

Research Article



Morphometric Analysis of the Foramen Magnum and the Occipital condyles

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ABSTRACT

Anomalies of craniovertebral junction are of interest not only to an anatomist, but also to the clinicians because many of these deformities produce clinical symptoms. Abnormalities of this area can be classified as congenital, developmental, acquired, traumatic, tumors, inflammatory, occurring either alone or in combination. Most suitable surgical techniques are to be established for a careful planning mainly based on the foramen magnum size to refrain from any neurological injury. The aim of this study is to conduct the morphometric analysis of the foramen magnum and the occipital condyles and to assess bony variations in the region of foramen magnum and the occipital condyles. One has to be familiar with the anatomical structure of foramen magnum region and the probable variations of the structures in order to achieve the appropriate exposures with the best surgical outcome.

Keywords: Morphometric analysis, anomalies, foramen magnum.

INTRODUCTION

Craniovertebral bony abnormalities have been recorded for many years in morphological and clinicoradiological studies¹. Anomalies of craniovertebral junction are of interest not only to an anatomist, but also to the clinicians because many of these deformities produce clinical symptoms. Abnormalities of this area can be classified as congenital, developmental, acquired, traumatic, tumors, inflammatory, occurring either alone or in combination². The occipital condyles represent the cranial portion of the craniocervical junction. The space-occupying lesion ventral to the spinal canal at the level of the foramen magnum can be reached using a ventral or dorsal approach. Newly described transcondylar approach requires information regarding the morphometric aspects of the occipital condyle³. The difficulties and high rate of morbidity associated with ventral approaches dictates to use a dorsal approach to the foramen magnum. Partial resection of the occipital condyle during transcondylar surgical approaches is an important step for access to the ventral and ventrolateral part of foramen magnum⁴. Therefore, the assessment of morphometry of foramen magnum and occipital condyles is helpful for lateral surgical approaches for reaching lesions in the middle and posterior part of cranial base. The foramen magnum, as a transition zone between the spine and the skull, plays a vital role as a landmark because of its close association to key structures such as the brain and the spinal cord. There are several developmental variations in the region of cranio-cervical junction, many of which resemble deformities. A reliable and exact radiologic diagnosis

requires knowledge of the morphological features of the variations and the appearance of their characteristic features in common radiological procedure⁵. The dura mater adheres to the internal surfaces of the cranial bones, particularly at the sutures, the cranial base and around the foramen magnum⁶. The foramen magnum includes specific neuroanatomical structures and their lesions in that region which require particularly microsurgical interventions. Anteriorly, the margin of the foramen magnum is slightly overlapped by the occipital condyles which project down to articulate with the superior articular facets on the lateral masses of the atlas. Each occipital condyle is oval in outline and oriented obliquely so that its anterior end lies nearer the midline than its posterior end. It is markedly convex anteroposteriorly, less so transversely, and its medial aspect is roughened by ligamentous attachments. The hypoglossal canal, directed laterally and slightly forwards, traverses deep to each condyle.

So, most suitable surgical techniques are to be established for a careful planning mainly based on the foramen magnum size to refrain from any neurological injury.²⁵ The squamous part of the occipital bone exhibits the external occipital protuberance, supreme, superior and inferior nuchal lines, and the external occipital crest, all of which lie in the midline, posterior to the foramen magnum. Current data, obtained from morphometric studies, on the anatomic and biomechanical properties of the craniovertebral junction, have made surgical intervention in the region safer⁶. The brainstem is vulnerable to compression at two critical sites, which are determined by the neuroanatomical relationship of the



meningeal tentorium and foramen magnum to the cerebral hemisphere (supratentorial) and brain stem (infratentorial)⁷.

Hence, the present study of morphometric analysis of foramen magnum and occipital condyles has been undertaken. It is hopeful that the data will be valuable particularly for the neurosurgeons, radiologists and orthopaedicians particularly in preoperative decision making process.

The aims this study is to conduct the morphometric analysis of the foramen magnum and the occipital condyles and to assess bony variations in the region of foramen magnum and the occipital condyles.

MATERIALS AND METHODS

Source of data and study area

A total number of 150 dry adult human skulls (of both sexes) available in the Department of Anatomy and Department of Forensic Medicine and Toxicology, S.C.B. Medical College & Hospital, Cuttack, during the time period of September 2013 to August 2014, were studied.

Method of collection of data

All the measurements were recorded using digital vernier caliper with minimum graduation upto 0.01mm. Measurements were done using the following bony landmarks on the skull-

1. Basion
2. Opisthion
3. Anterior tip of right occipital condyle
4. Posterior tip of right occipital condyle
5. Anterior tip of left occipital condyle
6. Posterior tip of left occipital condyle

Parameters were recorded as follows:

1. Anteroposterior diameter of the foramen magnum- distance between Basion and Opisthion.
2. Transverse diameter of the foramen magnum- maximum distance between the two lateral margins of foramen magnum.
3. Anterior intercondylar distance- distance between anterior tips of right and left occipital condyles.
4. Posterior intercondylar distance- distance between posterior tips of right and left occipital condyles.
5. The length of the occipital condyle (right and left)
6. The width of the occipital condyle (right and left)
7. The distance between anterior tip of right occipital condyle and basion.
8. The distance between anterior tip of left occipital condyle and basion.

9. The distance between posterior tip of right occipital condyle and opisthion.
10. The distance between posterior tip of left occipital condyle and opisthion.
11. Foramen magnum index: the anteroposterior diameter of foramen magnum divided by the transverse diameter of foramen magnum.

Inclusion Criteria: Fully ossified dry skull bones irrespective of age, sex, race.

Exclusion Criteria: Skulls showing gross asymmetry or deformity were rejected as unsuitable for morphometric study but were considered for bony variations.

All the measurements were performed by a single examiner, with zero setting of the vernier caliper tips before every new measurement, in order to avoid small variations of the equipment provoking bias in the outcome. Measurements were taken twice and average of two values was taken as final measurement.

Antero posterior diameter of Foramen Magnum

Maximum length between anterior and posterior margins of the foramen magnum as measured from basion to opisthion along the mid-sagittal plane.

Width or Transverse Diameter of Foramen Magnum

Maximum width between the lateral margins of the foramen magnum as measured from perpendicular to the mid-sagittal plane.

The largest antero-posterior axis of the occipital condyle was drawn and the midpoint of the axis was detected. The transaction of the midpoint of this line and midpoint of the transverse line dividing condyle was accepted as the centre or midpoint of the occipital condyle. The height of the occipital condyle was measured on the centre of the condyle. Occipital condyles were classified according to their size. The condyle shorter than 20 mm was called as type 1 (short). The condyle of (20 – 26 mm) was called as type 2 (moderate). The condyle longer than 26 mm was called as type 3 (long).

Method of Statistical Analysis

The following methods of statistical analysis have been used in this study. The results for each parameter (numbers and percentages) for discrete data and average (mean \pm standard deviation) for continuous data are presented in Tables and Figures.

1) Student 't' test.

The student 't' test was used to determine whether there was a statistical difference between left and right side in the parameters measured.

2) Proportions were compared using Chi-square test of significance.

3) The "p" value of less than 0.05 was accepted as indicating statistical significance.



Data analysis was carried out using Statistical Package for Social Science version 17. Photographs were taken with the help of Digital photography equipments. All data were tabulated and statistical analysis was done with the help of online Quickcalc app of Graphpad and then confirmed on Medcalc 12.2.1.0 desktop version. Microsoft Office Word 2007 and Excel 2007 were used for whole desktop publishing of the thesis.

RESULTS

A total number of one hundred and fifty (150) dry adult human skulls were studied. The statistical analysis was carried out and the results have been tabulated and represented in the form of bar diagrams and pie chart.

Table 1: The mean anteroposterior, transverse diameter of foramen magnum and foramen magnum index along with standard deviation

Number of skulls- 150	Anteroposterior diameter of foramen magnum (mm.)	Tranverse diameter of foramen magnum (mm.)	Foramen magnum index
Mean	35.30	29.49	1.2028
Standard deviation	2.709	2.572	0.10756
Minimum	27	24	1.01
Maximum	43	35	1.71

In the present study, mean anteroposterior diameter of foramen magnum in 150 skulls was found to be 35.30 mm, ranging from 27-43 mm with a standard deviation of 2.709. The mean transverse diameter of foramen magnum in 150 skulls was 29.49 mm, ranging from 24-35 mm, with a standard deviation of 2.572.

Table 2: Showing the percentage of foramen magnum index

Foramen Magnum Index	Number of skulls	Percentage
< 1.20	77	51.3
>=1.20	73	48.7
Total	150	100.0

Table number – 2 shows that, the mean foramen magnum index was found to be 1.20, in 150 specimens. It was found that the value was < 1.20 in case of 77 skulls and >= 1.20 in case of 73 skulls.

Table 3: Mean length of Anterior and posterior intercondylar distance, along with standard deviation.

	Number of skulls	Mean Length	Standard Deviation	Minimum Length (mm.)	Maximum Length (mm.)
Anterior Intercondylar	150	20.31	3.430	11	34
Posterior Intercondylar	150	41.17	3.758	32	49

The present study indicates that, the mean anterior intercondylar distance between two condyles in 150 skulls was found to be 20.31 mm with a range of 11-34 mm and a standard deviation of 3.431. Mean posterior intercondylar distance between the two condyles in 150 skulls was found to be 41.17 mm ranging from 32 – 49 mm having a standard deviation of 3.758.

Table 4: Comparison between mean length of right and left occipital condyle along with 't' and 'p' value.

	Number of occipital	Mean Length	Standard Deviation	Minimum Length	Maximum Length	't' value	'p' value
Right	150	22.45	2.379	15	29	0.544	0.770
Left	150	22.65	2.474	15	30		
Total	300	22.55	2.425	15	30		

After studying the occipital condyles, it was found that the mean length of right occipital condyle was 22.45 mm, ranging from 15-29 mm and with a standard deviation of 2.379. Similarly, we found the mean length of left occipital condyle was 22.65 mm, ranging from 15-30 mm with a standard deviation of 2.474. The mean length of total 300 occipital condyles was 22.55 mm, ranging from 15-30 mm and with a standard deviation of 2.425.

Table 5: Percentage of occipital condyles of different types

	Number of occipital condyles	Percentage
Type 1- short	30	10%
Type 2- moderate	263	87.67%
Type 3- long	7	2.33%



In this study, it was observed that, 30 occipital condyles were of short type (10%), and 263 condyles were of moderate type (87.67%) and 7 condyles were of long type (2.33%).

Table 6: Comparison between mean width of right and left occipital condyle along with 't' and 'p' value.

	Number of occipital condyles	Mean width (mm.)	Standard Deviation	't' value	'p' value
Right	150	12.55	1.786	3.571	0.060
Left	150	12.92	1.632		
Total	300	12.73	1.718		

Table no. 6 shows that, the mean width of right occipital condyle was 12.55 mm, with a standard deviation of 1.786. Similarly, the mean width of left occipital condyle was found to be 12.92 mm, with a standard deviation of 1.632. The mean width of total 300 occipital condyles was 12.73 mm, with a standard deviation of 1.718. The 't' value was found to be .060 (> 0.05).

Table 7: Comparison of mean distance between opisthion and posterior tip of right and left occipital condyle along with 't' and 'p' value

	Number of occipital condyles	Mean (mm.)	Standard Deviation	Minimum (mm.)	Maximum (mm.)	't' value	'p' value
Right	150	28.09	3.103	22	40	2.316	0.129
Left	150	27.59	2.645	20	38		
Total	300	27.84	2.889	20	40		

In the present study it was found that, the mean distance between the posterior tip of occipital condyle and opisthion was 28.09 mm on the right side with a standard deviation of 3.103 and 27.59 mm on the left side with a standard deviation of 2.645 respectively. It was found that this distance was greater on the right side than on the left side, with 'p' value being 0.129.

Table 8: Comparison of mean distance between basion and anterior tip of right and left occipital condyle along with 'p' value

	Number of occipital condyles	Mean (mm.)	Standard deviation	Minimum (mm.)	Maximum (mm.)	'p' value
Right	150	10.63	1.890	6	16	<0.001
Left	150	11.43	1.759	8	17	
Total	300	11.03	1.861	6	17	

It was observed that, the mean distance between the anterior tip of occipital condyles and basion was found to be 10.63 ± 1.89 mm on the right side and 11.43 ± 1.76 mm on the left side. On statistical analysis by student t- test, it was found that the 'p' value was < 0.001 showing its significance.

Out of total 150 skulls observed in the present study, posterior condylar canal was present in 67% (in 201 skulls) with a 'p' value of 0.539. The condylar canal was absent on the right side in 47 skulls and on the left side in 52 skulls. So, in the present study, it was found to be more absent on the left side.

In the present study, the most common type was found to be type 1 (56.0%), other types were seen in the following frequency—type 2: 3.0%, type 3: 20.8 %, type 4: 4.0%, type 5: 6.0%, type 6: 4.4%, type 7: 0.6% and type 8: 5.2%.

Shape of the Foramen Magnum

In the present study, the most common shape of the foramen magnum was two semicircles (25.9 %), whereas the most unusual was the irregular (0.7 %). Other shapes were seen in the following frequencies: pear - 22.4 %; egg - 21 %; oval -14.7 %; rhomboid - 14 %, and round - 1.4 %.

DISCUSSION

The morphometric analysis of foramen magnum and occipital condyle was studied in 150 human skulls. Measurements of each parameter were made meticulously in all the bones. The present study is discussed in comparison with the studies done earlier.

Foramen Magnum

Foramen magnum is a transition zone between the spine and the skull. Morphometric analysis of foramen magnum helps in planning of surgical intervention involving the base of the skull.

Comparison of our results and results reported in literature regarding anteroposterior and transverse diameter of foramen magnum.

Murshed AK¹² reported the Sagittal diameter (SD) and Transverse diameter (TD) of foramen magnum in males



were significantly greater than in females ($P < 0.001$). The area of the foramen magnum showed highly significant correlations for both Sagittal diameter ($P < 0.01$) and Transverse diameter ($r = 0.834$) ($P < 0.01$). In males, the means \pm SD were 37.2 ± 3.43 mm and 31.6 ± 2.99 mm for the sagittal and transverse diameters, respectively. In females, the means \pm SD were 34.6 ± 3.16 mm and 29.3 ± 2.19 mm for the sagittal and transverse diameters, respectively.

Muthukumar N¹³ found in a morphometric study of 50 dry skulls, the average anteroposterior diameter of foramen magnum was 33.3 mm and width was 27.9 mm.

Kizilkanat¹⁴ studied the occipital condyles, hypoglossal canal and foramen magnum in 59 Turkish-Caucasian skulls. The anteroposterior (34.8 mm) and transverse (29.6 mm) diameters of the foramen magnum reported in their study are similar to those reported by Muthukumar¹⁵ (33.3mm and 27.9 mm), Naderi¹⁶ (anteroposterior distance 34.7 mm), Wanebo and Chicoine⁽⁵⁷⁾ (36.0mm and 31.0 mm), Berge and Bergman⁶ (33.8mm and 28.3 mm).

In the present study, mean anteroposterior diameter of foramen magnum in 150 skulls was found to be 35.30 mm, range being 27-43 mm and the standard deviation of 2.709. The mean transverse diameter of foramen magnum in 150 skulls was 29.49mm, with the range being 24-35 mm and standard deviation of 2.572 (Table- 1 and 2).

Hence, the results of the present study is similar to the above mentioned studies. From the above data, it can be stated that there is significant difference between anteroposterior and transverse diameters. The anteroposterior diameter is generally larger than transverse diameter. Narrowing as well as widening of foramen magnum is important. The stenosis of the craniovertebral canal may result from congenital underdevelopment or deformity of the skull base. Foramen magnum is small in all individuals with achondroplasia. This is because of markedly diminished growth as a result of abnormal endochondral bone growth and premature fusion of the synchondroses.

Foramen magnum index

Muthukumar⁷ calculated foramen magnum index by dividing anteroposterior length of foramen magnum with the width. He determined the shape of foramen magnum using foramen magnum index. He considered the foramen magnum index was equal or more than 1.20. 46 % of the skulls exhibited an ovoid foramen magnum. In 20% of the skull, the occipital condyle protruded significantly into the foramen magnum. It was also stated that wide and sagittally inclined occipital condyles; medially protruberant occipital condyles along with a foramen magnum index of more than 1.2 will require extensive bony resection in transcondylar approach.

Kizilkanat⁸ and colleagues studied the morphometry of hyoglossal canal, occipital condyle and foramen magnum on 59 dry skulls and had given mean foramen magnum index as 1.2.

In the present study, the mean foramen magnum index was 1.20 mm with a standard deviation of .107 in 150 specimens (Table- 1 & 2).

The shape and morphological variations of foramen magnum are important in neurological interpretation. In an ovoid type of the foramen magnum, the ability of the surgeon to adequately expose the anterior portion of the foramen magnum might be difficult.

Naderi⁸ had analyzed the occipital condyles in details. The mean anterior intercondylar distance and posterior intercondylar distance were measured as 21.0 ± 2.8 mm and 41.6 ± 2.9 mm, respectively. **Kizilkanat⁹** studied the occipital condyles, hypoglossal canal and foramen magnum in 59 Turkish-Caucasian skulls. In his study, the anterior and posterior intercondylar distances were 22.6 mm and 44.2 mm, respectively.

Ozer MA¹⁰ demonstrated a study where morphological analysis of 704 sides of occipital bones of adult skulls was done. The mean anterior intercondylar distance and posterior intercondylar distance were found to be 20.9 ± 3.6 mm and 43 ± 4 mm respectively.

We found in our study, mean anterior intercondylar distances between two condyles to be 20.31 mm with a range from 11-34 mm. and a standard deviation of 3.431. The Mean posterior intercondylar distance between two condyles was found to be 41.17 mm with the range being 32 – 49 mm and a standard deviation of 3.759 (Table 3).

The results of present study is similar to other studies done previously. Occipital condyles converge ventrally. There is significant difference between anterior and posterior intercondylar distance. This leads occipital condyle to have different anterior and posterior angles. This difference in the anterior and posterior intercondylar distance reflects the asymmetry in the orientation of occipital condyles which may affect the lateral approach. According to recent studies, condylectomy provides the wider angle of exposure.

Naderi¹¹ had analyzed the occipital condyles in details. The mean length was found to be 23.6 ± 2.5 mm on the right side and 23.2 ± 2.4 mm on the left side respectively.

Muthukumar¹⁰ demonstrated in a morphometric study of 50 dry skulls, the average anteroposterior diameter of the occipital condyle was found to be 23.6 mm.

Avci E¹¹ conducted a study to define the micro surgical anatomy of foramen magnum region using 30 dry skulls specimen and 10 formalin-fixed cadaveric heads with perfused vessels. The mean length of right and left occipital condyle (anatomical) were 23.7 ± 2.6 mm and 24 ± 2.7 mm, respectively.

Kizilkanat¹² found out in a study, the mean anteroposterior length of the occipital condyles was 24.5 mm. When OC resection or a lateral approach to the FM is required, an intimate knowledge of the dimensions of the condyle is a necessary for a safe resection to be undertaken. In his study, the mean anteroposterior length of the OC was 24.5 mm, a value larger than those reported by **Muthukumar**¹³ (23.6 mm), **Naderi**¹⁴ (23.4 mm), and **Wanebo and Chicoine** (23.0 mm)¹⁵.

In our study, we found the mean length of the right occipital condyle was 22.45 mm, the range being 15-29 mm and standard deviation of 2.379. The mean length of left occipital condyle was 22.65 mm, range being 15-30 mm and standard deviation of 2.474. The mean length of total 300 occipital condyles was 22.55 mm, the range being 15-30mm and a standard deviation of 2.425. (Table-4).

Hence, no significant bilateral difference was found between right and left occipital condyle lengths as shown by the result of student t- test ($p = 0.770$ which is > 0.05). [Table – 4]. Hence our study can be compared with the above mentioned studies.

Comparison of condylar length in present study with radiological studies

Ozer MA¹⁶ demonstrated a study where morphological analysis of 704 sides of occipital bones of adult skulls was done by 3D-Doctor Demo version and it showed the width of occipital condyle to be 23.9 ± 3.4 mm (right) and 24 ± 3.3 mm (left) respectively.

Le TV¹⁷ demonstrated the mean length of occipital condyles to be 22.38 ± 2.19 mm. These measurements were used for preoperative planning for the feasibility of placement of an occipital screw. In our study, the mean lengths of condyle are less compared to that of radiological values. The differences between the results are possibly due to age, gender, racial and geographic variations in the cranial morphometrics of different studied populations.

Condylar Width

Comparison of condylar width in present study with that of other anatomical studies

Naderi S¹⁸ reported the mean width of occipital condyle to be 10.6 ± 1.4 mm (right), 10.6 ± 1.4 mm (left). **Kizilkanat**¹⁹ showed that, the mean transverse width of occipital condyles was 13.1mm.

Muthukumar²⁰ demonstrated in a morphometric study of 50 dry skulls, the average transverse diameter (width) of the occipital condyles was 14.72 mm.

We found the mean width of right occipital condyle was 12.55 mm, range being 8-21 mm and a standard deviation of 1.786. The mean width of left occipital condyle was 12.92 mm, range being 9-19 mm and standard deviation of 1.632. The mean width of total 300 occipital condyles

was 12.73 mm, range being 8-21 mm and standard deviation of 1.718. (Table-6).

No significant bilateral difference is found between right and left occipital condyle width as shown by the result of student t- test ($p = 0.060$ which is > 0.05). The present study is compared with anatomical and radiological studies. So, from the above table it can be stated that, the present study is similar to the other studies.

Comparison of condylar width of present study with that of other radiological studies.

Avci E⁴ showed the mean width of right and left occipital condyle (3D CT) were 12.0 ± 1.3 mm and 12.1 ± 1.5 mm, respectively. **Ozer MA**^{21,31} demonstrated a study and reported the width of occipital condyle 11.9 ± 2.3 mm (right), 10.7 ± 2.3 mm (left) respectively. A computer tomography based study done by **Le TV**²¹ on 340 occipital condyles in 170 patients showed that, the mean width was 11.8 ± 1.44 mm.

From the above table, it can be stated that the anatomical values in the present study is more than the radiological values.

In the final assessment of morphometric asymmetry of occipital condyles it can be stated that left occipital condyle appears to be slightly longer and wider than the right. The measurements of occipital condyles are useful in safe placement of occipital condyles screws for atlantooccipital fusion in occipital condyle fractures.

SUMMARY AND CONCLUSION

The study of base of skull is very important because significant structures pass through it. It can be concluded that careful radiological analysis of foramen magnum and occipital condyle is required before craniocervical junction surgery to prevent complications like hemorrhage, atlantooccipital instability and injury to major structures passing through foramen magnum. There are several developmental variations in the region of the craniocervical junction, many of which can resemble deformities. Some variations are minor anatomic abnormalities but they can cause severe diagnostic problems. These anomalies may be asymptomatic initially but may later clinically manifest. A reliable and exact radiological diagnosis requires knowledge of the morphologic features of the variations and the appearance of their characteristic features in the common radiologic procedures. The limitation of the study was that the corresponding first and second cervical vertebrae with the occipital bones could not be evaluated. Occipital bone with its condyles and foramen magnum represents the cranial end of craniocervical junction. Thorough knowledge of craniocervical junction is important for physicians of multiple disciplines such as orthopedics, neurology, ENT, radiology, neurosurgery and skull base surgery. Morphometrics of occipital condyle and foramen magnum is especially important for newly described transcondylar approach. The above said



parameters will be helpful in interpreting the neuroinvestigative procedures and also in planning surgical intervention involving the skull base. Hence, one has to be familiar with the anatomical structure of foramen magnum region and the probable variations of the structures in order to achieve the appropriate exposures with the best surgical outcome. This study will definitely be useful for the anatomists, neurosurgeons, radiologists and orthopedic surgeons.

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