directed inferior course

Fig. 5 Medially directed superior ventral course

Fig.6 Medially directed superior posterior course

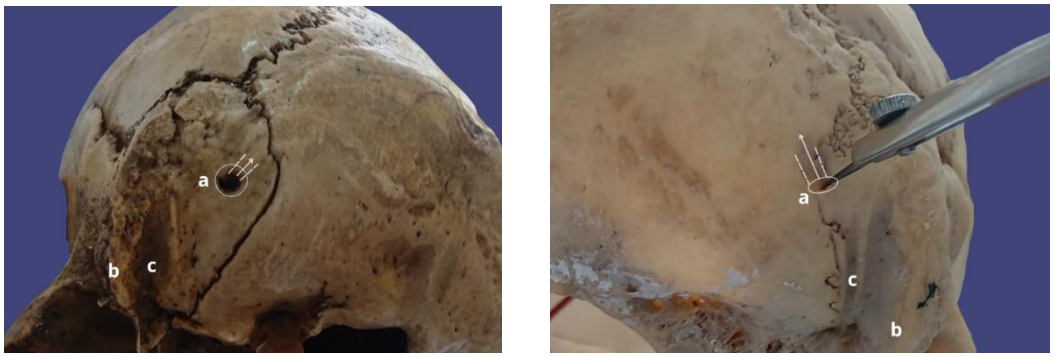

Figure 7,8. Main characteristics of the mastoid foramina, which served as the material for the study, along with some anatomical structures to facilitate navigation.

a – Circle/oval – diameter and length of the foramina at the defined borders, with an arrow indicating the exit of the foramen, predicted as the path of the emissary mastoid vein exiting from the foramen; the dashed line marks the edges of the groove forming the exit from the foramen.

b – Mastoid process, its posterior border.

c – Mastoid notch.

After measuring the exit from the mastoid foramen, we obtained the following results:

- **Exit from the right foramen:** The most common orientation is **medially-superiorly-posteriorly** (10 cases, 34.5%), followed by **medially-superiorly** (6 cases, 20.69%) and **medially-posteriorly** (5 cases, 17.24%). **Complete absence** of the foramen was observed in **7 cases (24.14%)**. Only a single case of **medially-superiorly-ventrally** oriented foramen exit was identified, suggesting this may be an anomaly.
- **Exit from the left foramen:** The most common orientations are **medially-superiorly-posteriorly** and **medially-posteriorly** (9 cases each, 31.03%), followed by **medially-superiorly** (4 cases, 13.79%) and **medially-inferiorly** (3 cases, 10.34%). Absence of the foramen was noted in **3 cases (10.34%)**. Only a single strictly medial case was identified, indicating a complete lack of groove formation.

The total presence of foramina on the right and left sides is 82.7% (48 cases), a significant indicator highlighting the prevalence of this emissary foramen.

No	Right foramina exit shape	Left foramina exit shape
1	Medially – Superiorly - Posteriorly	Medially – Superiorly – Posteriorly
2	Medially – Superiorly - Posteriorly	Medially – Superiorly – Posteriorly
3	Medially – Superiorly - Ventrally	Medially – Superiorly – Posteriorly
4	**Absent***	**Absent***
5	Medially – Superiorly - Posteriorly	Medially – Superiorly
6	**Absent***	Medially – Inferiorly
7	Medially – Superiorly - Posteriorly	Medially – Inferiorly
8	Medially - Posteriorly	Medially – Superiorly
9	Medially – Superiorly - Posteriorly	Medially – Superiorly
10	Medially – Superiorly - Posteriorly	Medially – Posteriorly
11	**Absent***	Medially – Posteriorly
12	Medially – Superiorly	Medially – Superiorly - Posteriorly
13	**Absent***	Medially – Superiorly - Posteriorly
14	Medially - Posteriorly	Medially – Posteriorly
15	Medially – Superiorly - Posteriorly	Medially – Posteriorly
16	Medially – Superiorly - Posteriorly	Medially – Posteriorly
17	**Absent***	Medially – Posteriorly
18	Medially – Superiorly - Posteriorly	Medially – Posteriorly
19	**Absent***	Medially – Posteriorly
20	Medially – Superiorly	Medially
21	Medially – Superiorly	Medially – Superiorly – Posteriorly
22	Medially – Posteriorly	Medially - Inferiorly
23	Medially – Superiorly	Medially – Superiorly – Posteriorly
24	Medially – Superiorly	**Absent***
25	Medially – Superiorly	Medially – Superiorly – Posteriorly
26	Medially – Superiorly - Posteriorly	Medially – Superiorly
27	Medially – Posteriorly	Medially – Superiorly – Posteriorly
28	Medially – Posteriorly	Medially – Posteriorly
29	**Absent***	**Absent***

Table 3. Results of the Measurement of Foramina Exit

CONCLUSION

The study aimed to investigate the anatomical variations of the mastoid foramen through morphometric analysis, emphasizing its clinical significance in neurosurgery. Key findings were obtained from the analysis of 28 dried human skulls: foramina were present in 48 out of 58 cases (considering both the right and left sides of one skull), which accounts for 82.7%, indicating that it is a relatively common opening among skulls. The most frequently observed shape of the foramina on both sides was star-shaped, suggesting the passage of veins and adjacent structures such as small nerves and arteries. The average diameter measured 0.12 cm, which aligns with standard measurements reported in previous studies.

The results of the study on the exits from the mastoid foramen highlight significant anatomical variability, which is critical for neurosurgery. On the right side, the most common orientation observed was medially-superiorly-posteriorly (34.5%), followed by medially-superiorly (20.69%) and medially-posteriorly (17.24%). Complete absence of the mastoid foramen was noted in 24.14% of cases. On the left side, the most frequently encountered exits were medially-superiorly-posteriorly and medially-posteriorly (both at 31.03%), followed by medially-superiorly (13.79%) and medially-inferiorly (10.34%). Absence of the foramen was noted in 10.34% of cases.

These anatomical variations can significantly affect access to vital structures, increasing the risk of complications. Awareness of such differences allows neurosurgeons to tailor their approaches to the individual anatomical characteristics of patients, thereby enhancing the safety and success of surgical interventions.

Understanding these variations contributes to recognizing potential anatomical challenges, ultimately leading to safer neurosurgical practices and improved treatment outcomes. Future research may further clarify these variations, refining surgical strategies in the region of the mastoid process.

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