Original Article

Morphometric Analysis of Foremen Magnum and Occipital Condyles Using CT Scan and its Relation to Gender

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ABSTRACT

Objective: This study focuses on the morphometric features of the foramen magnum and occipital condyles to assist in surgical procedures and forensic identification, with an emphasis on their correlation with gender.

Study Design: Retrospective study, analysing 3D-CT images of the skull base from 111 Pakistani individuals.

Place and Duration of Study: This study was conducted at the Radiology department of M. Islam Teaching Hospital, Gujranwala from March 2024 to February 2025.

Methods: Head CT scans of 111 individuals (58 males, 53 females) were analyzed using a Toshiba Aquillion 64-slice CT scanner (1 mm slice thickness, non-contrast). Measurements included foramen magnum length, width, area; right and left occipital condyle length and width; and minimum and maximum intercondylar distances. Data were analyzed using SPSS Version 23.

Results: A total of 111 CT scans were analyzed. The mean foramen magnum length was 36.68 ± 3.93 mm and width 29.76 ± 3.08 mm. Length, width, and intercondylar distances showed statistically significant differences between males and females. The mean right and left occipital condyle lengths were 23.75 mm and 23.47 mm, respectively. Left condyle width averaged 11.73 mm in males and 11.69 mm in females. The mean foramen magnum area was significantly larger in males (893.77 ± 164.82 mm²) than in females (828.17 ± 158.85 mm², $p < 0.05$).

Conclusion: Morphometric measurements of the foramen magnum and occipital condyles serve as vital anatomical landmarks that enhance the safety and precision of surgical planning in the craniovertebral region. They also provide CT-based, region-specific anatomical data for the Pakistani population and contribute to forensic identification by highlighting gender-based differences.

Key Words: Computerized tomography, Foramen magnum, Morphometry, Occipital condyles, Skull

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INTRODUCTION

The human skull, a complex structure housing the brain and sensory organs, serves as the foundation for understanding cranial anatomy. Within this intricate framework, the foramen magnum and occipital condyles play pivotal roles in both forensic identification and surgical interventions. The foramen magnum, the largest foramen in the human skeleton, is a vital anatomical landmark at the base of the cranium.[1] The tectorial membrane and apical ligament extend through the foramen magnum to anchor at its margins.[2]

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Anterolateral to the foramen magnum, the occipital condyles are two distinct bony projections located on the inferior surface of the occipital bone.[3] The craniovertebral junction (CVJ), comprising the foramen magnum, occipital condyles, and the first two cervical vertebrae (atlas and axis), relies on the occipital condyles as pivotal structures that connect the cranium to the spinal axis while maintaining the stability and structural integrity of this complex region.[4,5]

The foramen magnum's shape and dimensions are key determinants in the development and progression of numerous craniovertebral junction disorders.[2] The analysis of foramen shapes using CT scans has become increasingly important in clinical practice. Research states that surgical access to the skull base is more efficient when the foramen magnum is round, oval, or hexagonal, as these shapes offer increased working space.[6] While classical anatomy and neurosurgery texts traditionally describe the foramen magnum as oval, being wider posteriorly, and with its longest diameter in the anteroposterior direction. Studies such as those by Ilhan Bahsi[2] reveal that it can also appear as tetragonal, round, egg-shaped, hexagonal, pentagonal, or irregular.

Morphometric analysis of the occipital condyles is vital for determining the safe extent and direction of condylar drilling, preventing occipito-cervical destabilization, avoiding injury to the neurovascular structures of the hypoglossal canal, and improving surgical techniques for addressing pathologies in this complex anatomical region.[3,4]

The sensitivity of the craniovertebral junction to surgical manipulation has led to considerable debate regarding the most effective surgical approach, often described as the "surgical corridor," which refers to the space through which a surgeon accesses a lesion.[7] This concept emphasizes the necessity of selecting an appropriate pathway to ensure safe and efficient intervention. Additionally, morphometric analysis offers an affordable approach for determining sex with reasonable accuracy, particularly when dealing with incomplete skeletal remains from mass disasters or extensively decomposed bodies.[8] Studies have shown that sex can be accurately determined from cranial remains, with accuracy levels ranging between 65% to 88%.[1] In transcondylar surgical approaches to the foramen magnum, such as those employed in tumor resections, a thorough understanding of the anatomical features and variations of the foramen magnum and occipital condyles is essential for enhancing surgical exposure and minimizing the risk of neurovascular injury. Several studies have highlighted these variations, stressing the importance of tailoring surgical techniques to the specific anatomical characteristics of this region.[9]

METHODS

This study employed a retrospective study-based design, analysing three-dimensional computed tomography (3D-CT) images of the skull base from 111 Pakistani individuals with documented age and sex. Study was conducted at the Radiology department of M. Islam Teaching Hospital, Gujranwala from March 2024 to February 2025 after taking ethical approval from Institute's Review Board. The requirement of consent form was waived as it was conducted retrospectively.

Sampling Method: Simple convenience sampling.

Sample Size: Sample size of 111 participants is calculated with 90% confidence level, 7.1% absolute precision, and by taking the expected percentage of accuracy of foramen magnum in sex estimation as 71%. Following formula is used for sample size calculation:

$$n = \frac{z^2_{1-\alpha/k} P(1-P)}{d^2}$$

Inclusion Criteria: The study analyzed normal human skulls from patients over 18 years old of both sexes, who underwent CT scans for various medical or surgical diagnostic purposes. Only high-quality reconstructed CT images were considered.

Exclusion Criteria: Our exclusion criteria included CT images from patients under 18 years of age, low-quality images with artifacts or patient rotation, or images that did not fully capture the foramen magnum region and showed evidence of congenital anomalies, fractures, or previous surgeries involving the skull base region.

CT Machine: Head CT scans without contrast were conducted on a Toshiba Aquillion 64-slice CT machine with a slice thickness of 1 mm and analyzed using the software.

Measurements: In this study, 3D-CT images were evaluated, and several parameters were measured directly on the scanner's console using a millimeter scale. Observers were permitted to modify contrast, brightness, and zoom settings for enhanced visualization. One radiologist and one researcher took the readings independently to reduce the inter observer bias. The measured parameters were:

- **Foramen magnum length (FML):** To measure the anteroposterior length of the foramen magnum in the mid-sagittal section, the distance between the basion (anterior margin) and the opisthion (posterior margin) was recorded.
- **Foramen magnum width (FMW):** The transverse diameter of the foramen magnum was taken as the widest distance between its sides, measured at the points of greatest outward curve and perpendicular to the mid-sagittal section.
- **Right occipital condyle length (ROCL):** The length of the right occipital condyle was determined by measuring the span between its most anterior and most posterior margins along the longitudinal axis.
- **Left occipital condyle length (LOCL):** The length of the left occipital condyle was determined by measuring the span between its most anterior and most posterior margins along the longitudinal axis.
- **Right occipital condyle width (ROCW):** The distance from the outer side to the inner side of the right occipital condyle was measured as its width, at a right angle to its length.
- **Left occipital condyle width (LOCW):** The distance from the outer side to the inner side of the left occipital condyle was measured as its width, at a right angle to its length.
- **Intercondylar distance minimum (ICDMn):** The measurement between the innermost edges of the right and left occipital condyles was taken.
- **Intercondylar distance maximum (ICDMx):** The measurement between the outermost edges of the right and left occipital condyles was taken.
- **Foramen magnum area (FMA):** The area of the foramen magnum (FMA) was determined by applying the formula proposed by Ihsanullah et al.,[10] which is: Area = $1/4 \times \pi \times$ length $\times$ width**.**

Foramen magnum shape: The foramen magnum (FM) shapes were grouped into oval, round, egg, hexagonal, pentagonal, tetragonal, and irregular categories. A three-member team identified these shapes to reduce observational bias.

Data Analysis: Data was analyzed in SPSS version 23. For continuous data, the mean and standard deviation (SD) were calculated. Percentages were used for categorical data. All the parameters of the foramen magnum were compared between males and females using the Mann-Whitney U test and the independent samples t-test, with a significance level of $p < 0.05$.

RESULTS

A total of 111 CT scans were analyzed which showed much variation in the measurements. The mean of foramen magnum length was 36.68 mm ± 3.93 and the mean of foramen magnum width was 29.76 mm ± 3.08. The difference of mean of foramen magnum length and width for males and females was statistically significant with p values .008 and 0.053, respectively. The right occipital condylar length mean was 23.75 mm and for left it was 23.47 mm. The mean width of right occipital condyle was 11.64 mm in males and 11.39 mm in females. The mean width of left occipital condyle was 11.73 mm for males and 11.69 mm for females. The difference of mean of minimum and maximum intercondylar distance for males and females was statistically significant with p values of 0.024 and 0.008, respectively. The mean of area of foramen magnum for males was 893.77 mm ± 164.82 and for females 828.17 mm ± 158.85 with the difference being significant (p-value < 0.05). The comparison of all variables is shown in Table-1. Figure-3 bar charts show percentages of various shapes of foramen magnum in males and females.

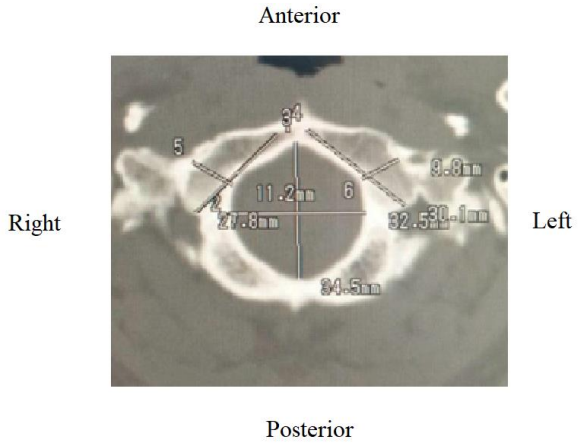

Figure No. 1A: Transverse section of the skull showing measurements of foramen magnum and occipital condyles. **1:** Foramen magnum length (34.5mm), **2:** Foramen magnum width (32.5mm), **3:** Right occipital condyle length (27.8mm), **4:** Left occipital condyle length (30.1mm), **5:** Right occipital condyle width (11.2mm), **6:** Left occipital condyle width (9.8mm).

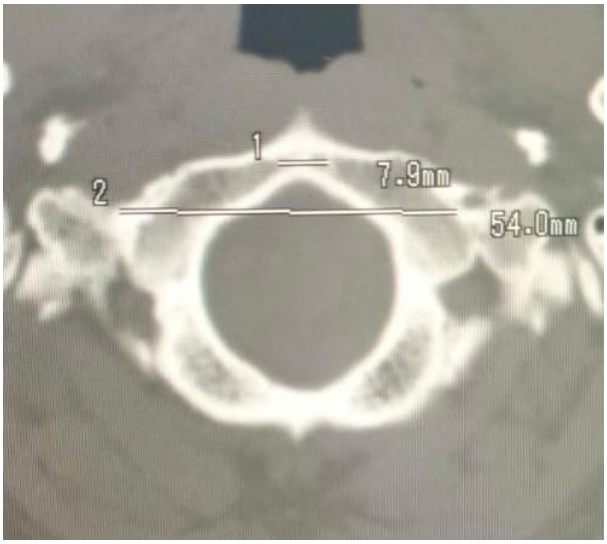

Figure No. 1B: Transverse section of the skull showing measurements of Intercondylar distance. **1:** Intercondylar distance minimum (7.9mm), **2:** Intercondylar distance maximum (54mm).

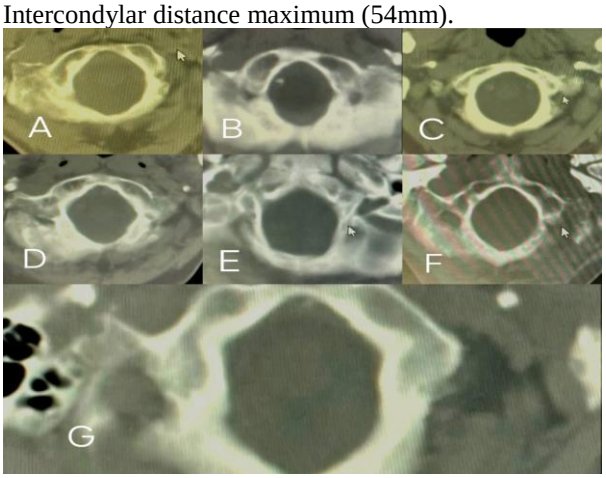

Figure No. 2: Pictures from CT scan showing various shapes of foramen magnum (A- Egg, B-Tetragonal, C-Round, D-Irregular, E-Pentagonal, F-Oval, G-Hexagonal).

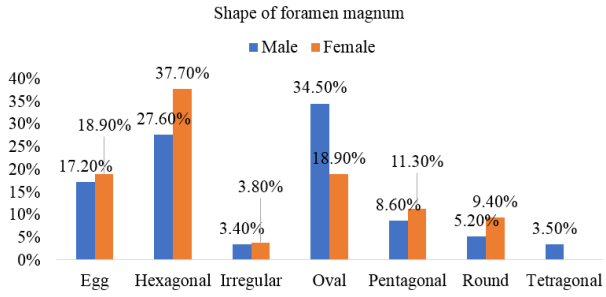

Figure No.3: Shape of Foramen Magnum

The comparative analysis of foramen magnum shapes between males and females reveals distinct morphological differences that align with the dimensional variations observed in the study. In males, the foramen magnum typically exhibits a more elongated oval shape, characterized by a pronounced anteroposterior elongation. Female foramen magnum

shapes tend to display a more hexagonal configuration, with more symmetrical proportions between length and width dimensions.

Table No.1: Comparison of variables in the foramen magnum region

	Male	Female	Total	p-value
FML (mm)	37.5±4.1	35.8±3.5	36.68±3.93	**0.008*** (M)
FMW (mm)	30.2±2.9	29.3±3.2	29.76±3.08	**0.053*** (M)
ROCL (mm)	24.2±2.9	23.3±2.0	23.75±2.52	**0.060** (t)
ROCW (mm)	11.64±1.70	11.39±1.77	11.52±1.72	**0.435** (t)
LOCL (mm)	23.9±2.9	23.1±1.9	23.47±2.48	**0.091** (t)
LOCW (mm)	11.73±1.58	11.69±2.03	11.70±1.80	**0.902** (t)
ICDMx (mm)	48.9±3.9	46.5±6.9	47.77±5.66	**0.008*** (M)
ICDMn (mm)	11.73±2.88	10.47±2.62	11.12±2.81	**0.024*** (M)
FMA (mm^2)	893.77±164.82	828.17±158.85	862.44±164.58	**0.013*** (M)

Note: (M) Mann Whitney U test, (t) Independent sample t-test, (*) Statistically significant (p-value<0.05)

DISCUSSION

The average values of foramen magnum length and width were 36.68 mm and 29.76 mm, respectively. In males the average length was 37.5 mm and average width was 30.2 mm while in females it was 35.8 mm and 29.3 mm, respectively. Our findings are similar to another study by Degno[11] where mean values of length and width of foramen magnum were 35.19 mm and 30.17 mm, respectively. Another study by Ominde[8] on 336 Nigerian patients also showed similar results with average length of foramen magnum being 34.70 mm and average value of width being 30.80 mm. When values for both parameters were separately compared for males and females, the Nigerian population results were almost similar to ours with average length of males 34.72 mm and for females 33.68 mm. This study also shows that the mean of foramen width for males was 30.87 mm and 30.76 mm for females. Atreya[1] study on Nepalese population showed similar results to ours when width of FM was considered being 28.9 mm while results were different for FM length being 33.5 mm. Our findings are closely aligned with two studies from Peshawar by Shahabuddin[12] and Ihsanullah[10] which reported similar foramen magnum dimensions, mean FM length: 35.5 mm and 35.69 mm; mean width: 31.9 mm and 31.58 mm, respectively. This consistency supports the possibility of developing population-specific morphometric baselines within Pakistan. However, a study from Lahore by Majid[13] on dry human skulls recorded significantly smaller values, mean FM length: 32 mm; mean width: 26 mm, highlighting notable variation. Despite being from the same national context, such differences may reflect regional, ethnic, or methodological influences. Although, all of these studies consistently reported FM length being greater than its width, affirming a general anatomical pattern across populations, Gruber[14] reported no sexual dimorphism between male and female gender with respect to the occipital condylar length and width.

A thorough understanding of the foramen magnum area is critical, given its association with conditions like atlas occipitalization and skull base hypoplasia.[8] The area of FM in our study was 862.44 mm^2. These results were quite similar to a study conducted by Ihsanullah[10] where mean area was 885.22 mm^2. Another study by Murshed[9] also had similar findings while considering FM area being 863.35 mm^2.

The occipital bone, due to its structural robustness and protected anatomical location, is highly suitable for sex estimation, particularly when the pelvis is absent. This makes it especially valuable in forensic analysis.[15,16] Morphometric assessment of the foramen magnum is an objective, non-destructive method and should be prioritized before invasive procedures.

Detailed knowledge of occipital condyle anatomy, including their size and shape variations, provides valuable insights for safe and effective surgical intervention.[4] Our study revealed the mean condylar length to be 23.61 mm and the mean condylar width 11.61mm which is higher than the observations made by Gumussoy[5] where the mean length and width were found to be 19.6 mm and 10.3 mm respectively. Similar observation to our study was reported by Rizvi[3] where the mean length and mean width was found to be 23.32 mm and 11.99 mm, respectively.

The average right occipital condyle length and width in males were 24.2 mm and 11.64 mm, respectively, whereas in females these values were 23.3 mm and 11.39 mm. On the left side, the mean occipital condyle length and width were 23.9 mm and 11.73 mm in males, and 23.1 mm and 11.69 mm in females. Thus, on both sides, male skulls exhibited larger measurements than female skulls. In contrast, Sholapurkar[17] in a study on dry adult human skulls, reported no significant sex-based difference in the transverse diameter of the right and left occipital condyles. While our study did not classify condyles into predefined morphological types, the measured lengths are comparable to the shorter

Type I condyles predominantly reported by Ominde et al.[18] This similarity should be kept in mind while dealing our population as limited condylar length can increase the likelihood of joint instability following condylectomy. Thus, occipital condyle morphometry holds clinical importance, as condylar dimensions influence the extent of safe bone removal in transcondylar approaches and play a key role in maintaining occipitocervical stability during skull base surgeries. [19,20]

The morphology and shape of the foramen magnum play a significant role in neurological assessment. In our study, the most commonly observed shape of the foramen magnum in males was oval (34.5%), which is lower than the 40% reported by Anjum.[4] In females, the hexagonal shape was predominant, observed in 37.7% of cases. In another CT based study conducted by Murshed[9] on 110 subjects, the maximum shape observed was round (21.8%). Degno[11] research on adult Ethiopian skulls states that the maximum number of skulls had round shape and accounted 25.9% of the total sample. This was contrary to our study where only 5.20% males and 9.40% females had round shape.

Research by Aljarrah[21] on the Saudi Arabian population, which examined the same parameters of the foramen magnum and occipital condyles, also reported higher values in males compared to females, consistent with our findings.

CONCLUSION

This study highlights the significance of foramen magnum morphometry in two key areas: first, in providing CT-based region-specific anatomical data for the Pakistani population; and second, in its surgical relevance, particularly for craniovertebral procedures, where accurate measurements help define surgical corridors and reduce operative risk. These findings provide essential anatomical reference points that can enhance the safety and precision of surgical planning in the craniovertebral region.

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Author's Contribution:

Concept & Design or acquisition of analysis or interpretation of data:	Zumirah Atiq, Amna Javaid, Ayesha Sanaullah
Drafting or Revising Critically:	Athar Maqbool, Saman Ali, Humna Akhtar Ali
Final Approval of version:	All the above authors
Agreement to accountable for all aspects of work:	All the above authors

Conflict of Interest: The study has no conflict of interest to declare by any author.

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