Research Article
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Morphological analysis of occipital condyles and foramen magnum as a guide for lateral surgical approaches

Abstract

Objectives: Surgical approaches to the craniovertebral junction (CVJ) are associated with a high mortality and morbidity when undertaken without detailed morphologic analysis of the region. In spite of the clinical importance of this area, there are only few anatomical reports are available in the literature. The aim of the present study was to present the detailed anatomy of the foramen magnum (FM) and occipital condyle (OC) for surgical approaches to the CVJ region.

Methods: Morphometric analysis was performed on 100 dried human occipital bones of unknown sex and age from Turkish population. Four parameters were measured for FM and eleven parameters for OC. FM shapes were classified. FM index was calculated.

Results: The antero posterior and transverse diameters of FM were 35,17±2,94mm and 29,73±2,53mm, respectively. Anterior and posterior intercondylar distances were 22,47±2,98mm and 41,54±3,78mm. Antero posterior and transverse diameters of OC were 23,47±2,44mm and 11,40±1,41mm. Sagittal intercondylar angle was 31,72±3,48 degrees on the right and 33,29±3,25 degrees on the left side. OC anterior tip-opisthion distance was 39,62±3,19mm on the right and 39,21±3,72mm on the left side; there was a significant difference between the right and left side for these two parameters ($p<0.05$). FM was classified into seven morphological shapes; tetragonal shape was the most commonly observed (24%).

Conclusion: This study gives a detailed morphological analysis of the CVJ, showing that most of the CVJ parameters are variable. Each surgical approach to this area has advantages, disadvantages, limitations and potential risks. Anatomical structures must be well-known and clinical and radiological diagnostic procedures like plain radiography, computed tomography and magnetic resonance imagining should be performed before surgery.

Keywords: craniovertebral junction, foramen magnum, morphometry, occipital condyle, surgical approach

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Abbreviations: CVJ, craniovertebral junction; FM, foramen magnum; OC, occipital condyle

Introduction

Craniovertebral junction (CVJ) refers to an area that includes the foramen magnum (FM), occipital condyles (OCs) and the first two cervical vertebrae, namely atlas and axis.[1] FM is in the center of the skull base and has three parts: the dorsal part of the FM (the squamosal part), the ventral part of FM (the basal or clival part), and the condylar part connecting the squamosal and the clival parts. The condylar part includes the OC, posterior margin of the jugular foramen and the hypoglossal canal.[2] OC is the only articulation between the occipital and the atlas.[3]

CVJ is associated with many important structures such as the medulla oblongata, upper spinal and low cranial nerves (glossopharyngeus, vagus, accessorius and hypoglossus), vertebral arteries with its branches and vertebral veins, as well as the atlas, axis and occipital bone with important ligamentous and muscular attachments.[4]

Embryology and developmental anatomy of this region is important for understanding pathologies on this region.[5] The measurements of structures vary in different stages of human life[6] and with diseases such as Down syndrome.[7] According to Nevel & Wood,[8] the base of cranium that includes the basioccipital, sphenoid and temporal bones continued to evolve and had significant morphological changes within hominid clade. There are also many developmental and ethnic variations in humans.[6] Therefore, this area has variable shapes, sizes and angles.

The most frequently reported lesions are extra and intradural tumors, vertebral artery lesions, rheumatoid diseases and malformations of the CVJ, synovial cysts, infections, syringobulbia and intrinsic lesions.[9] Occipitocervical synostosis is one of the most frequent osseous anomalies of the CVJ and may compress the brainstem, vertebral artery and cranial nerves.[10]

Many surgical approaches are associated with high mortality and morbidity when undertaken without detailed morphological analysis.[11] The shape, size and angle of the OC is important when choosing the surgical approach.[12] The kinetic anatomy of CVJ, bony configuration, vascular supply and course of the sub occipital vertebral arteries are important for skull base surgery.[1] In spite of the clinical importance of this area, there are only few anatomical reports available in the literature. The aim of the present study was to determine and define the detailed anatomy of the FM and OC for surgical approaches of the region.

Materials and methods

Morphometric analysis was performed on one hundred dried human occipital bones from a Turkish population of unknown sex and age, obtained from the bone collection of Ege University, School of Medicine, Izmir, Turkey. Measurements were made using a digital caliper accurate to 0,01mm and a protractor.

Four parameters were measured for FM and eleven parameters for OC based on the detailed study of Naderi et al.[3] The parameters were anterior and posterior intercondylar distances (Figure 1A & Figure 1C), transverse distance between two OCs (Figure 1B), sagittal intercondylar angle (Figure 2), anteroposterior length of OC (Figure 3A), transverse diameter of the OC (Figure 3B), the height of the OC (Figure 4), the distance between anterior tip of the OC and opisthion (Figure 5B), the distance between anterior tip of the OC and basion (Figure 5C), the distance between posterior tip of the OC and opisthion (Figure 5B), and the distance between posterior tip of the OC and basion (Figure 5D). For FM, anteroposterior length and transverse diameter was measured (Figure 3C & Figure 3D), FM index was calculated and FM shapes were observed.

FM shape was classified into seven types according to Chethan et al.,[13] round, egg-shaped, tetragonal, oval, irregular, hexagonal and pentagonal (Figure 6). FM index was calculated by dividing the anteroposterior diameter of FM by transverse diameter. Some measurements were made separately for the right and left sides. Right-left differences were assessed using paired t-test (Table 1). Data were presented as means±SEM (standard error of mean). P value less than 0.05 ($p \leq 0.05$) was considered statistically significant.

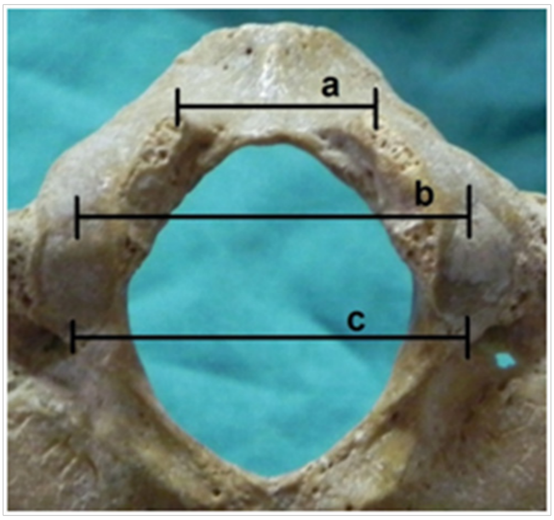

Figure 1 Intercondylar distances of the occipital bone.

A. Anterior intercondylar distance (the distance between two anterior tips of OCs);

B. Distance between two tops of OCs;

C. Posterior intercondylar distance (the distance between two posterior tips of OCs).

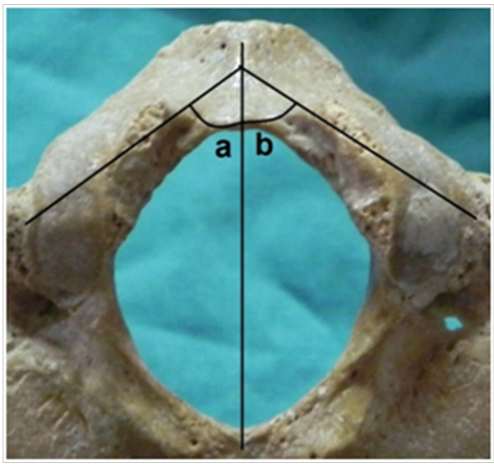

Figure 2 The condylar angles.

A. Right sagittal condylar angle;

B. Left sagittal condylar angle;

C. Sagittal intercondylar angle(a+b).

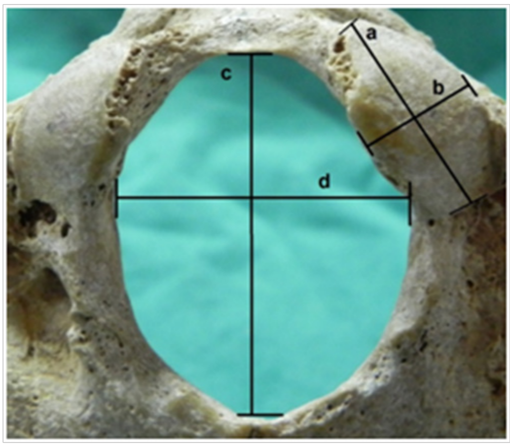

Figure 3 The condylar angles.

A. Right sagittal condylar angle;

B. Left sagittal condylar angle;

Sagittal intercondylar angle (a+b).

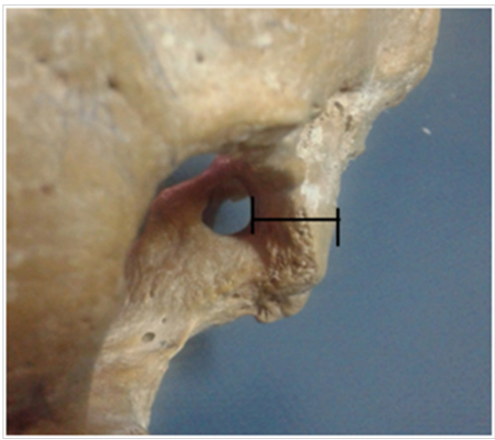

Figure 4 Height of the OC measured as the distance between the intracranial hypoglossal canal and midline of the OC.

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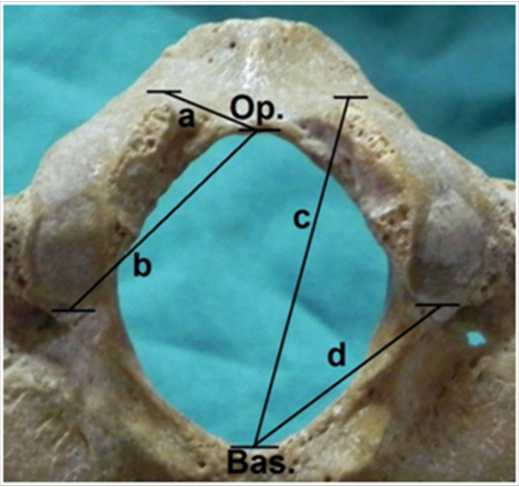

Figure 5 Distances between OC and opisthion, OC and basion.

A. Distance between anterior tip of OC and opisthion;

B. Distance between posterior tip of OC and opisthion;

C. Distance between anterior tip of OC and basion;

D. Distance between posterior tip of OC and basion.

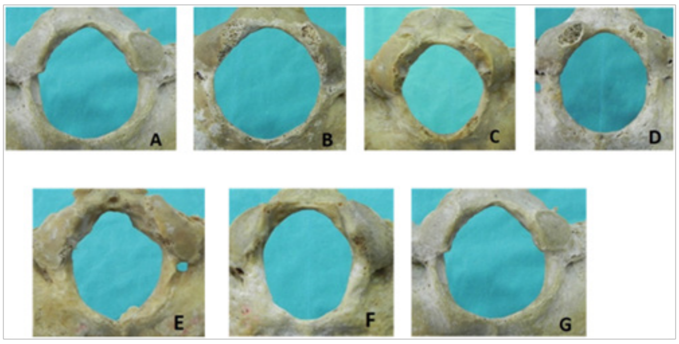

Figure 6 FM shapes.

A. Egg;

B. Round;

C. Tetragonal;

D. Oval;

E. Irregular;

F. Hexagonal;

G. Pentagonal.

Table 1 Measurements for the OC and FM (mean±SD). *, p<0.05

Parameter	N	Mean±SD(mm)	Min(mm)	Max(mm)	p
Anterior intercondylar distance	96	22,47±2,98	15,86	29,45	
Posterior intercondylar distance	98	41,54±3,78	32,9	52,31	
Transverse distance between two OC	98	37,21±3,19	29,08	45,06	
Anteroposterior diameter of FM	100	35,18±2,94	28,01	43,44	
Transverse diameter of FM	99	29,73±2,54	20,86	35,65	
Sagittal condylar angle (R)	98	31,72±3,48°	25°	46°	
Sagittal condylar angle (L)	98	33,29±3,25°	27°	49°	
Sagittal intercondylar angle	98	64,83±4,73°	55°	84°	0*
Length of OC (R)	97	23,44±2,60	16,45	31,06	
Length of OC (L)	97	23,49±2,71	16,65	30,15	
Length of OC (total)	98	23,47±2,44	17,17	30,6	0,751
Width of OC (R)	98	11,31±1,78	8,23	19,34	
Width of OC (L)	98	11,49±1,47	8,36	14,52	
Width of OC (total)	98	11,4±1,41	8,59	15,99	0,273
Height of OC (R)	98	9,04±1,18	6,01	12,02	
Height of OC (L)	98	9,02±1,22	5,71	11,64	
Height of OC (total)	98	9,03±1,13	6,13	11,45	0,871
OCAT-Op (R)	97	39,62±3,19	32,09	48,22	
OCAT-Op (L)	97	39,21±3,72	25,21	48,67	
OCAT-Op (total)	98	39,43±3,34	29,6	47,4	0,019*
OCAT-Bas (R)	97	11,99±2,2	1,68	17,81	
OCAT-Bas (L)	97	12,2±1,86	8,04	15,96	
OCAT-Bas (total)	98	12,09±1,76	6,43	16,67	0,364
OCPT-Op (R)	98	27,54±3,13	19,67	39,68	

Table continued...

Parameter	N	Mean±SD(mm)	Min(mm)	Max(mm)	p
OCPT-Op (L)	98	27,5±2,56	21,57	36,41	
OCPT-Op (total)	98	27,52±2,59	21,15	35,26	0,863
OCPT-Bas (R)	98	27,91±3,48	21,44	47,64	
OCPT-Bas (L)	98	27,96±2,48	22,6	35,67	
OCPT-Bas (total)	98	27,93±2,67	22,06	39,49	0,869
FM index	99	1,19±0,09	0,95	1,44	

FM, foramen magnum; R, right; L, left; OC, occipital condyle; OCAT, oc anterior tip; Op, opisthion; OCPT, oc posterior tip; Bas, basion

Table 2 Anteroposterior and transverse diameters of the FM (mm) and FM index

Parameters	Wanebo & Chicoine[11] n=32 Caucasian	Murshed et al.[33] n=110 Turkish	Muthukumar et al.[37] n=50 Indian	Naderi et al.[3] n=202 Turkish	Kizilkanat et al.[34] n=59, Turkish	Tubbs et al.[36] n=72 Caucasian	Chethan et al.[13] n=53 Indian	Present study n=100 Turkish
Antero-posterior	36	35,9±2	33,3	34,7	34,8	31	31±1,8	35,18±2,94
Transverse	28,3	30,4±2	27,9		29,6	27	25,2±2,4	29,73±2,54
FM index	-	-	-	-	1,2±0,1	-	1,2±0,1	1,19±0,09

Table 3 Comparison of FM shapes with earlier studies

FM shape	Chethan et al.,[13] n=53 Indian	Zaidi & Dayal[14] n=200 Indian	Sindel et al.,[39] n=95 Turkish	Murshed et al.,[33] n=110 Turkish	Present study (n=100) Turkish
Round	22,6%	0,5%	15,8%	21,8%	6%
Egg	18,9%	-	-	6,3%	12%
Tetragonal	18,9%	-	49,4%	12,7%	24%
Oval	15,1%	64%	18,9%	8,1%	10%
Irregular	15,1%	3,5%	6,3%	10,9%	22%
Hexagonal	5,6%	24,5%	5,3%	17,2%	21%
Pentagonal	3,8%	7,5%	4,2%	13,6%	2%

Table 4 Comparison of OC parameters with earlier studies

Parameters	Naderi et al.[3] n=202 Turkish	Kalthur et al.[9] n=71 Indian	Kizilkanat et al.[34] n= 59 Turkish	Bozbuga et al.[41] n=78 Turkish	Olivier[42] n=125, French	Muthukumar et al.[37] n=50 Indian	Present study n=100, Turkish 2015
Length of OC	23,6	22±2	24,5	-	23,7	26,6	23,47±2,44
Width of OC	10,5	11±2	13,1	-	11,5	14,7	11,4±1,41
Height of OC	9,2	-	-	-	8,8	-	9,03±1,13
OCPT-Op	26,4±2,3	28±2	-	-	-	-	27,52±2,59
OCPT-Bas	27,8±2,9	27±2	-	-	-	-	27,93±2,67
OCAT-Op	39,0±2,9	39±3	-	-	-	-	39,43±3,34
OCAT- Bas	10,8±1,5	12±2	-	-	-	-	12,09±1,76
Anterior intercondylar distance	21±2,8	-	22,6	22,8	-	-	22,47±2,98
Posterior intercondylar distance	41,6±2,9	-	44,2	30,2	-	-	41,54±3,78

OC, occipital condyle; OCPT-Op, the distance between OC posterior tip and opisthion; OCPT-Bas, the distance between OC posterior tip and basion; OCAT-Op, the distance between OC anterior tip and opisthion; OCAT-Bas, the distance between OC anterior tip and basion

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Results

The measurements of OC and FM for a total of 14 parameters are shown in Table 1. There were statistically significant differences between the right and left sides for the occipital condyleanterior tip-opisthion distance (OCAT-Op) and sagittal condylar angle ($p<0,05$), but no significant differences were found between right and left sides for the remaining parameters.

We measured the anteroposterior diameter of FM as 35,18±2,94mm, transverse diameter as 29,73±2,54mm, and FM index as 1,19±0,09 (Table 2). The shape of FM was round in 6%, egg-shaped in 12%, tetragonal in 24%, oval in 10%, irregular in 22%, hexagonal in 21% and pentagonal in 2%of the specimens (Table 3). The length, width and height of the OC were 23,47±2,44, 11,4±1,41 and 9,03±1,13, consequently. The OCPT-Op distance was measured as 27,52±2,59mm, OCPT-Bas as 27,93±2,67mm, OCAT-Op as 39,43±3,34mm, and OCAT- Bas as 12,09±1,76mm. The anterior intercondylar distance was 22,47±2,98mm, and posterior inter condylar distancemm.41,54±3,78 (Table 4).

Discussion

CVJ is in close relationship with many important structures, and therefore, lesions involving this area have potential risks.[4,14] Before surgery, clinical and radiological diagnostic procedures should be done and anatomical structures must be well identified.[13]

There are many factors that influence the treatment of CVJ lesions, such as etiology, location of the lesion, and the development of the individual.[15] As CVJ lesions may cause different destructions on bones and neurovascular structures such as the vestibule basilar system and lower cranial nerves, different surgical approaches are used.[15,16] Therefore, it is important to know the area and understand the limitations and potential risks for each approach.[17] In the last four decades, numerous surgical approaches and endoscopic-assisted microsurgical techniques have been developed for CVJ pathologies.[18] These surgical approaches may be classified as anterior, posterior and lateral approaches, each with advantages and disadvantages.

Anterior approach

Anterior approaches can be divided into trans oral, transmaxillar, transfrontal-transbasal, expanded frontal, transsphenoidal and transcervical. These approaches are used for reaching the lesions in atlas, axis and clivus or for fixation when there is a trauma in bone or ligaments which surround the odontoid process. The advantage is that lesions can be approached directly; the disadvantage is after removal of CSF fistulas, pseudomeningoceles and intradural lesions, there may be formed meningitis.[19] Anterolateral approach is used for extradural and osseous tumors,[20] especially vertebral artery pathologies.[21]

Lateral approach

CVJ lesions are currently approached by lateral approach.[3] This approach is used also to remove the petrous part of temporal bone in different degrees for reaching the clival region. Lateral approaches include translabirynthine, transcochlear and anterior transpetrousal approaches,[22] extreme lateral, far lateral,[23] transfacetal, partial transcondylar, complete transcondylar, extreme-lateral transjugular and transtubercular approaches with or without division of the sigmoid sinus.[3] Extreme lateral approach provides access to lesions in the middle of the FM.[24,25,15]

Posterior approach

Posterior approach is used for intradural tumors which are located at posterior or lateral part of the cervicomedullary junction.[26] It has several advantages-there is no need for drilling the OCs or lateral mass, and postoperative recovery is fast.[27] This approach can be divided into posterior suboccipital, posterolateral (lateral suboccipital), far lateral,[23] standard para median suboccipital and transcondylar approaches.[28,29]

Far lateral approach

Far lateral approach is used for tumors in the anterior side of the cervicomedullary junction.[28,29] Far lateral trans atlas approach is used for CVJ anomalies and rheumatoid arthritis.[30] Far lateral approaches may be far lateral transcondylar, transcondylar, retrocondylar, supracondylar, transtubercular and condylar fossa approaches.[3,31] Far lateral approach provides good exposure and a lateral viewing trajectory for accessing intradural and extradural lesions located at the ventral FM, ventral and ventrolateral brainstem and CVJ without brain retraction.[3,32] This approach is used for several types of tumors in this region, including FM meningiomas, schwannomas, chordomas, and chondrosarcomas. Vascular lesions, such as vertebral artery-posteroinferior cerebellar artery junction aneurysms, vertebrobasilar junction aneurysms, and ventrolaterally located brainstem cavernous malformations, can also be accessed with this approach.[3] Extensive dissection of paravertebral muscles and vessels such as the vertebral artery and removal of bony structures such as the OC and jugular tubercle is required. These maneuvers may result in injury to vascular structures (vertebral artery, jugular vein and bulb) and lower cranial nerves, and may also lead to craniocervical instability due to removal of the OC.[31]

If the antero-posterior diameter of FM is wide, it provides a better surgical exposure making it very suitable for condylar resection.[11] In transcondylar approach, the diameters of FM should be well known for a safe OC resection.[13] In our study, the anteroposterior diameter of FM was 35, 18±2,94mm. This is similar to the findings of Murshed et al.[33] as 35,9±2mm, Kizilkanat et al.,[34] as 34,8mm, Naderiet al.,[3] as 34,7±2,3mm, and Barut et al.35 as 35,6±2,45mm. Our measurement is larger than those of Chethan et al.,[13] as 31±1,8mm and Tubbs & Griessenauer[36] as 31mm (Table 2).

FM index is also important for choosing the surgical approach.[34] In patients with small FM, the transcondylar approach is more suitable. The gap between the FM and brainstem should be small in this approach.[11] When FM index is ≥1.2, the foramen is accepted to be ovoid.[30] Our FM index is similar to those of Kizilkanat et al.[34] and Chethanet al.[13] (Table 2).

Variations in FM shape should be taken into consideration during clinical and radiological diagnostic procedures and surgical approaches to the region. This is also important for determining how much bone must be removed.[34] In early fetal growth, during the development of skull base, FM is one of the centers of ossification[37,38] and because of evolutionary changes in FM, shapes are variable.[8] The irregular shape of FM may cause developmental anomalies of the bone and soft tissues at the CVJ.[13] In our study, the most common FM shape was tetragonal (24%). Chethan et al.[13] and Murshed et al.[33] found FM round, Zaidi & Dayal[14] oval & Sindel et al.[39] hexagonal in shape (Table 3). The variations in the shape of the FM may be due to the ethnical group or population studied.

OCs are located anterolaterally to the FM. The shape, size, and angle of the OC is important for choosing the surgical procedure, and studies present varying findings for the measurements.[12] Although a 1/3-2/3 resection may not cause craniocervical instability, total resection may do so.[35] The same amount of partial condylectomy may cause greater occipitocervical instability in a short OC compared to a long OC. Also, a long OC may require a more extensive resection for optimum visualization. Similar surgical considerations may be correct for the OC width.[31] Surgery in a wider condyle may be more demanding.[12]

The comparison of our measurements for the length, width and height of the OC, the anterior and posterior intercondylar distances are shown in Table 2. The distance between two OCs can lead to different anterior and posterior angles. Sagittal intercondylar angle ranges between 55˚ and 84˚. Our findings correlate with those of Barut et al.,[35] 63,7±7,75˚ and Kizilkanat et al.,[34] as 62,2±9,1˚. A wide range reflects the asymmetry in the orientation, length and shape of OCs and may affect the lateral approach.[3] According to Açikbaş et al.[40] condylectomy provides wider angle of exposure. Wide angle is an advantage for reaching to the ventral of the FM.[12]

The distance between the posterior tip of the OC and the opisthion is also important for surgical approaches. A larger distance provides a free corridor for posterolateral approaches[3] and a longer corridor provides a wider space for a far lateral transcondylar approach.[31] In our study, the distance between OC posterior tip and opisthion was 27,52±2,59mm, the distance between OC anterior tip and opisthion 39,43±3,34mm, and the distance between OC anterior tip and basion 12,09±1,76mm. Comparison of our findings with earlier studies is shown in Table 4. The measurements in these studies are similar in value, except for the posterior intercondylar distance measured by Bozbuga et al.[41] which is lower, possibly due to different reference points taken for the measurement.

Regression analysis studies have been performed for the morphology of FM and OC in identification of sex, ethnic group and age.[42] Although some studies suggested these did not have a correlation with the sagittal and the transverse diameter of the FM,[43] other studies reported a sexual dimorphism for FM dimensions with all parameters being significantly higher in males.[44] Kamath et al.[45] found sex predictability (higher values in males) for FM area (70.3%), followed by sagittal diameter (69.6%), and least for transverse diameter (66.4%), similar to the study of Uthman et al.,[46] for FM area and Raghavendra Babu et al.,[47] with higher predictability for FM area and sagittal diameter compared to transverse diameter.[9] Rai et al.[48] found OC and FM dimensions higher in males compared to females No stastistically significant difference was found in adults for different age groups for the OC[49] and FM.[50] Varsha et al.[51] found that the antero-posterior diameter of the OC in male skulls was found higher than the female skulls, however there was no significant difference in the transverse diameter of OC in male and female skulls.

In summary, several anatomical parameters were measured for the FM and OC in this study to give a detailed morphometric analysis of the CVJ on a high number of occipital bones. The limitation of this study is the lack of knowledge regarding the age and gender of occipital bones studied.

Conclusion

CVJ is a complex area and most of the parameters here are variable. Therefore, before surgery, anatomical structures must be well known and clinical and radiological diagnostic procedures like plain radiography, computed tomography (CT) and magnetic resonance imagining (MRI) should be performed. It should be known that each surgical approach has advantages, disadvantages, limitations and potential risks. The findings of this study will provide a database for choosing the right surgical approach and also for successful instrumentation and minimizing mortality and morbidity in the region.

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Conflict of interest

Author declares that there is no conflict of interest.

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