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MORPHOMETRIC AND MORPHOLOGY STUDY OF FORAMEN JUGULAR IN DRY SKULL

[1]Dr. Preeti Goswami
Professor Maulana Azad Medical College New Delhi
(ORCID ID: 0000-0001-7235-1246)
[2.]Dr. Yogesh Professor Anatomy Radha Govind Institute Medical Sciences Meerut
(ORCID ID: 0000-0002-8561-3599)
[3.]Dr. Charu Gupta Assistant Professor Anatomy Radha Govind Institute Medical Sciences Meerut
(ORCID ID: 0009-0004-0152-8090)
[4]*Dr. Rahul Srivastava Assistant Professor Anatomy Radha Govind Institute Medical Sciences Meerut
(ORCID ID: 0000-0002-5153-936X)
*Correspond author: **rahulcom1994@gmail.com**

Abstract

Background:

The jugular foramen is a major opening at the skull base located between the temporal and occipital bones and transmits important neurovascular structures including the internal jugular vein and cranial nerves IX, X, and XI. Due to its anatomical complexity and clinical importance, variations in its size and morphology are significant for surgical and radiological procedures involving the skull base.

Materials and Methods:

This descriptive cross-sectional study was conducted on 37 intact adult dry human skulls obtained from the osteology collection of the Department of Anatomy. Skulls with damage or deformity in the jugular foramen region were excluded. Measurements of anteroposterior diameter, mediolateral breadth, and depth were recorded bilaterally using a digital vernier caliper. Morphological features including septation patterns and shape variations were also documented. Data were analyzed using mean, standard deviation, and standard error, and right and left sides were compared using paired Student's t-test with $p < 0.05$ considered significant.

Results:

The mean anteroposterior diameter measured 14.67 mm on the right and 14.20 mm on the left side, showing no statistically significant difference ($p = 0.265$). The mediolateral breadth measured 10.35 mm on the right and 7.91 mm on the left side, demonstrating significant right-sided predominance ($p < 0.001$). Mean depth values were nearly equal on both sides (10.50 mm right, 10.41 mm left) with no significant difference ($p = 0.858$). Morphological analysis showed that the single (non-bipartite) jugular foramen was the most common type (56.8%), while various incomplete and complete bipartite forms constituted the remaining cases.

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Conclusion:
The study demonstrates that while anteroposterior diameter and depth of the jugular foramen are bilaterally symmetrical, mediolateral breadth shows significant right-sided dominance. Morphological variations including septation are commonly encountered. These findings provide useful anatomical data that can assist in radiological interpretation and improve surgical planning in skull base procedures involving the jugular foramen.

Keyword:Jugular foramen; Morphometry; Skull base anatomy; Septation; Bipartite jugular foramen; Dry human skull; Morphological variation; Jugular fossa; Cranial nerves IX, X, XI;

Introduction

The jugular foramen is one of the most important openings at the base of the skull, located between the petrous part of the temporal bone and the occipital bone. It serves as a passage for major neurovascular structures including the internal jugular vein and cranial nerves IX (glossopharyngeal), X (vagus), and XI (accessory), making it an anatomically and clinically significant region.[1]

Anatomically, the jugular foramen is irregular in shape and is often subdivided into compartments by fibrous or bony septa that transmit neural and vascular components. Previous anatomical investigations have demonstrated considerable variation in its size and morphology, often showing asymmetry between right and left sides, usually due to dominance of venous drainage.[2,3]

Morphometric studies assess parameters such as anteroposterior diameter, mediolateral breadth, and depth, whereas morphological studies evaluate shape, septation patterns, and presence of domed bony roofs. Such analyses are important for understanding normal anatomical variation and provide essential data for radiological interpretation and surgical planning.[4]

Knowledge of jugular foramen anatomy is essential for neurosurgeons, otolaryngologists, and radiologists in managing skull base lesions such as glomus jugulare tumors, schwannomas, meningiomas, and other posterior cranial fossa pathologies. Detailed anatomical information helps reduce operative complications including cranial nerve injury and venous bleeding.[5]

Dry skull–based studies offer precise morphometric evaluation without soft tissue interference and are therefore valuable in establishing population-specific anatomical standards. Hence, the present study aims to evaluate morphometric dimensions and morphological variations of the jugular foramen in dry adult human skulls to contribute useful data for anatomical, radiological, and surgical applications.[6]

Materials and Methods

The present study was conducted in the Department of Anatomy using dry adult human skulls obtained from the osteology collection of the department to evaluate morphometric and morphological variations of the jugular foramen. A total of 37 intact adult dry human skulls of

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unknown sex were included in the study. Skulls showing damage, deformity, or erosion in the region of the jugular foramen were excluded to ensure accuracy of measurements.

Each skull was examined on both right and left sides, and morphometric parameters including the anteroposterior diameter, mediolateral breadth, and depth of the jugular foramen were measured. All measurements were recorded in millimeters using a digital vernier caliper with an accuracy of 0.01 mm, and depth measurements were obtained using the depth probe attached to the caliper. Care was taken to position the measuring instrument properly to minimize observational error, and measurements were recorded systematically.

In addition to morphometric assessment, morphological features of the jugular foramen were also examined, including its shape, presence or absence of septation, compartmental division, side predominance, and presence of a domed bony roof or variations in the jugular fossa. All findings were recorded using a structured observation format.

The collected data were entered into Microsoft Excel and subjected to statistical analysis. Mean values, standard deviation, and standard error were calculated for all parameters. Comparison between right and left sides was performed using paired Student's t-test, and a p-value less than 0.05 was considered statistically significant. Ethical approval for the study was obtained from the institutional ethics committee prior to commencement of the study.

Result

Table 1 compares the anteroposterior (AP) diameter of the jugular foramen between the right and left sides. The mean AP diameter on the right side was 14.67 mm, whereas on the left side it was slightly smaller at 14.20 mm, indicating a marginally larger jugular foramen on the right side.

The standard deviation was 1.50 mm on the right side and 2.24 mm on the left side, suggesting that measurements on the left side showed greater variability among specimens compared to the right side. The standard error of mean was 0.25 mm on the right side and 0.37 mm on the left, indicating reliable estimation of the mean values with relatively small sampling error.

Statistical comparison yielded a t-value of 1.13 with a p-value of 0.265, which is greater than the conventional significance level of 0.05. This indicates that the observed difference between the right and left sides is not statistically significant.

Table 1. Comparison of AP Diameter of Jugular Foramen

Side	Mean (mm)	Standard Deviation	Standard Error	P value	T value
Right	14.67	1.50	0.25	0.265	1.13
Left	14.20	2.24	0.37		

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Fig 1 morphometric measurement AP Diameter of Jugular Foramen

Table 2 presents the comparison of the mediolateral (ML) breadth of the jugular foramen between the right and left sides. The mean ML breadth on the right side was 10.35 mm, while the left side measured 7.91 mm, indicating that the jugular foramen is considerably broader on the right side.

The standard deviation was 1.78 mm on the right and 2.11 mm on the left, showing slightly greater variability in measurements on the left side. The standard error values of 0.29 mm (right) and 0.35 mm (left) indicate reasonable precision in estimating the mean measurements.

Statistical analysis revealed a t-value of 5.56 with a p-value < 0.001, which is far below the threshold of statistical significance ($p < 0.05$). This confirms that the difference in ML breadth between the two sides is highly statistically significant.

Thus, the findings demonstrate a clear right-sided predominance in mediolateral breadth of the jugular foramen. This asymmetry is anatomically important and may be related to dominance of venous drainage structures on the right side, which has clinical relevance in skull base surgeries and radiological interpretation.

Table 2. Comparison of ML Breadth of Jugular Foramen

Side	Mean (mm)	Standard Deviation	Standard Error	P value	T value
Right	10.35	1.78	0.29	<0.001	5.56
Left	7.91	2.11	0.35		

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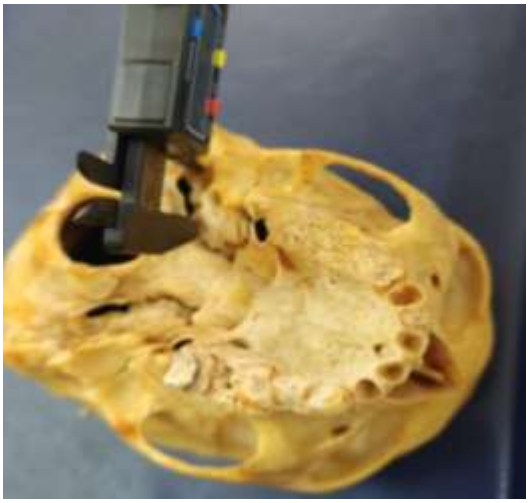

Fig 2 showing measurement of Breadth of Jugular Foramen

Table 3 shows the comparison of the depth of the jugular foramen between the right and left sides. The mean depth on the right side was 10.50 mm, while the left side measured 10.41 mm, indicating that the depth of the jugular foramen is almost identical on both sides.

The standard deviation was 2.40 mm on the right and 2.78 mm on the left, suggesting slightly greater variability in measurements on the left side. The standard error values of 0.39 mm (right) and 0.46 mm (left) indicate acceptable precision in the estimated mean values.

Statistical comparison yielded a t-value of 0.18 with a p-value of 0.858, which is much higher than the significance threshold of 0.05. This shows that the difference in depth between the two sides is not statistically significant.

Table 3. Comparison of Depth of Jugular Foramen

Side	Mean (mm)	Standard Deviation	Standard Error	P value	T value
Right	10.50	2.40	0.39	0.858	0.18
Left	10.41	2.78	0.46		

Table 4 demonstrates the distribution of morphological variations in the shape of the jugular foramen observed in the study sample. The results indicate that the single (non-bipartite) type was the most common configuration, observed in 21 specimens (56.8%), suggesting that in more than half of the studied cases, the jugular foramen remained undivided.

Among the divided forms, bipartite configurations showed multiple patterns of occurrence. Bilateral incomplete bipartite foramina were found in 4 cases (10.8%), representing the most frequent variant among the bipartite forms. Additionally, incomplete bipartite division on the left

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side alone was observed in 3 cases (8.1%), indicating that partial septation tends to occur more often than complete division.

Complete bipartite division on both sides was present in 3 cases (8.1%), whereas complete bipartite division on one side was noted in 2 cases (5.4%), showing that fully separated compartments are comparatively less frequent than incomplete partitions.

Less common variants included bilateral bipartite, B/L bipartite, right-sided bipartite, and incomplete bilateral bipartite configurations, each observed in 1 case (2.7%), demonstrating that asymmetric or rare combinations occur infrequently.

Overall, the findings indicate that while the non-bipartite jugular foramen predominates, various degrees of septation and bipartite divisions occur in a considerable proportion of specimens, reflecting substantial morphological variability. These variations have important anatomical and surgical implications, particularly in procedures involving the posterior cranial fossa and jugular foramen region, where knowledge of septation patterns is critical to avoid neurovascular injury.

Table 4 shape of Jugular foramen

Shape category	Frequency (n)	Percentage (%)
Single (Non-bipartite)	21	56.8
B/L incomplete bipartite	4	10.8
Incomplete bipartite (L)	3	8.1
B/L complete bipartite	3	8.1
Complete bipartite	2	5.4
Bilateral bipartite	1	2.7
B/L bipartite	1	2.7
Right bipartite	1	2.7
Incomplete B/L bipartite	1	2.7

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Fig 3 showing the shape of B/L incomplete bipartite

Discussion

The jugular foramen is one of the most complex and clinically significant openings at the skull base, transmitting vital neurovascular structures including the glossopharyngeal, vagus, and accessory nerves along with the internal jugular vein. Owing to its functional importance and structural complexity, detailed morphometric and morphological evaluation of the jugular foramen has been the focus of numerous anatomical and radiological studies.[7]

In the present study, the mean AP diameter measured 14.67 mm on the right side and 14.20 mm on the left side, showing mild right-sided predominance. However, statistical analysis revealed that this difference was not significant ($p = 0.265$), suggesting near symmetry in AP dimensions between the two sides. Similar findings have been reported in earlier investigations. Idowu (2004) documented mean AP diameters of approximately 14.5 mm on the right and 14.0 mm on the left in a Nigerian population.[8] Patel and Singel (2007) also observed right-sided predominance with values of 14.8 mm and 14.3 mm for right and left sides respectively,[9] while Gupta et al. (2012) reported AP diameters of 15.2 mm on the right and 14.6 mm on the left in North Indian skulls.[10] Comparable findings were further described by Muthukumar et al. (2005),[11] Wysocki et al. (2006),[12] Khanday et al. (2013),[13] Gopalakrishna et al. (2014),[14] Amin et al. (2016),[15] Kale et al. (2018),[16] and Sharma et al. (2020),[17] all demonstrating slight right dominance without consistent statistical significance. Thus, the AP diameter findings of the present study are in agreement with global anatomical data indicating minimal bilateral difference.

A more pronounced asymmetry was observed in mediolateral breadth. In the present study, the mean ML breadth measured 10.35 mm on the right side compared with 7.91 mm on the left side, and this difference was highly statistically significant ($p < 0.001$). This finding indicates a clear right-sided predominance in ML dimensions of the jugular foramen. Similar right-sided enlargement has been consistently reported in earlier studies and is commonly attributed to dominance of venous drainage through the right internal jugular vein. Idowu (2004) reported ML breadth values of approximately 11.0 mm on the right and 8.5 mm on the left.[8] Patel and Singel (2007) found right and left ML measurements of 10.9 mm and 8.2 mm respectively,[9] while Gupta

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et al. (2012) documented values of 11.3 mm and 8.7 mm.[10] Comparable trends were reported by Muthukumar et al. (2005),[11] Sturrock (1988),[18] Khanday et al. (2013),[13] Gopalakrishna et al. (2014),[14] Amin et al. (2016),[15] Kale et al. (2018),[16] and Sharma et al. (2020),[17] all confirming consistent right-sided dominance.

Depth measurements in the present study revealed mean values of 10.50 mm on the right side and 10.41 mm on the left side, demonstrating almost identical dimensions with no statistically significant difference ($p = 0.858$). Similar bilateral symmetry has been reported in previous morphometric studies by Muthukumar et al.,[11] Patel and Singel,[9] Gupta et al.,[10] and Wysocki et al.[12] Further confirmation comes from Khanday et al.,[13] Gopalakrishna et al.,[14] Amin et al.,[15] Kale et al.,[16] and Sharma et al.[17] suggesting that depth measurements are less influenced by venous dominance compared to ML breadth.

Morphological analysis in the present study showed that the single (non-bipartite) jugular foramen was the most common configuration, observed in 56.8% of specimens. Similar morphological distributions have been reported previously. Sturrock (1988) reported undivided foramina in nearly 60% of skulls,[18] Idowu (2004) documented single foramina in about 55% of specimens,[8] while Patel and Singel (2007) observed septation patterns in approximately 40% of skulls.[9] Muthukumar et al. (2005) reported partial septation more frequently than complete division.[11] Comparable variability has also been described by Gupta et al.,[10] Khanday et al.,[13] Amin et al.,[15] Kale et al.,[16] Sharma et al.,[17] and Rao et al. (2021).[19]

These morphometric and morphological variations have important clinical implications. Enlargement of the right jugular foramen corresponds with dominance of the right internal jugular vein, which must be considered during skull base surgical procedures. Awareness of septation patterns helps surgeons avoid neurovascular injury, and radiologists must recognize normal asymmetry to avoid misinterpretation as pathological enlargement.

Overall, the present study demonstrates that AP diameter and depth measurements of the jugular foramen exhibit near bilateral symmetry, while mediolateral breadth shows significant right-sided predominance. Morphological analysis reveals that undivided foramina are most common, although septated variants are also frequently encountered. Comparison with multiple previous studies confirms that the present findings are consistent with established anatomical observations, reinforcing the importance of jugular foramen morphometry in surgical and radiological practice.

Conclusion

The present study provides a comprehensive morphometric and morphological evaluation of the jugular foramen in dry adult human skulls and highlights the presence of significant anatomical variations that are relevant to clinical and surgical practice.

Morphometric analysis demonstrated that the anteroposterior diameter and depth of the jugular foramen were nearly symmetrical on both sides, with no statistically significant difference

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observed between right and left measurements. In contrast, mediolateral breadth showed a highly significant right-sided predominance, indicating that the jugular foramen is generally broader on the right side. This asymmetry likely reflects dominance of venous drainage through the right internal jugular vein and corresponds with findings reported in earlier anatomical studies.

Morphological evaluation revealed that the single (non-bipartite) jugular foramen was the most common configuration, observed in more than half of the specimens. However, a considerable proportion of skulls exhibited incomplete or complete septation resulting in bipartite or compartmentalized foramina. These variations indicate that the jugular foramen demonstrates substantial structural diversity, which must be recognized as part of normal anatomical variation.

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