Anatomical determination of a safe entry point for occipital condyle screw using three-dimensional landmarks

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Abstract The occipital condyle (OC) is an important area in craniovertebral surgery, but neither its anatomical features nor the procedures concerning the OC have been detailed yet. The morphological analysis of the structures were made in totally 704 sides of the occipital bones of adult skulls by 3D-Doctor Demo version. The length and width of the OC were found to be 23.9 ± 3.4 (right), 24 ± 3.3 (left) and 11.9 ± 2.3 (right), 10.7 ± 2.3 mm (left), respectively. The mean anterior intercondylar distance and the posterior intercondylar distance were measured as 20.9 ± 3.6 and 43.1 ± 4 mm, respectively. The sagittal intercondylar angle was observed as $68.7 \pm 10.6^\circ$. The sagittal condylar angle was observed to be $32.9 \pm 7.6^\circ$ and $38.2 \pm 7.3^\circ$ in the right and left, respectively. The head circumference was observed to be 65.6 ± 7.8 and 64.4 ± 7.2 mm in the right and left, respectively. The head area was measured as 231.9 ± 53.3 and 214.9 ± 45.1 mm² in the right and left, respectively. The most common type was oval-like (59.67%), whereas the most unusual one was two-portioned condyle (0.32%). In Pearson correlation analysis, it was significant that a statistically strong relation was noticed between the length and area, and the circumference and area. The findings suggest that the oval type was more successful to work with, while the triangular, circular and two-portioned types were highly risky for the fixation resonance as the surface got quite smaller. As a

result, we suggest that by resecting nearly half of the OC, the border of the hypoglossal canal can be involved.

Keywords Occipital condyle · Entry point · Craniovertebral fixation · Craniocervical junction

Introduction

The occipital condyles (OC) of the skull are located with the superior articular facets of the atlas vertebra and form an important junction between the cranium and the vertebral column [3, 10, 11]. Each OC is oval in outline and oriented obliquely so that its anterior end lies nearer the midline. It is markedly convex anteroposteriorly, slightly convex transversely, and its medial aspect is roughened by ligamentous attachments [13].

Its integrity is of vital importance for the stability of the craniovertebral junction.

The difficulties and high rate of morbidity associated with surgical approaches [1, 7–9].

The lateral approach is a versatile procedure to this area and allows us to manage a variety of intra- and extradural tumors, as well as aneurysms, of the vertebrobasilar system [2, 14, 15, 21, 22]. The lateral approach consists of a range of progressive bone excluded based on the lesion being treated. These partial resections have been performed as retrocondylar, paracondylar, supracondylar, partial, and complete transcondylar approaches. The important advantages of the lateral approaches are better visualization of the ventral to the lower brainstem, reach to intra- extradural tumors, control of the ipsilateral vertebral artery and to minimize of the development of a cerebrospinal fistula [15, 21, 22].

The interest for transcondylar approach requires information regarding the morphometric aspects of the OC and

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structures around it [2, 3, 10, 11, 16]. The main question to be answered in the pre-operative decision-making process is whether the shape, size, and angle of the OC affect our surgical technique.

Even though the studies concerning the importance of anatomical features of the OC serve as milestones in skull base surgery, there is still a great necessity for a more detailed studies [9, 10, 20]. As a few studies have examined the arrangements of the OCs and their paracondylar structures in detail, our team have studied the arrangements of the OCs of the craniovertebral junction. Especially in interventional operations like nail insertion; the direction, angle and position of the nail may change according to the OC type and the difference in measurements may change the surgical technique. This study was planned because determining the shape, length, and width of the OC is important as it is used as an orientation point in cases requiring craniovertebral surgery.

Materials and methods

144 cranium, 208 occipital bones, totally 704 sides of adult dry skulls of unknown age and sex obtained from the Turkish population were used to measure the dimensions and determine the localization of the OC. The macro mode of Sony DSC H1 5.1 megapixel camera was used for photography. The photographs were taken in aperture priority mode, with f 3.5 diaphragm clarity and at four zoom adjustment. The skulls were fixed horizontally. The shots were made by fixing the camera 37.5 cm away from the OC with the help of a tripod at an angle of 78° with the horizontal surface.

Fig. 1 Perimeter measurement of the OC using Able Software Corporation 3D-Doctor V 3.5050402 Demo version. OC occipital condyle; FM foramen magnum

The pictures were then uploaded onto a personal computer and a specific software (Able Software Corporation 3D-Doctor V 3.5.050402 Demo version for Windows 98/NT/2000) was used to calculate the surface areas of the reflections of the OC (Fig. 1). With the software, inferior contours of the OCs were manually chosen and their perimeter, form, area, angles and relations with the other structures were evaluated on the right and left sides separately. Fourteen parameters, including the distances and angles related to the OCs and the structures around them were measured. Some of these measurements of the OC are shown on the photograph of the skull in Fig. 2.

The distances measured between two different points were as follows (Fig. 2):

1. The length of the OC,
2. The width of the OC,
3. The height of the OC
4. The perimeter of the OC,
5. The area of the OC,
6. Anterior intercondylar distance (distance between the anterior tips of right and left OCs),
7. Posterior intercondylar distance (distance between the posterior tips of right and left OCs)
8. Distance between the anterior tip of the OC and the basion,
9. Distance between the posterior tip of the OC and the basion,
10. Distance between the anterior tip of the OC and the opisthion,
11. Distance between the posterior tip of the OC and the opisthion,
12. Sagittal intercondylar angle (the angle between the long axes of right and left OCs),

Fig. 2 a–b Calculation of some of the measurements made of the OC and paracondylar structures made of the OC using the V 3.5050402 Demo version. OC occipital condyle; B basion, O opisthion, α (ICA) sagittal intercondylar angle, β sagittal condylar angles, RCA right condylar angles, a anterior intercondylar distance, b posterior intercondylar distance, c anterior tip of OC and opisthion, d anterior tip of OC and basion, e posterior tip of OC and basion, f posterior tip of OC and opisthion

13. Right sagittal condylar angle (the angle between the right OC axis and the midline).
14. Left sagittal condylar angle (the angle between the right OC axis and midline).
15. The distance between the basion and the opisthion.
16. The presence of canalis condylaris.

Descriptive statistics (mean, minimum, maximum, standard deviation) were evaluated for all the parameters collected from dry skull measurements. Differences between the data of skull measurements were analyzed by the Student t test. The Pearson correlation test was used in the statistical analysis which was made among four values (the longest edge and area; the widest edge and area; the outer angle and area, and the hole diameter and area). For

all the analyses, $p < 0.05$ was accepted as statistically significant, while $p < 0.01$ was accepted as highly significant.

The OC was classified into eight types according to its shape as follows: type 1, oval-like condyle; type 2, kidney-like condyle; type 3, S-like condyle; type 4, eight-like condyle; type 5, triangular condyle; type 6, ring-like condyle; type 7, two-portioned condyle and type 8, deformed condyle (Fig. 3). The third condyle, asymmetrical foramen magnum, exocranial aspect of foramen magnum and hypocondylar arch were investigated.

Results

The OCs, which articulate with the atlas, protrude from the external surface of this part. These condyles were located lateral to the anterior half of the foramen magnum. The OCs were oval in shape, convex downward, face downward laterally, and have their long axes directed forward and medially.

The results obtained from the linear and angular measurements were presented in Table 1. The length and width of the OC were found to be 23.9 ± 3.4 (right), 24 ± 3.3 (left) and 11.9 ± 2.3 (right), 10.7 ± 2.3 mm (left), respectively. The mean anterior intercondylar distance and the posterior intercondylar distance were measured as 20.9 ± 3.6 and 43.1 ± 4 mm, respectively. The distance between the anterior tip of the OC and the basion was measured as 12.6 ± 2.5 and 10 ± 2 mm in the right and left, respectively. The distance between the anterior tip of the OC and the opisthion was observed to be 41.4 ± 3.9 and 39.7 ± 4 mm in the right and left, respectively. The distance between the posterior tip of the OC and the basion was 29.4 ± 3.2 and 29.5 ± 2.9 mm in the right and left, respectively. The distance between the posterior tip of the OC and the opisthion was observed as 29 ± 3.1 and 30 ± 3.2 mm in the right and left, respectively.

The sagittal intercondylar angle was observed to be $68.7 \pm 10.6^\circ$. The sagittal condylar angle was found to be $32.9 \pm 7.6^\circ$ and $38.2 \pm 7.3^\circ$ in the right and left, respectively. The distance between the basion and the opisthion was measured as 37.2 ± 3.5 mm. The head circumference was observed to be 65.6 ± 7.8 and 64.4 ± 7.2 mm in the right and left, respectively. The head area was measured as 231.9 ± 53.3 and 214.9 ± 45.1 mm² in the right and left, respectively. No statistical significance was noticed between the left and right sides.

The most common type was type 1 (59.67%), whereas the most unusual type was type 7 (0.32%). Other types were seen in the following frequencies: type 2; 22.95%, type 3; 4.09%, type 4; 4.59%, type 5; 4.26%, type 6; 2.45% and type 8; 1.63% (Fig. 3).

Fig. 3 Types of form of the occipital condyle (OC). **a** type 1: oval-like condyle, **b** type 2: kidney like condyle, **c** type 3: S-like condyle, **d** type 4: eight-like condyle, **e** type 5: triangle condyle, **f** type 6: ring-like condyle, **g** type 7: two-portioned condyle, **h** type 8: deformed condyle

Table 1 The results of measured linear and angular parameters of the occipital condylus (OC) (mm)

	Mean $\pm$ SD (maximum–minimum)	
	Right	Left
The length of the OC	23.9 $\pm$ 3.4 (40.1–16.5)	24 $\pm$ 3.3 (39.7–13.7)
The width of the OC	11.9 $\pm$ 2.3 (19.5–7.2)	10.7 $\pm$ 2.3 (21.8–5.1)
The head circumference of the OC	65.6 $\pm$ 7.8 (90.56–16.1)	64.4 $\pm$ 7.2 (86.6–43.1)
The area of the OC	231.9 $\pm$ 53.3 (375.7–110.5)	214.9 $\pm$ 45.1 (347.1–119.1)
Distance between the anterior tip of OC and basion	12.6 $\pm$ 2.5 (36.1–7.6)	10–2 (16.6–5.6)
Distance between the posterior tip of OC and basion	29.4 $\pm$ 3.2 (37.9–20.8)	29.5 $\pm$ 2.9 (41.3–22.5)
Distance between the anterior tip of OC and opisthion	41.4 $\pm$ 3.9 (51.2–32.2)	39.7 $\pm$ 4.0 (49.3–27)
Distance between the posterior tip of OC and opisthion	29 $\pm$ 3.1 (36.4–21.8)	30–3.2 (37.1–21.3)
Sagittal condylar angle	32.9 $\pm$ 7.6 (87.2–5.4)	38.2 $\pm$ 7.3 (58–15.3)
Sagittal intercondylar angle	68.7 $\pm$ 10.6 (103.4–33.4)	
The distance between basion and opisthion	37.2 $\pm$ 3.5 (45–27)	
Anterior intercondylar distance	20.9 $\pm$ 3.6 (29.8–11.1)	
Posterior intercondylar distance	43.1 $\pm$ 4 (54.2–31.9)	

Out of 304 bone cases, a hole consistent with canalis condylaris was seen in 252 samples (82.3%), when no hole was observed in 52 cases (17%). The difference in hole

structures was shown in Fig. 4. Asymmetrical foramen magnum was not observed in any of the specimens. In one case, hypocondylar arch structure that formed between

both OCs was observed (Fig. 5a). An another cranium was identified with marked exocranial process of the foramen magnum (Fig. 5b).

Discussion

Most of the craniovertebral approaches necessitate either partial or complete resection of the OC and morphometrical analysis of the OC and the paracondylar structures [3, 10, 11, 13, 15]. Despite the fact that the variation in shapes of the OC as well as the measurements and incidence have been recognized in the previous clinical and anatomical studies, it has been observed during the dissection that the pattern of the OC in the craniovertebral junction was not as simple as it had been reported by many authors [4, 10, 12, 13, 16, 18]. Especially the difference in measurements of the OC and the related structures showed a wide diversity and various investigators have not come to an agreement upon this. These results confirm the variability in almost all

the measured OC parameters, including length, width, and a variety of angles. The OC is an oval mass articulating with C1 lateral mass. Its length ranges between 16.7 and 30.6 mm (mean 23.6 mm) [5, 17, 19]. The OC width ranges between 6.5 and 15.8 mm (mean 10.5 mm) [3, 11].

The OC converges ventrally. The anterior and posterior intercondylar distances are 21.0 and 41.6 mm, respectively. This causes the OC to have different anterior and posterior angles. Sagittal intercondylar angle ranges between 22 and 103° (mean 59.3°) [1, 3]. This width reflects the asymmetry in the orientation, length and shape of the OC and may affect the lateral approach. According to Acikbas et al. [1] study, condylectomy provides a wider angle of exposure. The presence of an already wider sagittal condylar angle seems to be more advantageous for reaching the ventral foramen magnum.

The distances between the anterior and posterior tip of the OC and the basion were measured as 10.8 and 28 mm, respectively. The distances between the anterior and posterior tip of the OC and the opisthion were measured as 39

Fig. 4 Different foramen condylare (FC) types **a** the absence of bilateral hole, **b** the presence of one-sided hole, **c** bilateral big hole, **d** bilateral small hole, **e** a big hole on the left side, **f** a small hole on the right side, **g** double arrow a double hole on the right side

Fig. 5 A hypochondylar arch **a** and the paracondylar process **b** were identified. *OC* occipital condyle, *arrow* paracondylar process

and 26.4 mm, respectively. The distance between the posterior tip of the OC and the opisthion is also an important anatomical factor. The larger the distance is, the freer the corridor for posterolateral approaches becomes.

In summary, although the studies reported by Oliver, Bozbuga and Guidotti addressed the types of OC; they did not mention the rate of each particular type. On the other hand, their classifications are inadequate, too simple and not applicable to clinical practice. Naderi et al. [11] have done the first study which made a systematic and detailed classification of the OC, based on its shape, and revealed the percentage of each particular type. A variety of OC shapes have been described, including two-semicircles type, oval type, rhombus type, bean-shaped type, prismatic types, flattened type, convex types, flattened-convex types, short and broad types, flat and long types, small and convex types [1, 3, 10]. The most common shape of the OC was oval-like type (59.67%), whereas the most unusual type was two-portioned type (0.32%). Other frequent variations included a kidney-like, S-like, eight-like, triangle, ring-like and deformed type which was seen in 22.95, 4.09, 4.59, 4.26, 2.45 and 1.63% of the specimens, respectively (Table 2).

Naderi et al. [11] study found a weak correlation between the length of OC and head circumference. In the present study, however, we found no relation between the circumference of the head and the length of OC. Furthermore, there was no correlation between the OC length and the basion–opisthion distance. The lack of relationship

between the length of OC and head circumference, and the lack of correlation between the anteroposterior diameter of foramen magnum and head circumference suggest that the OC and the foramen magnum may be having different sizes. A surgeon cannot decide about the easiness of condylectomy based on the head size. A condylectomy produced requires a radiological investigation.

We believe that the chances of surgical success will increase in craniocervical intersections as the safe region might be larger owing to the larger distances between the posterior tip of the OC and the basion, posterior tip of the OC and the opisthion, and posterior intercondylar. The distance between the posterior tip of the OC and the opisthion is also an important anatomical factor. The larger the distance is, the freer the corridor for posterolateral approaches becomes. Posterior intercondylar distances will be larger when the sagittal intercondylar angle is wider. Here, the angle and the distance are in direct proportion. As the angle becomes wider, the distance will increase accordingly and the area for a safe surgical procedure will become larger (Fig. 6). When the sagittal condylar angle is evaluated, for a smooth nail insertion it is substantial that the angle with the condyle horizontal surface should not be acute or obtuse, but it should be close to right angle. Condyle types with a short length, narrow area, acute-

Table 2 The rates of occipital condyles of different types

Types of condyles	Total
1–Oval-like	420 (59.7%)
2–Kidney-like	162 (23%)
3–S-like	29 (4%)
4–Eight-like	32 (4.5%)
5–Triangle	30 (4.2%)
6–Ring-like	17 (2.3%)
7–Two-portioned	2 (0.3%)
8–Deformed	12 (1.7%)
Total	704 (100%)

Fig. 6 Schematic illustration of the posterior view of craniocervical junction presenting the location of the OC entry point

angled sagittal intercondylar angle and obtuse-angled sagittal condylar angle are among the ones which are not suitable for nail insertion.

In nail insertion, the oval-like OC specimens are the ones with the largest perimeter, and therefore, the highest surgical success (Fig. 3a). We also found a strong correlation between the length and area (0.83), and the perimeter and area (0.92), and this was statistically significant at the 0.01 level. According to the Pearson correlation analysis index, the most influential factors over the OC area are length and perimeter. The high frequency rate of oval type (50%) increases the chances of success in fixation. The other condyle types including triangle (Fig. 3e), ring-like (Fig. 3f), two-portioned (Fig. 3g) and deformed condyle (Fig. 3h), where the fixation surface is quite narrow, might cause problems in terms of orientation as the surgical resonance area is narrow and the length is short. The quite low frequency rate of these types (19.3%) is in fact a chance. The reason of some paracondylar structure differences is the permanency of hypocondylar arch parts which should have been remissed gradually and disappeared by birth. Hypocondylar arch and paracondylar processes were observed, each one in a separate case (Fig. 5a, b). The presence of paracondylar bone should also be considered within the plan of surgical resonance on foramen magnum and the OC.

The relation between the OC and the hypoglossal canal is important for the transcondylar approaches. The hypoglossal canal is surrounded inferiorly by the OC. The hypoglossal canal runs its way posteromedially and anterolaterally in the OC [6]. The distance between the hypoglossal canal and the posterior border of the OC is about 12.2 mm [10]. That means the drilling bone 12 mm from the posterior border of the OC does not harm the hypoglossal canal. The length of OC was determined meanly as 23.9 mm at the right side and 24 mm at the left one. As a result, we suggest that by resecting nearly half of the OC (12.52 ± 0.05 mm), the border of the hypoglossal canal can be involved.

The maximum amount of drillable OC without opening the posterior border one-third or half of the long axis of the OC [2, 9]. Previous researchers reported that the OC could be removed with a 12 mm safe zone (nearly half of the OC), without drilling the hypoglossal canal and its contents [2, 9].

The anatomical and biomechanical results of partial condylectomy in a short type are different from those obtained in a long type OC. The same amount of partial condylectomy may cause greater occipitocervical instability in a short OC, whereas a long condyle 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.

Conflict of interest None.

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