A Morphological and Morphometric Study of Foramen Ovale in Dry Skulls of Indian Population

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Background and Aim The foramen ovale is a clinically significant foramen present in the skull base. The mandibular nerve is an important structure traversing this foramen and the trigeminal ganglion is also located just above the foramen ovale in the Meckel’s cave. These two structures are targeted by neurosurgeons and pain physicians in patients with trigeminal neuralgia. Clinical procedures for treating trigeminal neuralgia necessitate very precise knowledge about the foramen ovale. Hence, this study was designed to evaluate the morphology and morphometry of foramen ovale and its variations in dry skulls of India.

Materials and Methods This study was conducted in 100 adult dry skulls of either sex. The foramen ovale was assessed for morphology and morphometry bilaterally using digital Vernier calipers. The summary data for all the measurements are presented in this study. The statistical analysis was performed using SPSS version 19.

Results The most common shape of the foramen ovale was found to be oval. Oval-shaped foramen ovale was present in 72% (right side) and 68% (left side) of dry skulls that were examined. A mean length of 6.62 ± 1.11 mm (right side) and 6.72 ± 1.08 mm (left side) and width of 3.78 ± 0.89 mm (right side) and 3.89 ± 0.73 mm (left side) were observed. The distance between the foramen ovale and the zygomatic point was 35.65 ± 3.24 mm (right side) and 34.91 ± 2.58 mm (left side). The distance between the zygomatic point and the anterior margin of the external auditory meatus was 21.79 ± 3.25 mm (right side) and 18.62 ± 2.37 mm (left side).

Conclusion An in-depth knowledge of the morphology and morphometry which include the different metric and nonmetric parameters and the variations in foramen ovale in dry skulls has been studied, which will be helpful to neurosurgeons and pain physicians to plan their clinical procedures which involve the base of skull.

Keywords ► morphology ► morphometry ► foramen ovale ► skull base

Introduction

The foramen ovale is present in the infratemporal surface of the greater wing of sphenoid and it is an important foramen which transmits the mandibular division of the trigeminal nerve, lesser petrosal nerve, emissary veins, and accessory meningeal vessels.1 The morphology and morphometry of foramen ovale are different among various subgroups of human population.2–4 These morphometric details are lacking in the Indian population to the best of our knowledge. The mandibular nerve which traverses the foramen ovale and trigeminal ganglion that is situated in the Meckel’s cave are targeted by neurosurgeons and pain physicians in patients with trigeminal neuralgia. Trigeminal rhizotomy procedures which are done for treating trigeminal neuralgia necessitate an in-depth knowledge about the foramen ovale. Hence, this study was designed to evaluate the morphology and morphometry of foramen ovale and its variations in dry skulls of India. The primary objectives of this study were to describe (1) the morphology of foramen ovale and (2) its distance from zygomatic point in dry skulls of Indian
population. The secondary objectives of the study were (1) to compare the distance of foramen ovale from zygomatic point between right and the left side and (2) to describe the presence of accessory foramina around the foramen ovale in the dry skulls of Indian population.

Materials and Methods

This study was designed as a cross-sectional study to describe the various morphological and morphometric parameters of 100 dry skulls belonging to Indian population. This study was conducted in Department of Anatomy, Sri Venkateshwarav Medical College Hospital & Research Center, which is located in Pondicherry. This medical college is a tertiary health care center located in the suburban region of Pondicherry which is a coastal town along the eastern coast of India. The study population comprised of adult dry skulls of India, which were collected from different medical colleges in Pondicherry. Adult dry skulls of either sex, which had fused basisphenoid, were included in the study. The specimens with damaged skull base were excluded from the study. Thirty adult dry skulls of either sex were obtained from Sri Venkateshwarav Medical College Hospital & Research Center and the remaining 70 skulls were obtained from other medical colleges in Pondicherry with prior permission from the respective colleges. All skulls were analyzed in the Department of Anatomy, Sri Venkateshwarav Medical College Hospital & Research Center between the years 2016 and 2018. The shape, length, and width of the foramen ovale were assessed (Fig. 1). The distance between foramen ovale and zygomatic point was measured (Fig. 2) using digital Vernier calipers. The other measurements which were assessed include (1) distance from anterior margin of external acoustic meatus (EAM) to zygomatic point (Fig. 3), and (2) accessory bony structures of foramen ovale. All measurements were made using “INSIZE” digital sliding Vernier calipers according to the methodology followed by Kanyata et al. This study was conducted as an observational study. The sample size was estimated to be 90 using the formula for one sample t-test and substituting the values: delta = 0.65 mm, standard deviation = 2.17 mm with a significance level of 0.05 and power of 0.80. The summary data for all the measurements are presented in this study. Subgroup analyses for all the above-mentioned parameters were performed between the right- and the left-sided foramina. The statistical analysis was performed using SPSS version 19.

Results

Shape of Foramen Ovale

The most common shapes of foramen ovale found in our study are oval, irregular, almond, and D-shaped. Some of the uncommon shapes of foramen ovale found in our study included pear and round shapes. It was found that the foramen ovale was oval in shape in 72% of the skulls on the
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right side as compared with 68% of the skulls on the left side (►Table 1).

Accessory Bony Structures
It was found that there were no accessory bony structures associated with foramen ovale in most of the dry skulls (86% of the right side vs. 92% on the left side). But some uncommon accessory bony structures that were found to be associated with foramen ovale included a bony shelf or a complete or incomplete pterygoalar bar (►Table 2).

Foramen of Vesalius and Canaliculus Innominatus
The foramen of Vesalius is an accessory foramen which is found anterior to the foramen ovale and when present will allow the passage of the emissary veins.¹ This foramen was found to be present in 7% of the dry skulls on the right side and 3% on the left side. The canaliculus innominatus was found in 1% of dry skulls on the right side and was not present in any of the dry skulls on the left side.

Morphometry of Foramen Ovale
The longest internal diameter of the foramen ovale was measured as the length of the foramen using a sliding digital Vernier calipers. However, the shortest internal diameter was measured as the width of the foramen ovale. The mean length of the foramen ovale was found to be 6.62 ± 1.11 mm on the right side and 6.72 ± 1.08 mm on the left side. The mean width of the foramen ovale was found to be 3.78 ± 0.89 mm on the right side and 3.89 ± 0.73 mm on the left side.

An imaginary line passing through the centers of the two foramen ovales meet the zygomatic arch on either side. The point at which this line intersects the zygomatic arch is known as the zygomatic point. The distance between the foramen ovale and the zygomatic point was also measured in our study and this distance was found to be 35.65 ± 3.24 mm on the right side and 34.91 ± 2.58 mm on the left side.

The distance between the zygomatic point and the anterior margin of the EAM was measured and it was found to be 21.79 ± 3.25 mm on the right side and 18.62 ± 2.37 mm on the left side.

Comparison of Different Morphometric Parameters
It was found that the distance between the foramen ovale and zygomatic point on the right side was significantly lower than the distance between the foramen ovale and zygomatic point on the left side (p = 0.007) (►Table 3).

It was also found that the distance between the anterior margin of the EAM and the zygomatic point of the foramen ovale on the right side was significantly higher compared with the distance between the anterior margin of the EAM and the zygomatic point on the left side (p < 0.001).

Other morphometric parameters like the length and the width of the foramen ovale were not found to be significantly different between the right and the left sides in our study.

Discussion
The knowledge about the morphology and morphometry of the foramen ovale will be useful in planning for surgeries involving trigeminal ganglion or while doing rhizotomy procedures. Such knowledge will be of use to neurosurgeons as well as pain physicians. These morphometric parameters

Table 1 Frequency and percentage of various shapes of foramen ovale

<table>
<thead>
<tr>
<th>Variables</th>
<th>Right side</th>
<th>Left side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency</td>
<td>Percent</td>
</tr>
<tr>
<td>Almond</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>D-Shape</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Irregular</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Oval</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td>Pear</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Round</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
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</table>
and the different variations seen in foramen ovale can also add to the existing literature about the foramen which may be useful to Anatomists.

Morphology
Shape of Foramen Ovale
Ray et al observed that 63% of the skulls on the right side and 60% of the skulls on the left side possessed oval-shaped foramen ovale. Khan et al have reported that one skull has a large irregular foramen with 12 mm APD (anteroposterior diameter) and 6 mm TD (transverse diameter). So it is seen that in our study, the foramen ovale is oval shaped in two-thirds of the skulls which is in agreement with earlier studies. The shape of the foramen ovale can cause unforeseen difficulties in surgical procedures if there are any unusual shapes that may be present in the patients.

Accessory Bony Structures
Some of the accessory bony structures that have been found are completely or incompletely ossified pterygoalar and pterygospinous ligaments, bony shelves at the margins of the foramen ovale, and bony septations of the foramen ovale. Khan et al also noted that one skull had a bony spicule which divided the foramen ovale into two. The foramen present in the ossified pterygoalar ligament is termed as foramen of Hyrtl and the foramen present in the ossified pterygospinous ligament is termed as foramen of Civinini. Tubbs et al identified the ossified ligaments of Hyrtl and Civinini in 2.6% of cases. In studies conducted by Reymond et al, it was found that 4.5% of cases had septation in the foramen ovale. Similar results pertaining to the above mentioned morphological variations were also obtained in our study.

When the pterygoalar ligament undergoes ossification, it forms two calcified foramina namely the foramen of Hyrtl and foramen of Civinini. The branches of the mandibular nerve may pass through the foramen of Hyrtl. The lingual branch of the mandibular division of the trigeminal nerve and sometimes artery supplying the trigeminal ganglion may pass through the foramen of Civinini. Entrapment of the lingual branch in the foramen of Civinini may result in numbness of the tongue and pain during movements of the mandible. In old age, the pterygoalar ligament undergoes ossification around the nerve and the middle meningeal artery. When the nerve undergoes inflammation, there is no space for the nerve to expand and this may be one of the predisposing factors for trigeminal neuralgia. Such accessory bony structures may hinder easy access during percutaneous procedures targeting the foramen ovale.

Table 2 Frequency and percentage of various accessory bony structures of foramen ovale

<table>
<thead>
<tr>
<th>Variables</th>
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<th></th>
<th>Left side</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency</td>
<td>Percent</td>
<td>Frequency</td>
<td>Percent</td>
</tr>
<tr>
<td>No</td>
<td>86</td>
<td>86</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>Bony shelf</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Complete pterygoalar bar</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>FV&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>FV&lt;sup&gt;a&lt;/sup&gt; and CI</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Incomplete pterygoalar bar</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Abbreviations: CI, canaliculus innominatus; FV, foramen vesalius.

Table 3 Frequency and percentage of various shapes of foramen ovale

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Paired differences</th>
<th>t</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of right foramen ovale</td>
<td>100</td>
<td>6.6293</td>
<td>1.1187</td>
<td>0.14967</td>
<td>–0.751</td>
<td>0.454</td>
</tr>
<tr>
<td>Length of left foramen ovale</td>
<td>100</td>
<td>6.7205</td>
<td>1.0823</td>
<td></td>
<td>–1.192</td>
<td>0.236</td>
</tr>
<tr>
<td>Width of right foramen ovale</td>
<td>100</td>
<td>3.7873</td>
<td>0.89225</td>
<td>0.07318</td>
<td>–0.12806</td>
<td>0.903</td>
</tr>
<tr>
<td>Width of left foramen ovale</td>
<td>100</td>
<td>3.8973</td>
<td>0.73629</td>
<td></td>
<td>–0.12806</td>
<td>0.903</td>
</tr>
<tr>
<td>Distance between foramen ovale and zygomatic point on right side</td>
<td>100</td>
<td>35.655</td>
<td>3.2423</td>
<td>0.12806</td>
<td>2.751</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Distance between foramen ovale and zygomatic point on left side</td>
<td>100</td>
<td>34.911</td>
<td>2.573</td>
<td></td>
<td>1.873</td>
<td>0.066</td>
</tr>
<tr>
<td>Distance from anterior margin of EAM to zygomatic point on right side</td>
<td>100</td>
<td>21.793</td>
<td>3.2494</td>
<td>0.39139</td>
<td>3.2494</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Distance from anterior margin of EAM to zygomatic point on left side</td>
<td>100</td>
<td>18.623</td>
<td>2.3721</td>
<td></td>
<td>1.873</td>
<td>0.066</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; EAM, external auditory meatus.
Canaliculus Innominatus
The lesser petrosal nerve is a branch that arises from the tympanic plexus formed by the ramification of the glossopharyngeal nerve over the promontory, which usually passes through the foramen ovale, but rarely may pass through a separate foramen that lies between the foramen ovale anteriorly and foramen spinosum posteriorly, called the canaliculus innominatus. The presence of this canaliculus is rarely reported in other studies. In the present study, only one of the dry skulls had this structure.

Morphometry
Length and Width of Foramen Ovale
The study by Ray et al found the length to be 7.46 mm on right side and 7.01 mm on left side and the width to be 3.21 and 3.29 mm on the right and left sides, respectively. Lang et al found the length of adult foramen ovale to be 7.2 mm and width to be 3.7 mm. Hwang et al observed the length to be 8.24 mm on left side and 8.1 mm on the right side and width to be 4.12 and 4.01 mm on the right and left sides, respectively. Somesh et al reported the mean AP diameter to be 7.64 and 7.56 mm on right and left sides, respectively. In the study conducted by Wadhwa et al, the mean length of the right and left foramen ovale was found to be 6.8 and 6.5 mm and the mean width of right and left foramen ovale to be 3.7 and 4 mm, respectively. These results were found to be closely related to the data obtained from the present study. This might be due to the fact that the number of nerve fibers passing through the trunk of the mandibular nerve is fairly constant in the human population.

Foramen Ovale, External Acoustic Meatus, and Zygomatic Point
The foramen ovale can be identified with the surface markings—zygomatic point, pupil point, and maxillary point. The zygomatic point can be identified by a point from anterior margin of the EAM. The foramen ovale is usually located at the apex of a pyramid whose base is formed by joining zygomatic point, pupil point, and maxillary point. With the help of the above-mentioned points, one can locate the foramen ovale percutaneously for rhizotomy procedures.

Kanyata et al reported the mean distance between EAM and zygomatic point to be 23.54 ± 2.26 mm and 23.49 ± 2.16 mm on the right and left sides, respectively. Patil et al found the mean distance between the foramen ovale and zygomatic point was found to be 32.58 ± 1.72 mm and 32.75 ± 1.31 mm on the right and left sides, respectively. The results from the present study which is closely related to the previous studies may be used by neurosurgeons and pain physicians for performing percutaneous rhizotomy procedures in the Indian population.

Though the morphometric measurements were made using digital Vernier calipers in dry skulls with utmost care, imaging modalities may be used in further studies to correlate this data with similar morphometric measurements in live patients as some variations may be present.

Conclusion
The results of this study will provide an in-depth knowledge about the foramen ovale in dry skulls to the anatomists. This knowledge will also be useful to clinicians and surgeons in planning and executing procedures of the skull base in Indian population. The variations in the foramen ovale are important to the clinicians as they may pose some difficulties in the clinical procedures and thus prior knowledge of these variations may mitigate these difficulties.

Conflict of Interest
No external funding and no conflict of interest declared.

References