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Clinical and anatomical importance of foramen magnum and craniocervical junction structures in the perspective of surgical approaches

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Abstract: This study was conducted to investigate the clinical and anatomical importance of the relevant region from the perspective of surgical approaches by determining the morphometric analysis of the craniocervical junction and foramen magnum (FM) region and determining their distances from important anatomical points. This research was carried out with 59 skulls found at the Anatomy Laboratories of Erciyes and Ankara Medipol University. Metric measurements of FM and condyle, FM shape, condyle-fossa relationship, and pharyngeal tubercle (PT) were made in mm-based dry bone samples of unknown age and sex. The distance between the anterior notches and the FM was 87.01±4.35, the distance between the anterior notches and the PT was 77.70±4.24, the distance between the PT-sphenooccipital junction was 13.23±2.42, and the FM index was 81.86±7.47. The anteroposterior and transverse lengths of FM were determined as 33.80±2.99 and 27.72±2.30, respectively. The morphometric and morphological data available regarding the craniocervical junction showed significant differences between populations. Comprehensive knowledge of this topic will provide a better approach to treat Arnold Chiari Malformation, FM meningiomas, and other posterior cranial fossa lesions. Therefore, we believe that FM and craniocervical junction morphology will be a guide not only for anatomists, but also for radiologists, neurosurgeons, ENT surgeons, and orthopedists.

Key words: Foramen magnum, Craniocervical junction, Morphometry, Transoral/transpharyngeal approach

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Introduction

The craniocervical junction (CCJ) is a complex transition area between the skull and upper cervical spine that provides stability and movement. The most important part of the CCJ is the foramen magnum (FM), which is primarily formed by the occipital bone. The FM located in the posterior part of the cranial floor is important, and surgery in this region has its own problems due to the complex anatomy of the CCJ [1]. Similar to FM achondroplasia, cerebral herniation, and meningioma, pathological FM dimensions can cause stenosis. The brainstem and spinal cord pass through the FM, opening the base of the skull. FM stenosis occurs when the opening narrows, putting pressure on the brain or the spinal cord. Compression of structures passing through it affects the flow of blood and cerebrospinal fluid, leading to life-threatening respiratory complications, lower cranial nerve palsy, and paresis of the upper and lower extremities [2]. In addition, in cases where other parts of the craniofacial skeleton are involved, such as serious injuries, accidents, fire, or explosion, knowing the morphology of the FM is extremely important in determining the clinical approaches to be applied to the region. In addition to the clinical conditions mentioned

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above, many changes occur in the posterior cranial fossa in tonsillar ectopia and Chiari I malformations [3, 4]. Therefore, we believe that it will be useful to know the anatomy of the region with all details in determining the CCJ approaches to make the most accurate intervention in this region.

Surgical approaches to pathologies in the upper part of the CCJ and spinal cord vary as anterior, posterior, or posterolateral approaches depending on the anatomical location and extent of the pathology. It is possible to reach the front of the FM, craniocervical junction, clivus, and lower brainstem with immediate and optimal exposure using the anterior or lateral/posterolateral approach [5]. The far-lateral transcondylar approach is considered optimal to access this region and is widely used to access anatomical regions near the FM in lesions ranging from posterior inferior cerebellar artery aneurysms to clivus chordomas [6]. On the other hand, the transcondylar approach is an extension of the basic far-lateral approach, and as it includes a condylar intervention, it increases the surgical exposure area and provides access to the lower clivus and premedullary area (Fig. 1) [7]. Before the transcondylar approach, important preoperative information such as FM shape, length, and width of the condyles minimizes injury to neural structures and retraction, while knowing the anteroposterior and transverse lengths of the FM is also important for calculating the surgical area [6].

Generally, anteriorly located lesions can be reached via the transoral route, which is the most common but suitable only for extradural lesions. If the pathology is inferior to that of the clivus, ventral to the cervicomedullary junction, or the first three cervical vertebrae, transoral/transpharyngeal approaches are effective direct decompression methods. The use of this approach is limited to intradural lesions because of the risk of cerebrospinal fluid leakage and infection [8]. The transoral-transpharyngeal approach not only directly reaches the ventral midline of the craniocervical junction but also effectively prevents damage to important anatomical structures such as the internal carotid artery, cranial nerves, and endocrine glands [9]. The most common application of the transoral approach is resection of the odontoid process in cases of congenital basilar intussusception, rheumatoid arthritis, and congenital atlantoaxial dislocation [8, 10, 11].

In summary, although each approach has its own limitations, transoral/transpharyngeal approaches have begun to be used more commonly in craniocervical junction pathologies. Therefore, for regional surgery, morphological analysis of the CCJ should be performed well. Therefore, it is important to know the morphology of the FM, which is an important anatomical point for the craniocervical junction and its distance from other structures. Previous studies have generally focused on FM morphology. However, the relationship between the condyles, FM, and surrounding structures is important in terms of surgical planning. Therefore, this study aims to guide clinicians in related region surgery, especially in transoral/transpharyngeal surgeries, by making a more detailed morphometric analysis of the CCJ and FM regions and determining their distances to important anatomical points.

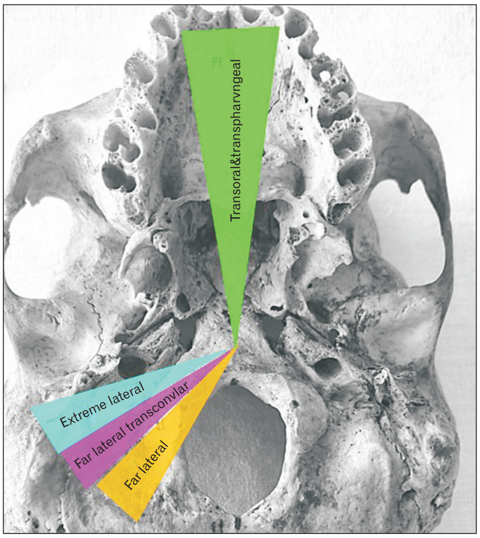

Fig. 1. Posterolateral, transoral and transpharygeal approaches. Adapted from Luzzi et al. (Turk Neurosurg 2019;29:875-86) [7].

Materials and Methods

This descriptive study was conducted on 59 dry human adult (18–60 age) skulls of Anatolian ancestry origin, obtained from the Department of Anatomy, Faculty of Medicine, Ankara Medipol, and Erciyes Universities. The genders of skulls were unknown. However, using SPSS analysis (Skewness and Kurtosis, Gaussian distribution), it was determined that the data were distributed between certain values, and that there were no extreme values that would affect the results. This descriptive study was approved by the E-81477236-604.01.01-3639 decision of the non-interventional clinical research ethics Committee of Ankara Medipol University. All skulls used in the study were dry, complete, and showed normal anatomical features. Skulls with broken and deformed FM were excluded from this study.

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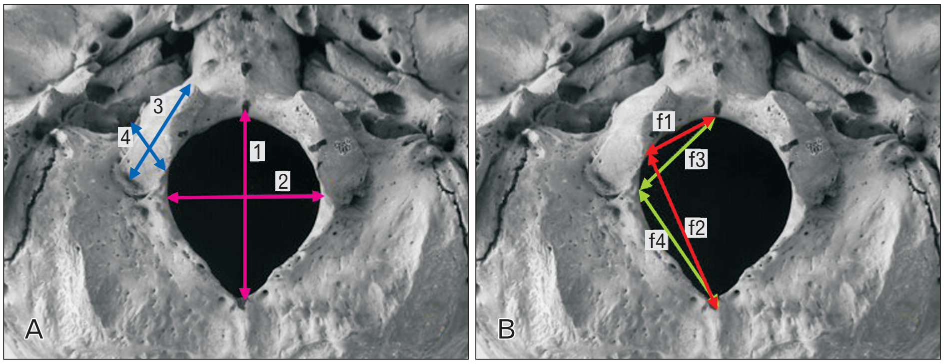

Fig. 2. Morphological measurements of foramen magnum (FM) and occipital condyle (OC). (A) 1: FM anteroposterior length, 2: FM transverse length, 3: OC length, 4: OC width. (B) f1: the distance from the anterior midpoint of the FM to the most protruding point of the medial edge of the OC, f2: posterior of the FM distance from its midpoint to the most protruding point of the medial edge of the OC, f3: from the anterior midpoint of the FM to the midpoint of the medial edge of the OC, f4: from the posterior midpoint of the foramen magnum to the midpoint of the medial edge of the occipital condyle.

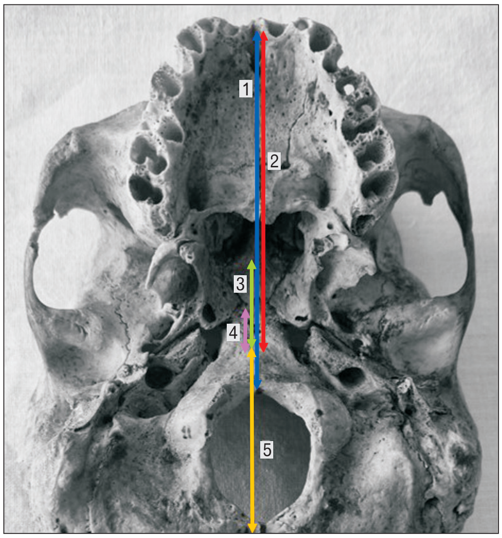

Fig. 3. Relationship of PT with key points. 1: distance between anterior notchs-medial of FM, 2: distance between anterior notchs-TP, 3: distance between PT-sphenooccipital junction, 4: distance between PT-ala of vomer, 5: distance between PT-basion. PT, pharyngeal tubercle; FM, foramen magnum.

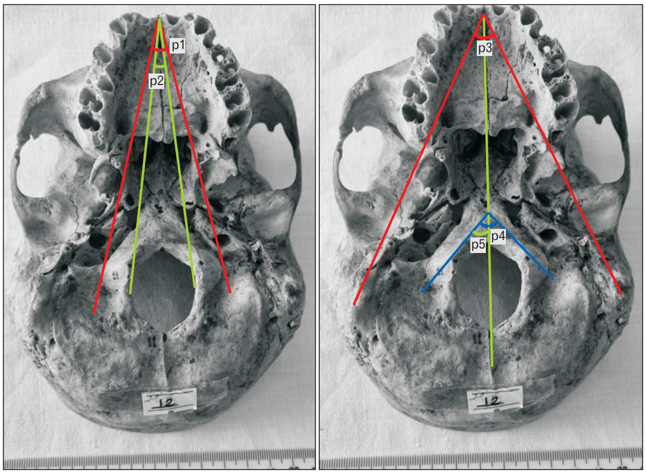

Fig. 4. Angles associated with FM. p1: angle between anterior notchs and lateral of occipital condyle (AN-OC/L), p2: angle between anterior notchs and medial of occipital condyle (AN-OC/M), p3: anterior notchs angle between mastoid process (AN-MP), p4: sagittal intercondylar angle (SIA), p5: sagittal condylar angle (SCA).

Various parameters measured using a Vernier caliper are shown (Fig. 2). Area of the FM (Afm)

It is the surface area of the FM and is calculated using the formula derived by Radinsky [5].

Area of FM (Afm)=$1/4\ \pi wh$

$\pi\rightarrow$ Mathematical constant=22/7

$w\rightarrow$Transverse diameter of FM (TDfm)

$h\rightarrow$Anteroposterior diameter of FM (APDfm)

FM index (Ifm): $w\times100/h$.

The distances between the FM, occipital condyle (OC), pharyngeal tubercle (PT), and anterior notches in the craniocervical region and angulations are shown in Figs. 3, 4.

The above parameters were recorded as an average of two observations, which were measured independently by two different people. The mean and standard deviation for each parameter were calculated and expressed as mean±SD. The mean and standard deviation for each parameter were calculated and expressed as mean±standard deviation. In addition to the shape of the FM, they were classified as egg shape, leaf shape, hexagon, or pentagon.

Results

Dimensional anatomy of the FM region

The metric parameters of the FM are listed in Table 1. The mean transverse and anteroposterior lengths of the FM were 27.718±2.30 mm and 33.80±2.99 mm.

Results of FM area

The results for the FM area are shown in Table 1. The mean FM area were 953.80±76.90 mm^2.

Results of FM index

The FM index results are shown in Table 1. The mean FM index was 81.86±7.47 mm^2.

Results of FM shapes

The FM shapes evaluated in the 59 cases are shown in Fig. 1. While egg shape was observed at the highest rate (44%), leaf shape was observed at the rate of 20%, hexagon was 10%, and pentagon was 26% (Fig. 5).

Dimensional anatomy of The OC

The metric parameters of the OC are listed in Table 1. The length of the OC on the right and left sides of the occipital condyle was determined as 20.85±1.67 mm and 21.34±2.19 mm and the width as 11.98±2.09 mm and 12.45±1.96 mm, on the right and left sides; respectively.

Distances between key guide points at the craniocervical junction

The distances between key guide points at the craniocervical junction are shown in Table 2. The mean distances of the PT to the sphenooccipital junction, ala of vomer posterior ridge and basion were found to be 13.23±2.42 mm, 18.45±8.68 mm and 12.10±1.56 mm, respectively. Also, the mean distances of the anterior notch to the FM and PT were found to be 87.01±4.35 mm and 77.70±4.24 mm, respectively.

Morphological measurements of FM and OC relationship

The relationship between the FM and OCs was evaluated using four different parameters. According to the results obtained from the parameters, the distances from both the anterior and posterior midpoints of the FM to the midpoint

Table 1. The metric parameters of FM and OC

Parameter	n	Min–max	Mean±SD
FM tranvers length (mm)	59	21.92–32.37	27.718±2.30
FM anteroposterior length (mm)	59	24.58–40.48	33.80±2.99
FM area (mm^2)	59	714.28–1,229.78	953.80±76.90
OC length-right (mm)	59	18.89–23.08	20.85±1.67
OC width-right (mm)	59	9.78–12.03	11.98±2.09
OC length-left (mm)	59	19.14±2.98	21.34±2.19
OC width-left (mm)	59	10.67–14.67	12.45±1.96
FM index	59	62.00–91.00	81.86±7.47

FM, foramen magnum; OC, occipital condyle; Min, minimum; Max, maximum.

Table 2. Distances between key guide points at the craniocervical junction

Parameter	Min-max (mm)	Mean±SD (mm)
Between anterior notchs and medial of FM	77.47–95.33	87.01±4.35
Between front notchs and PT	68.27–86.08	77.70±4.24
Between PT-sphenooccipital junction	8.67–19.19	13.23±2.42
Between PT- ala of vomer posterior ridge	16.73–24.87	18.45±8.68
Between PT and basion	8.90–14.56	12.10±1.56

FM, foramen magnum; PT, pharyngeal tubercle; Min, minimum; Max, maximum.

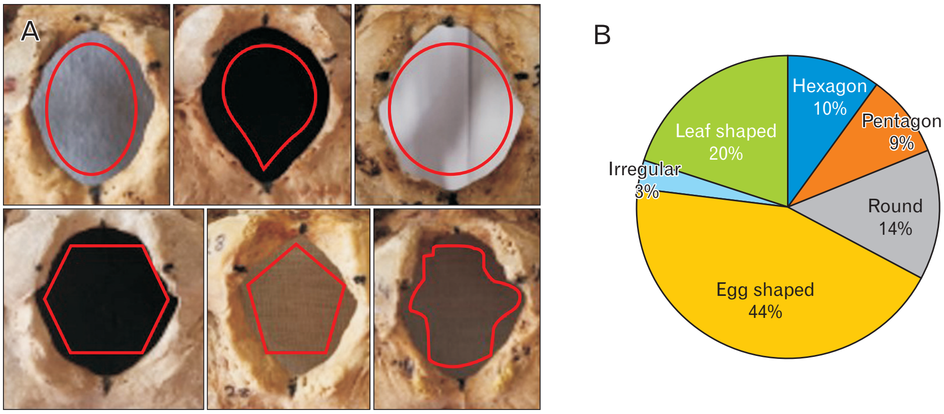

Fig. 5. Foramen magnum (FM) shapes. (A) FM shapes, (B) percentages of FM shapes.

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Table 3. Morphological measurements of FM and OC relationship

Parameter	Min–max	All mean±SD	Right	Left
F1	9.67–20.79	15.29±4.42	14.47±4.25	16.11±4.74
F2	20.89–35.76	27.29±7.79	26.95±7.85	27.63±7.95
F3	11.01–26.34	12.96±5.03	12.57±4.31	13.36±6.31
F4	29.67–40.45	28.98±8.97	28.20±9.04	29.76±8.87

FM, foramen magnum; OC, occipital condyle; Min, minimum; Max, maximum.

Table 4. Important angulations between FM and spheno-occipital junction structures

Parameter	n	Min-max	Mean±SD
p1: AI-OC/L	59	25.53–31.90	27.69±1.81
p2: AI-OC/M	59	13.93–15.93	14.89±.87
p3: AI-MP	59	49.42–52.85	50.92±1.26
p4: SIA (°)	59	53.95–89.20	68.71±9.41
p5: SCA (°)	59	24.59–38.10	33.53±5.67

FM, foramen magnum; AI, anterior incisors; OC/L, occipital condyle/lateral border; OC/M, occipital condyle/medial border; MP, mastoid process; SIA, sagittal intercondylar angle; SCA, sagittal condylar angle; Min, minimum, Max, maximum.

of the medial edge of the OC and the most protruding point of the medial edge were higher on the left side than on the right side (Table 3).

Angles associated with FM and sphenooccipital junction

The FM and sphenooccipital junction angle values are listed in Table 4. Angles of anterior notchs with mastoid process, carotic canal, the opposing most medial border of FM, and the most lateral point of OC were detected as 50.92°±1.26°, 27.45°±1.56°, 14.89°±.87°, and 27.69°±1.81°, respectively. The mean sagittal intercondylar angle (SIA) was 68.71°±9.41°, and the mean sagittal condylar angle (SCA) was 33.53°±5.67°.

Discussion

This research was carried out to evaluate the morphology of the FM, which is an important anatomical point for the CCJ, and its distance from other structures from the perspective of various guide points.

The anteroposterior and transverse lengths of the FM were clinically important for calculating the surgical area. In this study, transverse and anteroposterior lengths of the FM were found to be 27.718±2.30 and 33.80±2.99 mm, respectively. In the literature, these lengths have been reported as 33.3±1.56 and 27.9±1.89 mm by Muthukumar et al. [12], 34.84±2.32 and 29.39±1.73 mm by Sampada et al. [13], 33.57±2.82 mm and 27.49±2.61 mm by Singh et al. [14]. In our study, the sagittal length was higher than the transverse length in accordance with the literature, and these results were consistent with the normal oval shape of the FM.

The FM area concerns the CCJ and the entire posterior cranial fossa. While the mean FM area was found to be 953.80±76.90 mm^2 in our study, it was reported as 853.36 mm^2 by Degno et al. [15], and as 752.07±111.97 mm^2 by Dasegowda et al. [1]. By using with two different formulas, Gocmen Mas et al. [16] reported the mean area as 790.47±99.86 mm^2 and 783.66±99.34 mm^2, respectively. We believe that the differences between FM areas in the literature may be due to nutritional status, race, and geographical diversity, as well as the calculation method used.

It has been reported that the FM index is used in the selection of the surgical approach to the skull base with sex determination, and the cranial index can vary between 70–90 [1, 14, 17]. In our study, the FM index was determined as 81.86±7.47. We believe that our results are compatible with the literature and that the index will provide clinicians and neurosurgeons with important information for approaching the cranial base with maximum safety and minimum mortality and morbidity. In addition, many studies have reported that the FM index helps determine the shape of the FM, so it should be considered in surgical planning [1, 8, 12, 14, 17].

The adult form of FM occurs before approximately 5 years of age, with different patterns of development occurring between the anterior and posterior foraminal margins [18, 19]. It has been reported in the literature that this variability may be due to sexual dimorphism, differences in population types, and ethnic groups, and that the irregular shape of FM may be due to developmental anomalies such as Chiari malformation of bone and soft tissues at the craniovertebral junction [14, 20, 21]. In our study, it was found that the highest rate of FM was egg-shaped (44.4%) and the lowest rate was hexagon (10%). Similar to our study, Dasegowda et al. [1], Sampada et al. [13], Vidya and Nagashree [8], Singh et al. [14], Aljarrah et al. [22] reported the highest rate of egg shape. Variations in the FM shape should be considered during radiological diagnostic procedures and surgical approaches in the region. The shape of the FM is considered an important marker for determining the amount of bone tissue that must be removed.

Knowing the length and width of the occipital condyle helps to safely remove the posterior 1/3 of the condyle [5, 23]. Techniques such as extreme transfacial, partial transcondylar, and far lateral approaches may require partial or complete removal of the occipital condyle [24-26]. The dimensions and orientation of the occipital condyle may affect the surgical approach to craniocervical lesions. Different researchers state that variable morphometry of the occipital condyle may result from different data assimilation methods and genetic characteristics of different populations [23, 27, 28]. In our research results, the length of the occipital condyle was determined as 20.85±1.67 and 21.34±2.19 mm and the width as 11.98±2.09 and 12.45±1.96 mm, on the right and left sides; respectively, Luzzi et al. [7] reported the length and width of the right condyle as 23.6±1 and 11.7±1 mm, and the left condyle as 23.5±1 and 11.3±1 mm; respectively. In the study of Degno et al. [15] in which they evaluated skulls of Ethiopian origin, the length and width of the occipital condyle were found to be 25.69 mm and 12.76 mm on the right side, and 26.96 mm and 13.04 mm on the left side, respectively. In this study, we attempted to analyze the morphometry of the occipital condyle during craniocervical surgery and provide a reference database to design customized implants and screws for the Turkish population. Such data may also enable the identification of osteological remains of the Turkish population in particular while allowing comparison with other study populations. In addition, since the amount of condyle to be resected will change depending on how much the condyle invades the foramen, it is thought that knowing the length and width of the condyle will be a guide for relevant field experts. In patients with a small FM and large occipital condyles, the transcondylar approach is a safer surgical method for conditions that require removal of the condyles.

The major advantage of midline transfacial approaches, including transoral, transnasal, transmaxillary, and extended frontal approaches and their various modifications and extensions, is direct anterior surgical access through large spaces in the nasal cavity, nasopharynx, paranasal sinuses, and oral cavity [28-30]. However, these midline pathways are transversely narrow and their lateral borders are delimited by critical neurovascular structures. Therefore, it has been reported in the literature that the distance between the PT, located in the center of this region, and the surrounding structures is surgically important, especially in lesions requiring a posterior approach [10, 30-32]. In our study, the distances between PT and spheno-occipital junction; PT and ala of vomer, PT and basion were determined as 13.23±2.42 mm, 18.45±8.68 mm and 12.10±1.56 mm; respectively. Ceri et al. [10] reported that the distance between PT-basion was 12.58±1.40 mm and the distance between the PT-ala of the vomer was 17.60±2.17 mm. We also examined the relationship between anterior notchs and FM and PT, which has not been measured before and which we think may be important for transoral & transpharyngeal approaches. Our findings revealed that the distance between the anterior notches and anterior border of the FM was 87.01±4.35 mm, and the distance between the anterior notches and PT was 77.70±4.24 mm. Knowing the distance between the anterior notches and PT to the structures at the craniocervical junction will provide important data for surgical interventions in this region.

Although posterolateral approaches provide a more comfortable working area than anterior approaches, they have been associated with increased mechanical instability and neurovascular iatrogenic injury since the occipital condyles are usually punctured [29]. For this reason, we think that the relationship between the occipital condyle and FM is one of the most important parameters for creating a safe surgical field in interventions in the region. According to the results obtained in the relationship between the FM and occipital condyle in our study, the shorter the f1, f2, f3, and f4 distances, the more OC diffused into the FM. Therefore, there was an increase in the surgical exposure area. It has been reported in the literature that there may be an increase of 5–7 mm in the mean exposure for 50% condylar resection [10, 33]. These distances from the anterior mid/posterior midline of the FM to the posterior border and midpoint of the OC are important in craniocervical surgery, as they represent the exposure angle in suboccipital craniotomy and 50% condylar drilling, respectively. In this respect, we believe that knowing the relationship between the FM and condyle will reduce the complications that may occur due to condyle resection in posterolateral approaches.

During interventional procedures, the entry direction, angle, and position may change according to the craniocervical region anatomy, and differences in measurements may change the surgical procedure. For example, the sagittal intercondylar angle is vital during screw placement in the occipital condyle [28, 34]. In our study, the sagittal intercondylar angle was 68.71°±9.41°, the SCA was 33.53°±5.67°, and the angle between the anterior notches and the most lateral point of the occipital condyle was 27.69°±1.81°. We believe that a wider condylar angle will provide a safer surgical field, especially for FM and surrounding surgeries. The AI-OC/lateral border (OC/L), AI-OC/medial border (OC/M), SIA, and SCA were related to the axial plane orientation of the craniocervical junction. The shorter the AI-OC/L, AI-OC/M, and CA-MP, the wider the SIA and SCA. Given these interrelationships, preoperative evaluation of angular measurements, such as SIA and SCA, can predict the area occupied by the anterior ends of the condyles in the anterior medial or distal medial corridor. It has been reported in the literature that an SIA and SCA wider than 70° and 35°, respectively, will reduce the surgical range of motion of anterior approaches to ventral intradural FM lesions, often resulting in the need for partial anterior condylectomy, with all relevant biomechanical consequences [24, 29]. In such cases, a posterolateral intradural approach, which may be simpler and less invasive, both anatomically and biomechanically, may be recommended. Conversely, the transoral and transpharyngeal approaches may be more advantageous in narrower cases of SIA and SCA.

The most important limitation of our study was that the ancestry, sex and origin of the skull was not clearly known.

Comprehensive morphometric analysis of the craniocervical junction is important not only for basic anatomical information, but also for planning and performing transoral, transpharyngeal, and posterolateral surgical approaches in the treatment of pathologies such as posterior cranial fossa lesions, meningioma, and Arnold chiari symptoms. In addition, it guides relevant field experts in determining the limitations of the surgical field and minimizing the risk of complications.

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Author Contributions

Conceptualization: BTD, BB. Data acquisition: DP, SE. Data analysis or interpretation: BTD, DP. Drafting of the manuscript: BTD, SE. Critical revision of the manuscript: BTD, BB. Approval of the final version of the manuscript: all authors.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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