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Foramen Rotundum Dimensions and Landmarks in Indian Adults: Anatomical Insight for Skull Base Surgery

Khursheed RAZA[a], Neha XALXO[b], S SHIVSHANKAR[c], Krishna S PATIL[c], Rashmi Bala PATEL[d], Ajay Kumar PATEL[e]

[a]Associate Professor, Department of Anatomy, All India Institute of Medical Sciences, Deoghar, India

[b]Assistant Professor, Department of Anatomy, All India Institute of Medical Sciences, Rajkot, India

[c]Assistant Professor, Department of Anatomy, Balvir Singh Tomar Institute of Medical Science and Research, Jaipur, India

[d]Assistant Professor, Department of Obstetrics and Gynecology, All India Institute of Medical Sciences, Raipur, India

[e]Associate Professor, Department of Anatomy, All India Institute of Medical Sciences, Raipur, India

ABSTRACT

Background: *The foramen rotundum (FR) is a critical skull base aperture transmitting the maxillary division of the trigeminal nerve. Its anatomical variations have significant implications for diagnosis and surgical approaches to skull base lesions. However, population-specific morphometric data for the Indian population remain limited.*

Objectives: *This study aims to evaluate the morphometric characteristics and anatomical features of the FR in Indian adults using both dry skulls and computed tomography (CT) scans, with emphasis on establishing surgical landmarks for safe skull base surgery.*

Methods: *Thirty dry adult human skulls and thirty high-resolution CT scans of adult patients (≥18 years) without skull pathology were examined. Morphometric measurements of the FR, including breadth, height and distance from the anterior clinoid process, were recorded using digital Vernier calipers (dry skulls) and specialized CT analysis software. Statistical comparison between left and right sides was performed using paired t-tests ($p \leq 0.05$).*

Results: *The FR was bilaterally present in all specimens with predominantly round shape and regular margins. No accessory foramina, septations, or confluence were observed. In dry skulls, mean breadth and*

Address for correspondence:
Dr. Ajay Kumar Patel, Associate Professor
Department of Anatomy, All India Institute of Medical Sciences, Raipur (CG), India
Email: dr.ajaykumar2008@gmail.com

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height measured 3.82±0.99 mm and 3.59±0.65 mm (left) and 3.82±0.91 mm and 3.54±0.77 mm (right), respectively. Corresponding CT scan measurements were 2.94±0.53 mm and 2.54±0.44 mm (left) and 2.85±0.45 mm and 2.40±0.44 mm (right). No statistically significant asymmetry was observed between sides. The mean distance from the anterior clinoid process to FR was 10.50±1.19 mm (dry skulls) and 14.06±1.86 mm (CT scans), with no significant lateralization.

Conclusion: *The present study establishes population-specific morphometric data for FR in Indian adults and validates the anterior clinoid process as a reliable surgical landmark. These findings provide essential reference points for endoscopic and lateral skull base approaches, enhancing diagnostic accuracy and surgical safety while highlighting the need for population-tailored anatomical references in clinical practice.*

Keywords: foramen rotundum, morphometry, radiological, CT scan, dry skull.

INTRODUCTION

Cranial nerve foramina serve as essential exits from the skull, allowing cranial nerves to pass through along with accompanying vascular structures any factor like narrowness or pathological conditions such as achondroplasia, fibrous dysplasia and osteopetrosis may led to severe clinical implications. Foramen rotundum (FR) can be involved by nasopharyngeal tumor or tumors from Gasserian ganglion (1). There is always left–right asymmetry in FR and it has been reported to have 0.38 mm of left-right asymmetry with 95% of confidence interval (2). and it is also reported that incidence of trigeminal neuralgia (TN) is more on right side due to narrower FR on the right side of the cranium causing entrapment of the maxillary nerves as a primary cause (3, 4) and management of atypical facial pain can be done through transfacial transpterygomaxillary access to FR and the maxillary nerve (5). Non-visualization of FR on radiograph suggests that the tumors is originating in or extending to the pterygopalatine fossa, from oral, orbital, or maxillofacial regions (6). It has been reported that FR can be located inside sphenoidal sinus (SS) or embedded in the wall of the SS, which must be evaluated before endoscopic endonasal transsphenoidal approach (EETA) for skull base lesion (7). It has also been proposed that the lateral transorbital approach (LTOA) related to FR offers an alternative for repairing lateral sphenoid sinus encephaloceles, bypassing the risks associated with EEA (8). Therefore, FR is clinically important foramen of the middle cranial fossa in skull base surgery. The FR is in the greater wing of the sphenoid bone, below and behind the superior orbital fissure (SOF) in the middle cranial fossa. It leads to the pterygopalatine fossa, positioned above and to the side of the pterygoid canal's opening and the maxillary nerve, stemming from the trigeminal ganglion, traverses this foramen (9). The average size of FR is 3.26 x 2.66 mm (10). The FR can be of various shape and can have partition (11-13). The FR arises from the embryonic foramen lacerum anterius, situated between the orbitosphenoid and alisphenoid. A bony spur typically forms from the greater wing of the sphenoid bone, segregating the foramen rotundum from the superior orbital fissure; however, its absence may lead to a persistent foramen lacerum anterius, predominantly observed in lower mammals like rodents and uncommon in humans. Any discrepancies in the development may led to accessories foramen and study have shown that there can be rotundal foramens transmitting emissary vein (14). The FR is oval-shaped during fetal development but generally becomes round-shaped after birth. Therefore, skull base foramina variations are clinically crucial for diagnosis and safe surgery, requiring in-depth knowledge of their dimensions, topographical anatomy and morphological variations. Understanding these ensures the assessment of potential neurovascular impingement in various conditions, aiding both neoplastic and non-neoplastic diagnoses (10, 15, 16).

Utilizing cranial nerve landmarks in surgery prevents injury and assessing their distances from vital structures is crucial in lateral cranial base approaches (6, 7). Suprazygomatic and under zygomatic approaches have been proposed in infants less than six months and adults for maxillary block or radiofrequency thermocoagulation, respectively, at FR (19, 20).

Modern magnetic resonance imaging (MRI) and computed tomography (CT) imaging offer unprecedented views of skull foramina in living individuals, revolutionizing diagnostic medicine. Understanding size ranges and symmetry variations in these foramina greatly assists in assessing radiologic films for diagnostic purposes (21-23). Deciphering skull base CT scans can be challenging, especially when identifying small openings, which might provoke curiosity or uncertainty. Therefore, recognizing variants is vital to avoid potential confusion in interpretation (24).

The literature on FR predominantly focuses on the Western population and detailed morphometric analysis in Indian subjects are lacking. This study aims to bridge these gaps by conducting anatomical and morphometric evaluations specifically in the Indian population by observing the anatomical features and morphometric details of skull base foramina on both side in dry bones and in CT scans of patients and taking anterior clinoid process and the new reference point for FR. ❑

MATERIALS AND METHODS

The morphometric study was a collaborative effort between the Department of Anatomy, All India Institute of Medical Sciences (AIIMS), New Delhi, and the Departments of Anatomy and Radiodiagnosis of Vardhman Mahavir Medical College & Safdarjung Hospital, New Delhi, India. Thirty dry adult human skulls and CT scans from 30 adult patients were included in the study. The present study utilized dry adult human skulls with normal gross morphology excluding those with gross deformities or defects, along with CT scans from non-traumatic adult patients aged 18 and above, without a history of head trauma, congenital cranial defects, severe destructive neoplastic or inflammatory lesions of the skull base or surrounding soft tissue and bone dysplasia involving the skull.

Foramen rotundum measurements in dry skulls were recorded endocranially using digital Vernier calipers with sensitivity 0.1 mm. High-resolution unenhanced CT scans were conducted using a 40-slice Philips Brilliance 190 P scanner. Observations on foramina in dry skull included dimensions, shape, margins, confluence with adjoining foramina, septation and distances from anterior clinoid process, among other parameters. This included axial CT scans slice with a slice thickness of 0.8 mm and exposure setting of 120 kV; 250 mAs; 0.75 s rotation times; 0.417 pitch values, 6x0.75 mm collimation; and 512X512 matrixes. The images were transferred to the workstation and then a Philips CT Viewer was used to measure the dimensions of the FR on coronal sections at the smallest level viewed on CT images. The recorded observations were meticulously tabulated and discussed in light of the previous literature. Statistical analysis, performed using paired t-tests with SPSS software version 19.00, considered $p \leq 0.05$ as statistically significant. This analysis aimed to compare morphometric parameters between right and left sides, taking into consideration mean values, standard deviation (SD) and range. ❑

RESULTS

Observation of foramen rotundum in dry skull

Anatomical features – The foramen was bilaterally present in all examined dry skulls. Most had a round shape except for one case where the FR showed a reniform outline bilaterally (Figure 1). Margins were consistently regular across all skulls, with no septation or confluence observed. Unusual morphological features were absent in any of the dry skulls examined.

Morphometric evaluation – The morphometric observations of the FR are depicted in Table 1.

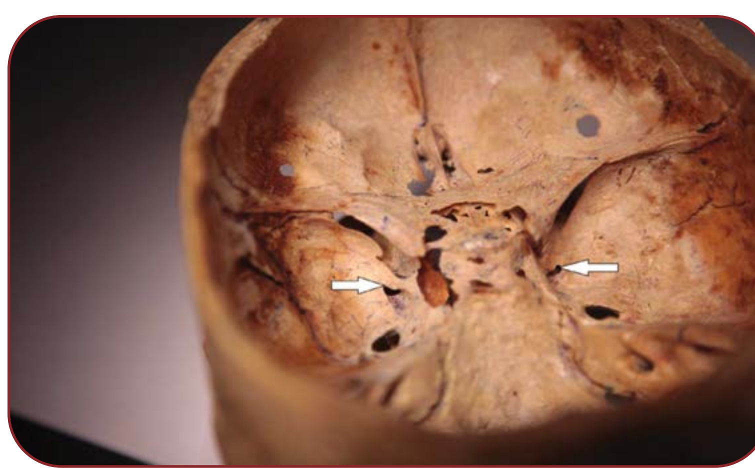

FIGURE 1. Foramen rotundum in dry skull

S. no.	Parameters	Mean±SD (mm) Range: max–min (mm)		p-value
		Left (n=30)	Right (n=30)	
01	Breadth/horizontal diameter	3.82±0.99 (7.80–2.50)	3.82±0.91 (7.20–2.50)	0.998
02	Height/vertical diameter	3.59±0.65 (5.20–2.50)	3.54±0.77 (5.20–2.50)	0.720
03	Distance between foramen rotundum and the anterior clinoid process	10.50±1.19 (12.50–8.20)	10.50±0.84 (12.80–9.00)	0.990

SD: standard deviation

TABLE 1. Morphometric observations of foramen rotundum in dry skulls

S. no.	Parameters	Mean±SD (mm) Range: max–min (mm)		p-value
		Left (n=30)	Right (n=30)	
01	Breadth /horizontal diameter	2.94±0.53 (4.10–2.20)	2.85±0.45 (3.70–2.20)	0.354
02	Height/vertical diameter	2.54±0.44 (3.40–1.80)	2.40±0.44 (3.70–1.70)	0.052
03	Distance between foramen rotundum and the anterior clinoid process	14.06±1.86 (19.50–10.30)	14.15±1.72 (17.20–10.80)	0.666

SD: standard deviation

TABLE 2. Morphometric observations of foramen rotundum in computed tomography scan

Observation of foramen rotundum in computed tomography scan

Anatomical features – It was present bilaterally in all CT scans of examined patients. The shape of the foramen was found to be round with regular margins in all CT scans. There was no evidence of septation or confluence of FR in any of the studied CT scans (Figure 2).

Morphometric evaluation – The morphometric observations of the foramen rotundum are depicted in Table 2.

The mean length and width of FR in dry skulls as well as in CT scans of patients in the present study did not show any significant difference between the two sides on statistical analysis (Tables 1 and 2). ❑

DISCUSSION

With embryonic development, the shapes of FR change from oval to round (14). Most of the published studies have described round-shaped FR (12, 25-27), which is in agreement with our findings. However, we found one case of reniform FR. In our study, FR was present bilaterally and without any deviation as sug-

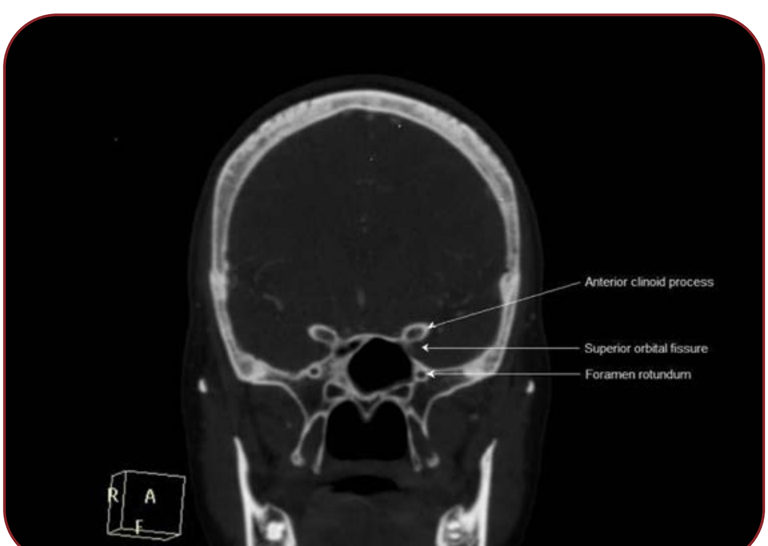

FIGURE 2. Foramen rotundum in computed tomography scan

gested in some of the studies about the duplication of FR due to septation (11-13). No accessory FR were present in our specimens, as earlier reported (24).

The mean length and width of FR was found to be greater than those reported by earlier studies in different population, except for some studies which found smaller dimensions (28, 29) (Table 3). Berlis *et al* conducted an anatomic and radiographic study of the FR on 60 macerated human skulls, with digital calipers and CT scan being used in the anatomic and radiological experiments, respectively. Foramen rotundum was studied in the coronal section of the CT scan, which revealed a mean breadth of 3.29 mm and 3.11 mm, respectively, and a mean height of 3.09 mm and 3.13 mm, respectively (30). Berge and colleagues explored the FR among one hundred dry human skulls. They observed that FR was mostly symmetrical, with asymmetry being found in only 8% of cases. Morphometric measurements were performed by using the digital caliper. The average height and width of FR was 2.66×3.26 mm, respectively. The left-sided foramina were found to be usually larger than the right-sided one (10), which suggested that the average diameter of FR can vary in different populations with length and breadth ranging from 5.20–2.50 mm and 4.10–2.20 mm, respectively. In our study, statistical analysis showed no significant difference between the two sides.

Few studies have provided the dimensions of FR in CT scans (30-32). Ginsberg *et al* performed a radiological study of FR on 123 CT scans of apparently normal patients and found that FR was consistently present in all subjects. Also, they observed that the inferior rotundal canal was present in 16% of patients and lateral rotundal canal in 8% of subjects (24).

Sepahdari *et al* performed temporal bone CT scans of 50 adult patients with facial and trigeminal nerve pathology. They found a mean diameter of the right and left FR of 3.00 mm and 3.01 mm, respectively (2).

The dimensions of FR as measured on CT scans are comparable to our study and show no significant difference between the two sides on statistical analysis (Table 4).

Various studies found asymmetry in the dimension of FR of both sides (2-4), which is in agreement with our study the FR was bigger on the left side than the right one.

TABLE 3. Mean dimensions of foramen rotundum in dry skulls across various studies

Studies	Mean length (mm)		Mean width (mm)	
	Left	Right	Left	Right
Berlis (30)	3.09		3.29	
Berge (10)	2.66		3.26	
Dogan (28)	4.36±0.66	4.48±1.15	3.36±0.54	3.34±0.92
Karthikeyan (29)	4.56	4.01	3.96	3.74
Present study	3.59±0.65	3.54±0.77	3.82 ± 0.99	3.82±0.91

TABLE 4. Mean dimensions of foramen rotundum in computed tomography scans across various studies

Studies	Mean length (mm)		Mean width (mm)	
	Left	Right	Left	Right
Berlis (30)	3.13		3.11	
Bhattarai (31)	2.41±0.49		2.40±0.55	
Erbagci (32)	2.5	2.4	3.1	3.2
Present study	2.54±0.44	2.40±0.44	2.94±0.53	2.85±0.45

Landmarks related to FR have been reported. The distance between FO and FR was greater by 11.09±1.9 mm on the right side than the left one (25). Most of the published studies have taken the distance from the center of FR to the midline (29), while we explored the distance between the adjacent anterior clinoid process and the FR, which was 10.50±1.19 mm x 10.50±0.84 mm on dry skull and 14.06±1.86 x 14.15±1.72 mm on CT scans, but we observed no statistically significant difference between the two sides (Tables 1 and 2). ❑

CONCLUSION

The present study systematically evaluates the morphometric and anatomical characteristics of the FR in dry skulls and CT scans of an Indian adult population, addressing a critical gap in population-specific skull base anatomy literature. Our findings confirm the bilateral presence of the FR in all specimens, with a predominantly round shape and regular margins, devoid of accessory foramina, septations, or confluence. While dry skull measurements revealed slightly larger dimensions than CT scans, there was no statistically significant asymmetry between the left and right sides in either modality, which reinforced the relative bilateral symmetry of the FR in this cohort.

A key contribution of the current study is the establishment of the anterior clinoid process as a consistent surgical landmark, with mean distances to the FR of 10.50±1.19 mm (dry skulls) and

14.06±1.86 mm (CT scans) showing no significant lateralization. These measurements provide critical reference points for endoscopic, transsphenoidal and lateral skull base approaches, where precise localization of the FR is essential to avoid neurovascular injury and optimize surgical outcomes.

Comparatively, our data align with global studies but also highlight subtle population-specific variations, underscoring the necessity of regionally tailored anatomical references for diagnostic radiology and surgical planning. The absence of significant asymmetry in the Indian population contrasts with prior reports of right-sided predominance in trigeminal neuralgia, suggesting that morphometric variations alone may not fully explain clinical lateralization – a finding that warrants further investigation.

In conclusion, the present study enhances the anatomical database for the FR in the Indian population, offering practical insights for clinicians and surgeons navigating the complexities of skull base pathology. Future research should explore correlations between FR morphology and clinical syndromes, as well as intraoperative validation of these landmarks to refine surgical precision and patient safety. ❑

Conflicts of interest: none declared.
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