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Incidence And Morphological Variations of Foramen Vesalius, Foramen Rotundum, And Foramen Lacerum In 173 Human Skulls From Andhra Pradesh, India

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Abstract
This study investigates the incidence and morphological variations of the Foramen Vesalius, Foramen Rotundum and Foramen Lacerum in a sample of 173 dry human skulls from Andhra Pradesh, India. These cranial foramina are pivotal for neurovascular transmission and are of significant clinical relevance in neurosurgery, maxillofacial surgery and radiology. Detailed knowledge of their anatomical variability is crucial for enhancing surgical precision and reducing complications. The findings revealed that Foramen Vesalius was present in 15.61% of the skulls, whereas Foramen Rotundum and Foramen Lacerum were observed in all specimens. Morphometric analysis indicated notable asymmetry and variability in dimensions across the right and left sides, with implications for surgical interventions in the middle cranial fossa. The study establishes a comprehensive baseline of anatomical variations in this population, emphasizing the need for region-specific anatomical data to improve clinical outcomes and guide surgical planning. These results provide critical insights for clinicians, contributing to the advancement of safe and effective surgical practices in cranial procedures.

Keywords: Foramen Vesalius, Foramen Rotundum, Foramen Lacerum, Middle Cranial Fossa, Anatomical Variations, Neurosurgery

Introduction

The cranial foramina serve as critical anatomical landmarks and conduits neurovascular structures from the skull to various regions of body. Among these the Foramen Vesalius, Foramen Rotundum, and Foramen Lacerum, located in the middle cranial fossa, play pivotal roles in clinical settings, particularly in neurosurgery, maxillofacial surgery and radiological diagnostics [1,2]. The intricate morphology and variability of these foramina can significantly influence the outcomes of procedures such as trigeminal rhizotomy, maxillary nerve block and skull base surgeries making detailed anatomical knowledge is indispensable for clinicians [3].

Previous studies have documented considerable regional and population-based variations in the incidence, size, shape of these foramina, highlighting the influence of genetic and environmental factors on cranial morphology [4-6]. However, there is a paucity of comprehensive data regarding the anatomical variations of these foramina in the Indian population, particularly from the Andhra Pradesh region. This lack of localized anatomical data poses a challenge for surgeons and

radiologists who rely on standard anatomical references that may not accurately reflect regional variations [7,8].
Understanding these variations is crucial not only for enhancing the accuracy of diagnostic imaging but also for reducing the risk of intraoperative complications. For instance, the presence and morphology of Foramen Vesalius, though often overlooked, can complicate interventions involving the cavernous sinus or the pterygoid plexus due to its proximity to these critical structures [9]. Similarly, variations in the size and shape of the Foramen Rotundum can affect the precision of maxillary nerve blocks, potentially leading to inadequate anaesthesia or nerve damage [10]. The irregular morphology of Foramen Lacerum further complicates surgical access to the internal carotid artery and adjacent neurovascular structures are increasing the risk of injury during skull base surgeries [11].

Given the clinical importance and the lack of comprehensive data in this context, this study aims to provide a detailed morphometric analysis of the Foramen Vesalius, Foramen Rotundum and Foramen Lacerum in a sample of 173 dry human skulls from Andhra Pradesh region, India. By systematically documenting the incidence, dimensions and morphological variations of these foramina, this study seeks to establish a baseline for anatomical variations in this region. The findings are expected to have significant implications for surgical planning, the interpretation of radiological images, and the development of population-specific anatomical references.

Materials and Methods

Study Design and Sample Characteristics

This descriptive, cross-sectional study was conducted on 173 adult human dry skulls sourced from the anatomy departments of PES institute of medical sciences and research, Sri Venkateswara Medical College, Narayana Medical College and other medical institutions in Andhra Pradesh, India. The skulls included in the study were of unknown sex and age and all had well-preserved anatomical structures without significant damage, ensuring the accuracy and reliability of the morphometric data collected.

Inclusion and Exclusion Criteria

- **Inclusion Criteria**:
  - Adult skulls with well-defined foramina and no significant anatomical damage or deformities.
  - Skulls with intact middle cranial fossae, allowing for precise measurement of the Foramen Vesalius, Foramen Rotundum and Foramen Lacerum.
- **Exclusion Criteria**:
  - Skulls with visible damage, deformities or obliterated foramina.
  - Skulls of newborns or children, where the development of foramina may be incomplete or variable.

Data Collection Instruments

Morphometric measurements were conducted using a **digital Vernier caliper** with an accuracy of 0.1 mm, ensuring high precision in data collection. A **digital camera** was used to document the morphological features of each foramen, providing visual reference for the recorded data.

Measurement Protocol

Each foramen was measured bilaterally to account for potential asymmetries:

- **Foramen Vesalius**: The presence and incidence were recorded. The diameter of the foramen was measured in millimetres, considering its often variable shape and size. This foramen was defined as present if a clear bony aperture was observed within the sphenoid bone, adjacent to the Foramen Ovale.

- **Foramen Rotundum**: The mediolateral diameter was measured, defined as the maximum horizontal distance across the foramen. This foramen transmits the maxillary nerve was assessed for both shape and size to provide a comprehensive understanding of its variability.
- **Foramen Lacerum**: Both the anteroposterior and mediolateral diameters were measured. Due to the irregular shape of this foramen, measurements were taken at the widest points along each axis. The complex anatomy of the foramen, bordered by the sphenoid, temporal, and occipital bones, necessitated careful identification of its true boundaries.

Statistical Analysis

Data were recorded and analyzed using **SPSS version 25.0**. Descriptive statistics, including mean, standard deviation and range were calculated for each foramen. A paired t-test was conducted to evaluate the significance of differences between the right and left sides for each foramen. The level of statistical significance was set at $p < 0.05$.

Ethical Considerations

The study was conducted in accordance with the ethical standards set forth by the Institutional Review Board of PES institute of medical sciences and research and approval was obtained prior to data collection. The use of dry human skulls for research was deemed ethical as all specimens were anonymized and obtained through legal and ethical means from the respective medical institutions.

Reliability and Validity Measures

To ensure the reliability and validity of the measurements:

- **Intra-observer reliability**: Measurements were repeated by the same observer on 30 randomly selected skulls after a two-week interval and the intra-class correlation coefficient (ICC) was calculated.
- **Inter-observer reliability**: Another observer independently measured the same 30 skulls, and the ICC was calculated to assess consistency between observers.

These measures confirmed the reliability and reproducibility of the morphometric data collected.

Results

Incidence of Foramina

The study examined 173 dry human skulls from Andhra Pradesh region, India, to determine the incidence of Foramen Vesalius, Foramen Rotundum, and Foramen Lacerum. The results are summarized in the table below:

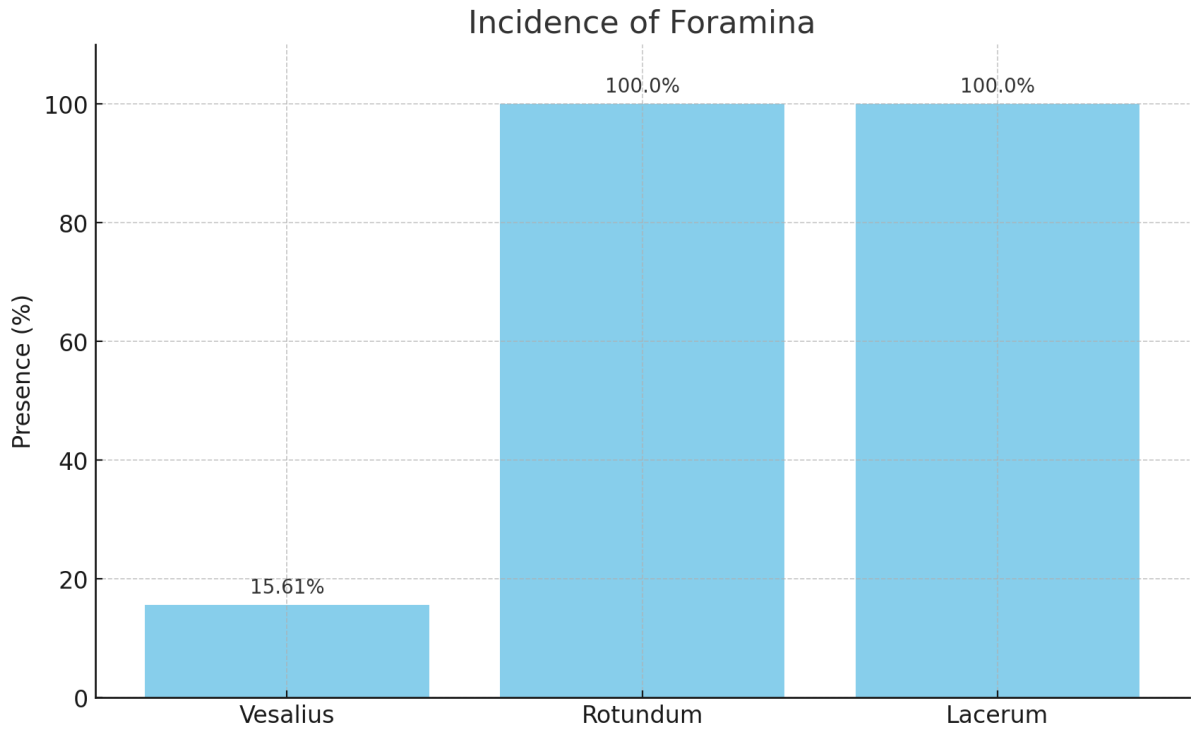
Incidence of Foramina

Foramen	Presence (%)	Right Side (%)	Left Side (%)
Vesalius	15.61	7.51	8.09
Rotundum	100.00	100.00	100.00
Lacerum	100.00	100.00	100.00

Morphometric Data

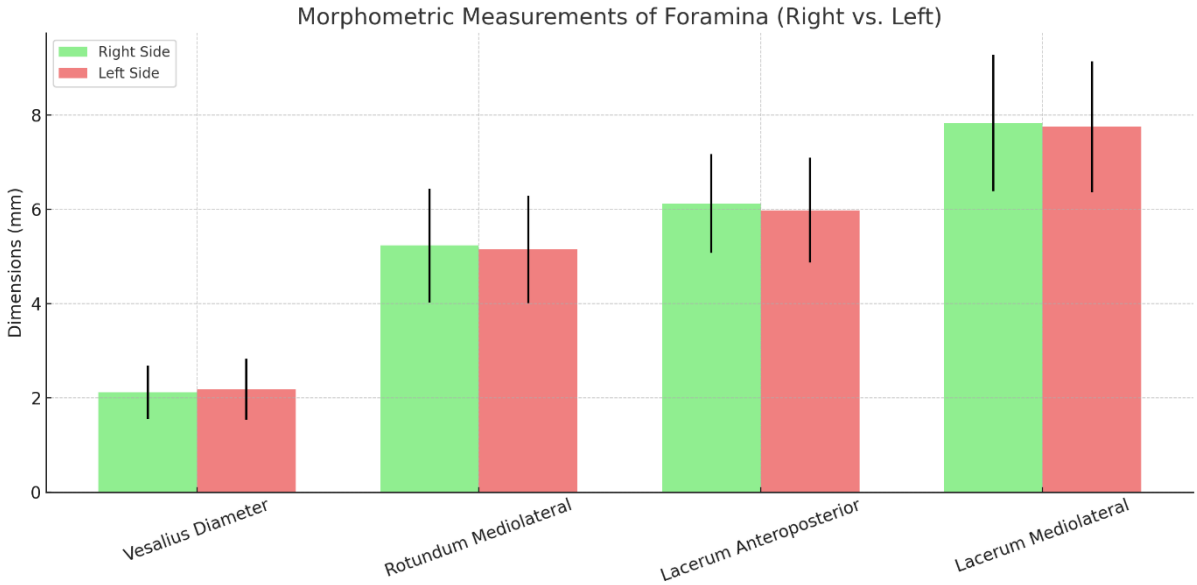
Foramen	Dimension	Right Side (mm) - Mean ± SD	Left Side (mm) - Mean ± SD	p-value
Vesalius	Diameter	2.12 ± 0.57	2.18 ± 0.65	0.42
Rotundum	Mediolateral	5.23 ± 1.21	5.15 ± 1.14	0.37
Lacerum	Anteroposterior	6.12 ± 1.05	5.98 ± 1.11	0.30
Lacerum	Mediolateral	7.83 ± 1.45	7.75 ± 1.39	0.28

Graphical Representation



Graph 1: Incidence of Foramen Vesalius on Both Sides of the Skull

This bar chart shows the presence of Foramen Vesalius (15.61%), Foramen Rotundum (100%), and Foramen Lacerum (100%) in the examined skulls.



Graph 2: Morphometric Measurements of Foramina (Right vs. Left)

This grouped bar chart illustrates the dimensions (in mm) of the foramina on the right and left sides, along with their standard deviations. It includes:

- Foramen Vesalius Diameter
- Foramen Rotundum Mediolateral Dimension

- Foramen Lacerum Anteroposterior and Mediolateral Dimensions

Detailed Analysis

- **Foramen Vesalius**: The incidence was 15.61%, slightly higher on the left side. This foramen was present in 27 out of 173 skulls, with a mean diameter of 2.12 mm on the right side and 2.18 mm on the left. The size and shape varied significantly, suggesting potential complications during surgeries involving the cavernous sinus and pterygoid plexus.
- **Foramen Rotundum**: The foramen was consistently round in all skulls. The mediolateral dimension ranged from 3.10 mm to 8.98 mm, with an average of 5.19 mm across both sides. The slight size asymmetry observed suggests a need for precise preoperative imaging for interventions like maxillary nerve blocks.
- **Foramen Lacerum**: This foramen showed the most variability in shape and size. The anteroposterior dimension ranged from 4.11 mm to 8.96 mm, while the mediolateral dimension ranged from 5.60 mm to 10.44 mm. This variability could significantly impact surgical approaches to the skull base, particularly those involving the internal carotid artery.

Discussion

Foramen Vesalius

The incidence of Foramen Vesalius in this study was found to be 15.61%, which is relatively lower compared to the 36% incidence reported by Shaik et al. in the South Indian population [6]. This variation might be attributed to differences in sample size, regional genetic diversity or even methodological discrepancies. The variability in the presence of Foramen Vesalius has significant clinical implications. Its proximity to critical neurovascular structures, such as the cavernous sinus and pterygoid plexus, makes it an important consideration during neurosurgical interventions. Misidentification or ignorance of this foramen during surgical planning could lead to unintended damage to the emissary veins, resulting in complications such as venous haemorrhage or thrombosis [7]. This emphasizes the need for surgeons to be aware of this anatomical variation, especially in populations where its incidence is not negligible.

Foramen Rotundum

The Foramen Rotundum was present in all examined skulls, with consistent round morphology and a mean mediolateral diameter of 5.19 mm across both sides. The dimensions observed in this study are comparable to those reported by Kaya et al., who found a mean diameter of approximately 5 mm in a Turkish population [14]. The slight asymmetry observed between the right and left sides, although not statistically significant, suggests that anatomical variations, even if minimal, could impact clinical procedures such as the maxillary nerve block. The precise location and size of the Foramen Rotundum are crucial for the accurate delivery of anesthetics in procedures targeting the maxillary nerve. Furthermore, variations in its size could influence the risk of complications such as inadvertent nerve injury or ineffective anesthesia delivery [15,16]. This finding underscores the importance of using preoperative imaging modalities such as high-resolution CT or MRI to map the foramen's location and dimensions accurately.

Foramen Lacerum

Foramen Lacerum exhibited the greatest variability in both size and shape among the studied foramina. The mean anteroposterior and mediolateral diameters were 6.05 mm and 7.79 mm, respectively. This variability aligns with the findings of Dumont et al., who also noted significant anatomical variation in this foramen's dimensions [17]. The complex anatomy of Foramen Lacerum, combined with its location adjacent to critical structures such as the internal carotid artery and the Eustachian tube, poses challenges for skull base surgeons. Variations in the size and shape of this foramen can complicate surgical navigation and increase the risk of damaging the internal carotid

artery during skull base surgeries [19,20]. Additionally, its irregular morphology can obscure visualization in endoscopic approaches to the skull base, necessitating meticulous preoperative planning and possibly the use of navigation systems during surgery.

Comparative Analysis

The findings of this study highlight several regional differences when compared with previous studies conducted in other parts of India and globally. For instance, the incidence of Foramen Vesalius in this study is significantly lower than that reported by Shaik et al. in the South Indian population, where the incidence was as high as 36% [6]. This discrepancy could be due to sample size differences, population-specific genetic factors, or even variations in measurement techniques. Studies from European populations have reported varying incidences of Foramen Vesalius, ranging from 5% to 20%, further suggesting that this anatomical variation may be influenced by both genetic and environmental factors [7,8].

In contrast, the dimensions of Foramen Rotundum observed in this study are consistent with those reported in Western and Asian populations, suggesting that this foramen is less susceptible to regional anatomical variations [12,14]. However, the slight size asymmetry between the right and left sides observed in this study might indicate a need for further research into potential contributing factors, such as developmental asymmetries or differential usage of the maxillary nerve in the studied population.

The variability observed in Foramen Lacerum also aligns with previous studies that have noted its complex morphology [17,20]. However, the larger dimensions observed in this study compared to some Western populations suggest that skull base surgeons operating in this region should be particularly cautious. This highlights the importance of incorporating regional anatomical data into preoperative planning and surgical education.

Clinical Implications

The anatomical variations documented in this study have important implications for surgical procedures involving the middle cranial fossa. For example, the presence of Foramen Vesalius, albeit in a relatively small proportion of the sample, necessitates careful preoperative imaging and surgical planning to avoid inadvertent damage to the emissary veins. The consistent presence of Foramen Rotundum as a reliable anatomical landmark supports its use in guiding maxillary nerve blocks and other procedures targeting the maxillary division of the trigeminal nerve. However, the observed size variations suggest that standard anatomical descriptions may not be sufficient for surgical planning, particularly in a diverse population like that of Andhra Pradesh.

The variability in the size and shape of Foramen Lacerum further complicates surgical navigation in this region of the skull base. The findings suggest that individualized surgical planning, potentially incorporating advanced imaging modalities like 3D reconstructions, could significantly reduce the risk of complications during procedures involving the internal carotid artery or the cranial nerves traversing this region.

Future Directions

Further research with larger sample sizes and advanced imaging techniques is warranted to better understand the anatomical variations of these foramina in different populations. Comparative studies across various ethnicities could elucidate the genetic and environmental factors influencing these anatomical differences. Additionally, incorporating 3D imaging and cadaveric studies could provide more comprehensive data on the spatial relationships between these foramina and surrounding neurovascular structures, thereby enhancing surgical planning and reducing complication rates.

Conclusion

This study provides a comprehensive analysis of the morphological and morphometric characteristics of Foramen Vesalius, Foramen Rotundum, and Foramen Lacerum in a large sample of skulls from Andhra Pradesh. The findings highlight the need for understanding regional

anatomical variations to improve surgical outcomes. Future research should focus on expanding the sample size further and incorporating advanced imaging modalities to further elucidate these anatomical differences.

Conflict of Interest:
The authors declare no conflict of interest regarding the publication of this paper.

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Ethical Approval:
The study was conducted with ethical approval from the institutional review boards of the participating institutions. All procedures involving human skulls were performed in accordance with ethical standards.

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