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 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 imaging should be performed before surgery.

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

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 squamous 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 life6 and with diseases such as Down syndrome.7 According to Nevel & Wood,8 the base of cranium that includes the basiocipital, 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.8 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. 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. 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., 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≤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.

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

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<th>Parameter</th>
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Parameter | N | Mean±SD(mm) | Min(mm) | Max(mm) | p
---|---|---|---|---|---
OCPT-Op (L) | 98 | 27.5±2.56 | 21.57 | 36.41 | 0.863
OCPT-Op (total) | 98 | 27.52±2.59 | 21.15 | 35.26 |
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 |
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 | Mursheed et al.\(^{12}\) n=110 Turkish | Muthukumar et al.\(^{13}\) n=50 Indian | Naderi et al.\(^{14}\) n=202 Turkish | Kizilkanat et al.\(^{15}\) n=59, Turkish | Tubbs et al.\(^{16}\) n=72 Caucasian | Chethan et al.\(^{17}\) 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.\(^{17}\) n=53 Indian | Zaidi & Dayal\(^{18}\) n=200 Indian | Sindel et al.\(^{19}\) n=95 Turkish | Muthukumar et al.\(^{13}\) n=110 Turkish | Murshed et al.\(^{12}\) n=50 Indian |
---|---|---|---|---|---|
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.\(^{2}\) n=202 Turkish | Kalthur et al.\(^{3}\) n=71 Indian | Kizilkanat et al.\(^{15}\) n=59 Turkish | Bozbuga et al.\(^{4}\) n=78 Turkish | Olivier\(^{25}\), French | Muthukumar et al.\(^{13}\) 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 opistion; OCAT-Bas, the distance between OC anterior tip and basion

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 condylantechnique tip-opposition 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 distance mm.41,54±3,76 (Table 4).

Discussion

CVJ is in close relationship with many important structures, and therefore, lesions involving this area have potential risks.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.13 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.13,15 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.13 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, transphenoidal 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 the ligaments which surround the odontoid process. The advantage is that lesions involving this area have potential risks.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.13 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.13,15 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.13 These surgical approaches may be classified as anterior, posterior and lateral approaches, each with advantages and disadvantages.

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 translabrynthine, transcoclear and anterior transpetrous approaches,22 extreme lateral, far lateral,21 transfacial, partial transcondylar, complete transcondylar, extreme-lateral transjugular and transtubercular approaches with or without division of the sigmoid sinus.13 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 medial 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.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.12,21 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-pen and soft tissues at the CVJ.11 In our study, the most common FM shape was tetragonal (24%). Chethan et al.13 and Mushedi et al.13 found FM round, Zaidi & Dayal16 oval & Sindel et al.9 hexagonal in shape (Table 3). The variations in the shape of the FM may be due to the ethnic group or population studied.

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 2.1, the foramen is accepted to be ovoid.10 Our FM index is similar to those of Kizilkanat et al.14 and Chethan et 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.14 In early fetal growth, during the development of skull base, FM is one of the centers of ossification12,16 and because of evolutionary changes in FM, shapes are variable. The irregular shape of FM may cause developmental anomalies of the brain and soft tissues at the CVJ.11 In our study, the most common FM shape was tetragonal (24%). Chethan et al.13 and Mushedi et al.13 found FM round, Zaidi & Dayal16 oval & Sindel et al.9 hexagonal in shape (Table 3). The variations in the shape of the FM may be due to the ethnic 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.8 Although a 1/3-2/3 resection may not cause craniofacial instability, total resection may do so.13 The same amount of partial condylectomy may cause greater occipitocervical instability in a short OC compared to
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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. Surgery in a wider condyle may be more demanding. 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., 63.7±7.75° and Kizilkaman et al., 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. According to Açıkbaş et al., condeectomy provides wider angle of exposure. Wide angle is an advantage for reaching to the ventral of the FM.

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 and a longer corridor provides a wider space for a far lateral transcondylar approach. 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., 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. Although some studies suggested these did not have a correlation with the sagittal and the transverse diameter of the FM, other studies reported a sexual dimorphism for FM dimensions with all parameters being significantly higher in males. Kamath et al. 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., for FM area and Raghaavendra Babu et al., with higher predictability for FM area and sagittal diameter compared to transverse diameter. Rai et al. found OC and FM dimensions higher in males compared to females No statistically significant difference was found in adults for different age groups for the OC and FM. Varsha et al. 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 imaging (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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None.

**Conflict of interest**

Author declares that there is no conflict of interest.

**References**


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