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Morphometric Analysis of Occipital Condyles: Gender Differences, Asymmetry, and Surgical Implications at the Craniovertebral Junction.

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ABSTRACT

Aim: *The occipital condyles (OC) are key structures at the craniovertebral junction (CVJ) that form the atlanto-occipital joint, enabling head movement and stability. Variations OC shape, size, and orientation can impact surgical outcomes, especially in partial occipital condylectomies. This study aims to analyze OC morphometry, explore gender differences, assess asymmetry, and examine clinical implications, particularly for craniovertebral surgeries.*

Methodology: *A cross-sectional morphometric analysis was conducted on 80 OCs from forty adult skulls, equally divided between male and female specimens. Measurements, including length, breadth, and inter-condylar distances (AICD, PICD), were taken using Vernier calipers. OCs were categorized into shapes (e.g., oval, circular, kidney-shaped), and asymmetry was assessed by comparing right and left condyle dimensions. Statistical analyses, including t-tests, ANOVA, and correlation, were used to identify significant variations.*

Results: *The average right OC length was 22.80 mm, and the left was 22.36 mm, with no significant side-to-side differences. Male OCs were significantly longer and broader than females ($p < 0.05$). Asymmetry was prevalent in 80% of samples, especially in non-oval shapes. Significant correlations were found between OC measurements, aiding surgical planning.*

Conclusion: *Gender-specific anatomical models and customized surgical approaches are essential due to variations in OC dimensions and high asymmetry rates. Detailed morphometry can guide surgeons, improving safety and outcomes in craniovertebral surgeries. Future research should develop predictive models using advanced imaging and AI.*

Keywords: *Occipital condyles, Craniovertebral junction, Morphometry, Gender differences, Asymmetry, Surgical planning.*

INTRODUCTION

The craniovertebral junction (CVJ) serves as the essential interface between the skull and the cervical spine, facilitating head movement, support, and stability. It includes several critical anatomical structures, of which the occipital condyles (OC) play a pivotal role by forming the atlanto-occipital joint [Menezes AH 2008].

This joint is established by the articulation of the OC with the superior facets of the atlas (the first cervical vertebra) [Susan Standring 2008]. The OC are positioned anterolaterally to the foramen magnum and serve as the primary connecting point that stabilizes the head while enabling its mobility. Understanding the morphometry and morphology of the OC is vital in various clinical and surgical contexts, particularly in surgeries involving the CVJ (Noble E.R 1996).

Variations in the shape, size, and orientation of the OC have been documented across different populations and can significantly influence surgical planning and outcomes. For example, the transcondylar approach (TA) for accessing lesions at the corticomedullary junction or ventral to the brainstem often involves partial removal of the OC to improve the field of view. This procedure, however, is associated with potential complications such as atlanto-occipital joint instability and hypoglossal nerve palsies, highlighting the need for a detailed understanding of the anatomical differnces of the OC (Banerji, 1999; Naderi et al., 2005; Pereira et al., 2012). Anatomical variations, including population-specific differences in OC dimensions, are often linked to these complications, emphasizing the importance of precise anatomical knowledge in surgical practice.

Clinical Significance of Occipital Condyles in Surgery

Partial occipital condylectomies are crucial in neurosurgical procedures aimed at addressing pathologies such as hypoglossal nerve schwannomas, foramen magnum meningiomas, and cervicomedullary hemangioblastomas (Michael Bruneau 2007)

These lesions can compress vital structures, necessitating precise surgical intervention to alleviate symptoms without causing further damage. The transcondylar approach has gained popularity for such surgeries due to its ability to enhance exposure and reduce the need for extensive tissue retraction. However, the procedure’s success relies heavily on detailed anatomical knowledge of the OC and their variations.

The OC's proximity to critical neurovascular structures, such as the hypoglossal nerve housed within the hypoglossal canal beneath the condyle, raises concerns during surgical planning. Variations in the size, shape, and asymmetry of the OC can alter the positioning of the hypoglossal canal, increasing the risk of nerve injury during partial condylectomies. Consequently, understanding these anatomical nuances is vital for minimizing surgical complications and improving patient outcomes (Tange et al., 2001; Wen et al., 1997).Detailed morphometric knowledge allows surgeons to predict possible complications, plan safer surgical approaches, and reduce the risk of nerve damage, joint instability, and other complications associated with procedures in the CVJ.

Literature Review: Morphometric Variations Across Populations

Several studies have documented various morphometric characteristics of the OC across different populations, highlighting significant differences in dimensions such as length, breadth, and inter-condylar distances (AICD and PICD). For instance, a study by Mahajan (2013). focused on an Indian population and reported notable variations compared to findings from European and African cohorts. These differences underscore the need for population-specific morphometric databases, which can help surgeons customize their approaches based on the anatomical characteristics of their patient population.

The shape of the OC has also been classified into several categories, including oval, circular, kidney-shaped, and triangular variants. Understanding these classifications is essential for grasping the functional biomechanics of the atlanto-occipital joint, as certain shapes may predispose individuals to conditions like atlanto-occipital joint instability. Moreover, the prevalence of specific shapes can vary significantly, even within the same demographic, suggesting a complex interplay of genetic and developmental factors that influence OC morphology.

Despite advances in anatomical research, there remains a lack of comprehensive data that integrates morphometric, morphological, and clinical findings to provide a holistic understanding of the OC. This gap is particularly evident in studies that fail to correlate asymmetry in OC dimensions with surgical complications, highlighting the need for further research. The present study aims to address this gap by providing detailed morphometric analyses, exploring gender differences, asymmetry, and their clinical implications.

Research Objectives

1. To analyze the morphometric characteristics of the occipital condyles, including length, breadth, and inter-condylar distances (AICD, PICD).
2. To examine the variations in OC dimensions between genders and assess the prevalence of asymmetry.
3. To investigate the correlation between OC dimensions and other cranial landmarks (OCAB, OCAO, OCPB, OCPO).
4. To identify potential clinical implications of these variations, particularly in the context of craniovertebral surgeries.

Methodology

Study Design

This study adopts a cross-sectional design, utilizing morphometric analysis of dried adult human skulls from various anatomical collections. The research was conducted in the Anatomy Department of Sree Balaji Medical College, with ethical clearance obtained prior to the commencement of the study. The cross-sectional design enabled a thorough examination of the morphometric characteristics of the OC across a diverse set of samples, ensuring a broad understanding of the anatomical variations.

Sample Selection

A total of eighty occipital condyles from 40 adult human skulls were analyzed. The sample comprised twenty male and 20 female skulls, providing an equal gender representation. Skulls with visible pathological alterations, trauma, or deformation were excluded to ensure accurate and reliable measurements. The age and demographic background of the skulls were recorded where available, although the study primarily focused on anatomical features without correlating them to age. This careful selection ensured that the data collected represented a standard anatomical baseline without being influenced by external deformities.

Morphometric Measurements

Detailed measurements were performed using high-precision Vernier calipers, accurate to 0.1 mm. The following parameters were recorded for both the right and left occipital condyles:

1. **Length (anteroposterior axis)-**C**:** Measured from the anterior to the posterior tip of the condyle.
2. **Breadth (transverse axis)-**H**:** Measured as the largest diameter from the medial to the lateral border of the condyle.
3. **Anterior Inter-Condyle Distance (AICD)-**A**:** Distance between the anterior tips of the right and left occipital condyles.
4. **Posterior Inter-Condyle Distance (PICD)-**B**:** Distance between the posterior tips of the right and left occipital condyles.
5. **AOC-B (Distance between anterior tip of occipital condyle and basion)-**D**:** Reflects anterior connectivity.
6. **AOC-O (Distance between anterior tip of occipital condyle and opisthion)-**E.

7. **POC-B (Distance between posterior tip of occipital condyle and basion)-**F**.**
8. **POC-O (Distance between posterior tip of occipital condyle and opisthion)-**G

Each measurement was taken three times, and the mean value was recorded to minimize observer bias. Fig: In addition to numerical data, digital photographs of each condyle were taken for qualitative assessment of shape and morphology. The repeated measurements ensured precision, while digital documentation allowed for further analysis of the morphological patterns.

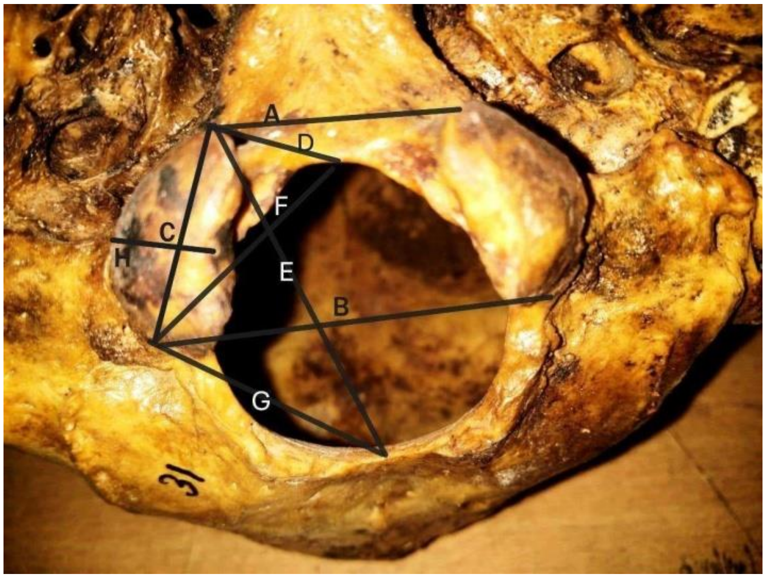

Fig1: Shows the linear parameters

Shape Classification and Asymmetry Assessment

The OC were classified into distinct shapes based on visual inspection and established anatomical criteria, categorized as oval, circular, kidney-shaped, triangular, deformed, and two-portioned (Fig:2). Asymmetry was determined by comparing the dimensions of the right and left condyles, with a difference of more than 1 mm in length or breadth considered significant. This classification system helped to better understand the functional implications of different OC shapes and how they might influence surgical outcomes.

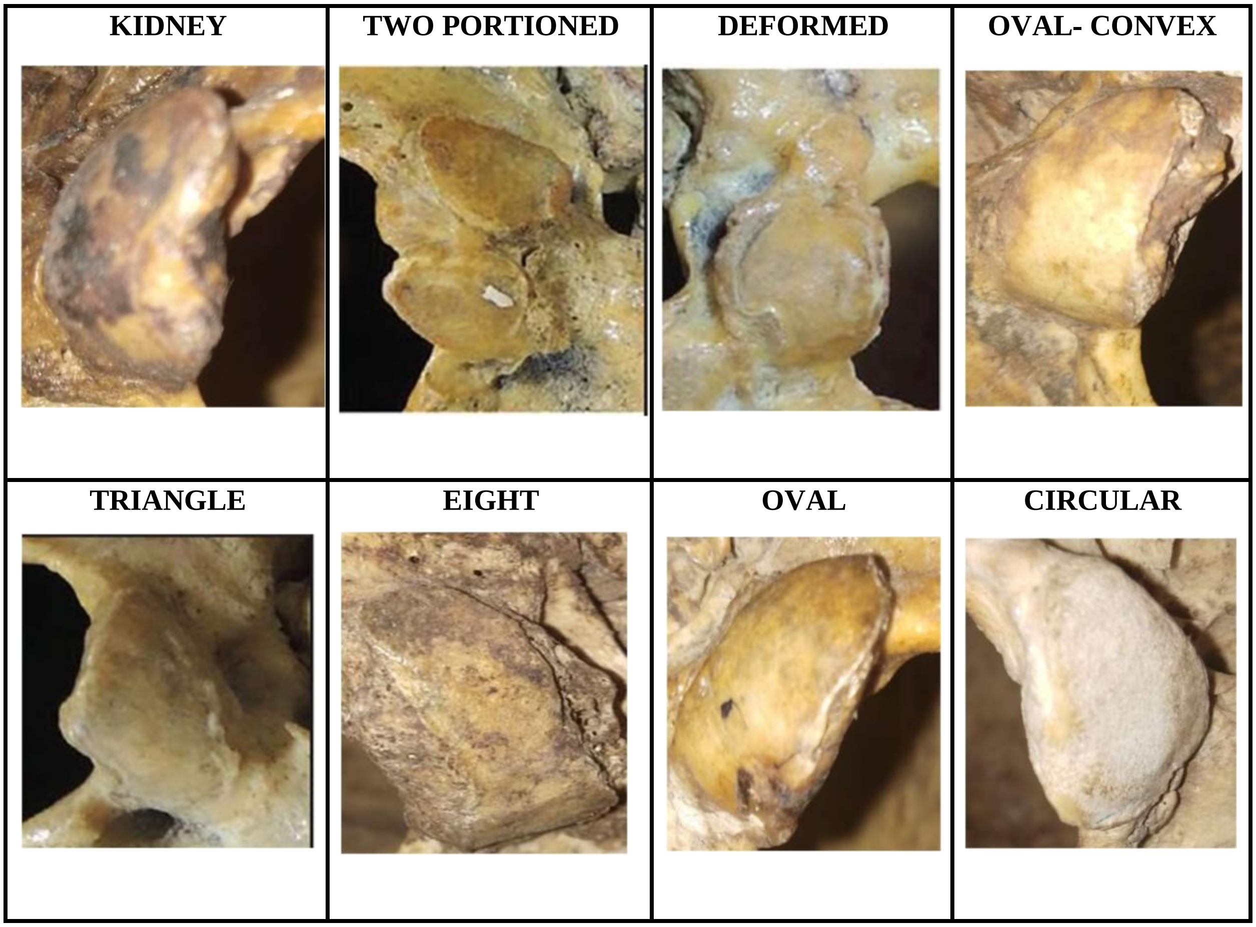

Fig: 2 shows different shapes of occipital condyle

Gender-Based Analysis

To explore potential gender differences, the sample was divided into male and female groups. Comparative analysis of each morphometric parameter was conducted using t-tests to determine if there were statistically significant differences between the two groups. Additionally, the prevalence of each condyle shape was compared between males and females to identify any gender-specific trends. This approach provided insights into how gender-based anatomical differences might necessitate customized surgical interventions.

Correlation Analysis and Statistical Methodology

In this study, Pearson's correlation coefficient (r) was utilized to explore the relationships between various morphometric measurements of the occipital condyles (OC). Key comparisons included length vs. anterior inter-condylar distance (AICD) and OCAB (distance between the anterior tip of the OC and basion) vs. OCPO (distance between the posterior tip of the OC and opisthion). The objective was to uncover any underlying patterns that could provide insights into potential surgical complications or assist in planning surgical approaches. Understanding these correlations is pivotal, as it can guide the development of predictive models, enhancing surgical safety and precision.

Mathematical Framework for Pearson's Correlation

The formula for Pearson's correlation coefficient is given by:

$$r = \Sigma((Xi - \bar{X})(Yi - \bar{Y})) / \sqrt{\Sigma(Xi - \bar{X})^2 * \Sigma(Yi - \bar{Y})^2}$$

- where:
  Xi and Yi represent individual values for two variables, such as the length of the OC (X) and AICD (Y).
  X and $\bar{Y}$ are the mean values of the respective variables.
  r ranges from -1 to +1, with:
  r = +1 indicating a perfect positive correlation.
  r = -1 indicating a perfect negative correlation.
  r = 0 suggesting no linear relationship.

For example, if we consider the variables X (OC length) and Y (AICD), the correlation coefficient r would quantify how closely variations in OC length predict changes in AICD. A positive r would indicate that longer condyles correspond to increased AICD values, while a negative r would suggest an inverse relationship.

Hypothesis Testing for Correlation:

1. Null Hypothesis (H0): There is no significant correlation between the two variables ($r = 0$).

2. Alternative Hypothesis (H1): There is a significant correlation between the variables ($r \neq 0$).

The statistical significance of the correlation was evaluated by computing the p-value. If the p-value was less than 0.05, H0 was rejected, and the correlation was deemed statistically significant.

Chi-Square Test for Categorical Data

To determine if there was a significant association between categorical variables such as gender and condyle shape, chi-square tests (χ^2) were conducted. The chi-square formula is:

$$\chi^2 = \Sigma ((O - E)^2 / E)$$

where:
- O represents the observed frequency of each category.
- E is the expected frequency, calculated as:
  E = (Row Total × Column Total) / Grand Total.

For example, if we are evaluating whether gender influences the prevalence of specific OC shapes (e.g., oval, circular), the chi-square statistic helps determine if the observed distribution differs significantly from what would be expected by chance.

Hypothesis for Chi-Square Tests:

1. H0: There is no association between gender and condyle shape.
2. H1: There is a significant association between gender and condyle shape.

A p-value less than 0.05 would lead to rejecting H0, indicating that the variations in OC shapes are significantly associated with gender.

Comparative Analysis Using t-Tests and ANOVA

To analyze differences in OC measurements across groups (e.g., male vs. female), t-tests and Analysis of Variance (ANOVA) were employed.

Independent Sample t-Test Equation:

$$t = (\bar{X}1 - \bar{X}2) / \sqrt{((s1^2 / n1) + (s2^2 / n2))}$$

where:
- $\bar{X}1$ and $\bar{X}2$ are the sample means for the two groups (e.g., male OC length vs. female OC length).
- $s1^2$ and $s2^2$ are the variances of each group.
- n1 and n2 are the sample sizes.

ANOVA (Analysis of Variance):

When comparing more than two groups, ANOVA was applied. The general equation is:

$$F = \text{Between-Group Variance} / \text{Within-Group Variance}$$

where:
- The between-group variance is derived from the differences between each group's mean and the overall mean.
- The within-group variance measures the dispersion within each group.

Statistical Software and Significance Levels

All statistical computations, including the generation of descriptive statistics (mean, standard deviation, and range), comparative analyses (t-tests, ANOVA), and tests for correlation and association (Pearson's correlation and chi-square tests), were conducted using SPSS version 26.0. The significance threshold was set at $\alpha = 0.05$. Thus, results with a p-value <0.05 were considered statistically significant, reinforcing the robustness and clinical relevance of the findings.

Expected Outcomes

1. **Detailed morphometric data on the occipital condyles:** Contributing to anatomical databases and surgical reference guides.
2. **Identification of significant gender differences and patterns of asymmetry in OC dimensions:** Helping to inform gender-specific surgical approaches.
3. **Insights into how variations in OC morphology may influence clinical outcomes, particularly in craniovertebral junction surgeries.**
4. **Development of a predictive model to inform surgical planning:** Potentially reducing the risk of complications such as hypoglossal nerve palsies and atlanto-occipital joint instability

RESULTS

This section presents a detailed statistical analysis of the morphometric and morphological characteristics of occipital condyles (OC), examining variations across sides, genders, shapes, and other key dimensions. Using robust statistical methods, including t-tests, ANOVA, chi-square tests, and correlation analyses, the study aims to uncover insights into the clinical and surgical implications of OC morphology.

Descriptive Statistics: Average Length and Breadth of Occipital Condyles

To establish baseline dimensions, we evaluated the average lengths and breadths of occipital condyles on both the right and left sides. [Table:1, Fig 1]

Table 1: Descriptive Statistics of Occipital Condyle Dimensions

Measurement	Mean (Right)	SD (Right)	Mean (Left)	SD (Left)	p-value (t-test)
Length (mm)	22.80	3.45	22.36	3.67	0.236
Breadth (mm)	12.49	2.12	12.80	2.01	0.433

The average length of the right occipital condyle was 22.80 mm, slightly exceeding the left at 22.36 mm; however, this difference was not statistically significant ($p = 0.236$). Similarly, the left condyle was marginally broader at 12.80 mm compared to the right at 12.49 mm, but the difference remained non-significant ($p = 0.433$). These findings suggest negligible side-to-side differences, which may hold clinical significance for symmetrical surgical approaches.

Gender-Based Analysis of Occipital Condyle Dimensions

Male occipital condyles were significantly longer and broader than those of females, as indicated by the p-values of 0.045 and 0.041, respectively. These gender-based morphological differences emphasize the need for gender-specific anatomical models, particularly in designing surgical implants and planning craniovertebral procedures. Tailored approaches can improve surgical outcomes and minimize associated risks [Table:2].

Table 2: Gender-Based Differences in Condyle Length and Breadth

Measurement	Mean (Male) Right	SD (Male)	Mean (Female) Right	SD (Female)	p-value (t-test)
Length (mm)	23.97	3.21	21.59	3.44	0.045
Breadth (mm)	13.04	2.05	11.87	2.01	0.041

Shape Distribution and Frequency Analysis

The most prevalent shape was "oval," particularly in males (65% on the right). Females exhibited a wider variety of shapes, including a notable occurrence of kidney and deformed forms. Chi-square analysis revealed that gender significantly influenced shape distribution ($\chi^2 = 12.54$, $p = 0.013$), underscoring anatomical differences between males and females. [Table:3 fig. 2]

Table 3: Frequency Distribution of OC Shapes by Gender

Shape Type	Female (Right)	Female (Left)	Male (Right)	Male (Left)
Oval	7 (35%)	5 (25%)	13 (65%)	10 (50%)
Circular	1 (5%)	4 (20%)	4 (20%)	4 (20%)
Eight	1 (5%)	2 (10%)	1 (5%)	2 (10%)
Triangle	1 (5%)	1 (5%)	-	-
Kidney	3 (15%)	2 (10%)	-	-
Deformed	3 (15%)	1 (5%)	-	-
Two-Portioned	2 (10%)	3 (15%)	1 (5%)	3 (15%)
Oval-Convex	1 (5%)	1 (5%)	1 (5%)	1 (5%)
Pyramid	1 (5%)	1 (5%)	-	-

Symmetry and Asymmetry Analysis

A significant 80% of occipital condyles were found to be asymmetrical, particularly among non-oval shapes such as circular and two-portioned types. The prevalence of asymmetry suggests a need for individualized surgical planning, as high variability can complicate procedures like partial condylectomies. Preoperative imaging is essential to accurately map anatomical features and enhance surgical precision [Table:4].

Table 4: Symmetry and Asymmetry in Length and Breadth

Symmetry Status	Frequency (n)	Percentage (%)
Symmetrical	16	20%
Asymmetrical	64	80%

Inter-Condyle Distance (AICD and PICD) Analysis

Significant gender differences were noted in both AICD and PICD, with males displaying larger inter-condylar distances ($p < 0.05$). These variations indicate a broader cranial base in males, which may have implications for joint stability and influence surgical entry points during craniovertebral procedures. [Table:5 fig. 1]

Table 5: Inter-Condylar Distances (Mean Values)

Measurement	AICD (Right)	AICD (Left)	PICD (Right)	PICD (Left)	p-value (t-test)
Male	1.92	1.68	4.32	3.94	0.032
Female	1.68	1.72	3.94	3.70	0.041

Table 6: The measurements of (AOC-B, AOC-O, POCP-B, POC-O)

Descriptive statistics for these measurements are as follows:

Measurement	Mean (mm)	Std Dev (mm)	Min (mm)	25th Percentile (mm)	Median (mm)	75th Percentile (mm)	Max (mm)
AOC-B	1.01	0.27	0.70	0.80	1.00	1.15	2.00
AOC-O	3.87	0.34	2.80	3.80	4.00	4.00	4.60
POC-B	2.87	0.26	2.00	2.80	2.80	3.00	3.40
POC-O	2.89	0.46	2.20	2.60	2.80	3.20	4.40

Correlation Measurements

Pearson correlation analysis revealed significant relationships, such as a strong correlation between OCAB and OCPO ($r = 0.998$, $p = 0.001$). This finding supports stable cranial alignment, which could guide surgical approaches. Additionally, moderate correlations between other measurements further clarify OC morphology.

The notation ($r = 0.998$, $p = 0.001$) represents the results of a Pearson correlation analysis: $r = 0.998$: This is the Pearson correlation coefficient, which quantifies the strength and direction of the relationship between two variables. A value of 0.998 indicates an extremely strong positive correlation, meaning that as one variable increases, the other tends to increase as well, perfectly in this case.

$p = 0.001$: This is the p-value, which assesses the statistical significance of the correlation. A p-value of 0.001 is very low, indicating that the observed correlation is statistically significant. In other words, there is less than a 0.1% probability that this correlation occurred by chance, suggesting a reliable and meaningful relationship between the two variables. [Table:6,7, Fig].

Table 7: Pearson Correlation Analysis

Measurement Pair	Correlation Coefficient (r)	p-value
Length vs. Breadth	0.512	0.023
OCAB vs. OCPO	0.998	0.001
AICD vs. PICD	0.402	0.055

DISSCUSSION:

The occipital condyles play a critical role in articulating with the atlas vertebra, forming the atlanto-occipital joint, which is essential for head stability and movements such as nodding (Susan Standring 2008). Understanding the morphological variations of the occipital condyles is important for clinicians, particularly neurosurgeons and orthopedic surgeons involved with the craniovertebral junction. (Mehmet Asim Ozer 2011, Al-Mefty O 1996)

In their study on occipital condyles, Sait et al. (2005) examined 404 condyles from 202 dry skulls, reporting an average length of 23.4 mm and an average width of 10.6 mm. Similarly, Muthukumar et al. (2005) studied 100 occipital condyles and found an average length of 23.6 mm. In our study, we observed an average condylar length of 22.58 mm and a width of 12.05 mm.

Xiang Jain et al. (2008) conducted a comparable study on 30 dry skulls, finding an average condylar length of 24.47 mm ± 3.32 mm on the left side and 25.16 mm ± 2.29 mm on the right side. By comparison, our research, which involved 40 dry skulls, recorded an average length of 22.36 mm ± 3.67 mm on the left side and 22.80 mm ± 3.45 mm on the right side.

These findings highlight variations in occipital condyle measurements across different studies, reflecting population-specific anatomical differences or methodological variations.

Understanding the variations in length, breadth, and orientation is critical for surgical procedures at the craniovertebral junction. Approaches such as transcondylar, transjugular, and far-lateral often involve manipulation or partial resection of the occipital condyles to access deeper structures. For example, longer condyles may require more extensive bone removal, while narrower or asymmetrical condyles can affect the stability of retraction or fixation devices (H Additionally, anterior, and posterior inter-condylar distances (AICD and PICD) were measured. In males, the AICD was 1.92 cm on the right side and 1.68 cm on the left; for females, it was 1.68 cm on the right and 1.72 cm on the left. For PICD, males showed 4.32 cm on the right and 3.94 cm on the left, while females had 3.94 cm on the right and 3.70 cm on the left. The mean anterior and posterior intercondylar distances were recorded as 21.0 ± 2.8 mm and 41.6 ± 2.9 mm, respectively. These findings are consistent with previous studies (Naderi 2005, Kizilkanat E.,2016; Fetouh FA 2013) that reported similar measurements for

AICD (2.1, 2.2, 2.0 cm), though our PICD results were slightly lower than those observed by others (Naderi 2005, Kizilkanat E.,2016; Fetouh FA 2013), who reported 4.1, 4.4, and 4.1 cm, respectively.

These measurements provide valuable insights into the spatial relationships at the craniovertebral junction. They are essential for planning surgical trajectories and understanding the alignment of the atlanto-occipital joint. Variations in these parameters may also have biomechanical implications. For instance, a greater inter-condylar distance could indicate a wider range of joint motion, potentially influencing head-neck stability. These anatomical differences should be considered in cases of trauma, degenerative changes, or congenital anomalies in the craniovertebral region, where joint biomechanics might be altered.

The observed variations in the shape and symmetry of occipital condyles carry significant clinical implications. Our study revealed that the most common shape was oval (43.75%), with other forms such as circular (13.75%), two-portioned (8.7%), and deformed (8.7%) also present.

According to Mehmet Asim Ozer (17), the most common shape observed was oval-like (59.67%), while the rarest was the two-portioned condyle (0.32%). This diversity underscores the need for individualized assessments in surgical planning, as different shapes may present unique challenges during procedures. Our study's findings align with previous research by Nadri et al.,2005; Kalthur et al., 2014 and Ozer et al., 2011which also identified the oval shape as the most common form of the occipital condyle.

However, slight deviations from previous data indicate that anatomical variations may differ across populations due to genetic, environmental, or developmental factors. Unique shapes, such as two-partitioned or pyramid forms, observed in this study expand the existing literature on anatomical diversity. This variability suggests that reliance solely on textbook descriptions of occipital condyle morphology may be inadequate for surgical planning.

For instance, non-oval shapes, especially deformed or asymmetrical types, could complicate the surgical approach, affecting the surgeon's ability to maintain precise alignment or access target areas around the condyle.(Sandeep et al 2016; Prescher A., 1996).In cases of occipital condylar fractures, the shape and size of the condyle can significantly influence treatment strategies. Management of such fractures often depends on the type of fracture line and the overall morphology of the condyle. For example, an oval-shaped condyle may exhibit a different fracture pattern compared to a kidney-shaped or deformed condyle (Ozer et al 2011).

The presence of asymmetrical shapes in 80% of the skulls examined suggests that surgeons cannot rely on a standardized anatomical model. Instead, individualized radiological assessment is essential to determine the specific morphology of the occipital condyles. This assessment helps in identifying the safest drilling angle, the amount of bone to be resected, and the placement of fixation devices. Failure to account for these anatomical variations may increase the risk of complications, such as injury to the vertebral arteries, spinal cord, or dura.

Correlation with other anatomical parameters:

Various distances were measured, such as the anterior and posterior tips of the occipital condyle (OC) to the basion, which were 1.01mm and 2.87 mm, respectively. Likewise, the distances from the anterior and posterior tips of the OC to the opisthion were recorded at 3.87 mm and 2.89 mm, respectively. The distance between the posterior tip of the OC and the opisthion is an important anatomical factor, as a greater distance provides a wider corridor in posterolateral approaches.

Linear parameters showed that the mean length and width of the OC were 22.75±2.90 mm and 12.97±1.53 mm, respectively, while the mean height was 9.21±1.22 mm, with these dimensions being comparable on both sides.

The anterior and posterior intercondylar distances were noted to be 17.81±2.93 mm and 38.91±4.16 mm, respectively.

The distance between the anterior tip of the OC (AOC-B) and the basion was 9.65±1.56 mm, while the distance between the AOC and the opisthion was 37.70±2.37 mm. The mean distance between the posterior tip of the OC (POC-B) and the opisthion was 26.48±2.24 mm, showing no significant difference between sides. However, the distance between the POC and basion was 27.54±2.81 mm, significantly greater on the right side (p-value= 0.01).

In skull base surgeries, where access to areas like the foramen magnum and posterior fossa is required, the occipital condyle serves as a critical landmark. Morphometric analysis of the occipital condyle has notable surgical implications for approaches such as the transcondylar approach, which involves drilling or resecting part of the condyle to access target lesions (Barut N, 2009). Variations in condylar shape and dimensions can influence the extent of bone removal and the surgeon's ability to maintain atlanto-occipital joint stability. Precise knowledge of the individual's anatomy can thus reduce the risk of complications, such as joint instability or damage to neurovascular structures, during skull base surgeries.

Conclusion

The comprehensive analysis of occipital condyle morphology reveals numerous key findings with direct clinical implications. The study identified significant gender differences, with males exhibiting longer and broader condyles compared to females. These insights underline the necessity for gender-specific anatomical models in surgical planning, which are vital for the design of suitable implants and surgical tools. Additionally, the study highlighted a high prevalence of asymmetry, with 80% of condyles showing differences between the right and left sides. This finding emphasizes the importance of individualized surgical approaches, where surgeons must anticipate variability and utilize advanced 3D imaging to customize interventions. The study also found a strong correlation between AOC-B and POC-O, suggesting stable cranial alignment. These correlations could be leveraged to guide surgical navigation, reducing the risk of complications such as nerve injury or joint instability during procedures. Variations in shape, particularly less common forms like kidney-shaped or two-portioned condyles, may present higher surgical risks. The detailed morphometric assessments stress the importance of understanding specific anatomical features to optimize surgical outcomes.

Future Directions

Future research should focus on the development of advanced AI models that can predict surgical risks based on condylar asymmetry. Such models could analyze a large set of preoperative imaging data to provide real-time recommendations to surgeons, identifying potential complications and suggesting the best surgical path. By learning from the patterns in the dataset, AI can offer insights that may not be immediately evident through traditional methods. For instance, machine learning algorithms could identify subtle anatomical variations and predict how these might affect joint stability or the risk of nerve damage during surgery. Further exploration of the relationship between condylar dimensions and joint stability could also inform the design of customized implants. By understanding how different dimensions contribute to the stability of the atlanto-occipital joint, engineers can create implants that better replicate the natural biomechanics of the joint, thus reducing post-surgical complications. Additionally, investigating the biomechanical implications of different condyle shapes on craniovertebral joint movements can provide a deeper understanding of how these anatomical structures influence the flexibility and stability of the head and neck region. This knowledge could be instrumental in enhancing surgical outcomes by guiding surgeons on the optimal approach to maintain or restore functionality.

Overall, the findings of this study advocate for a more personalized approach to craniovertebral surgery. The emphasis on detailed anatomical studies and the integration of predictive models could optimize surgical techniques, leading to better patient outcomes. Future research should build on these findings by including larger and more diverse samples, enabling the development of robust predictive models that further enhance patient safety and surgical efficacy.

Reference:

1. Menezes AH. Craniocervical developmental anatomy and its implications. Childs Nerv Syst. 2008; 24:1109-22
2. Susan Standring. Gray’s Anatomy, 40th Edition. Anatomical basis of clinical practice, Churchill Livingstone, London. 2008; 40:415
3. Noble E.R, Smoker W.R.K. The Forgotten Condyle: The Appearance, Morphology, and Classification of Occipital Condyle Fractures.American Journal of Neuroradiology. 1996; 17: (3):507-513
4. Banerji D. Extreme lateral transcondylar approach to the skull base. Neurology India, 1999;47:22– 30.
5. Naderi S, Korman E, Citak G, Güvençer M, Arman C, Senoglu M, et al. Morphometric analysis of human occipital condyle. Clin Neurol Neurosurg. 2005; 107:191–199.

6. Pereira, G. A. M.; Lopes, P. T. C.; Santos, A. M. P. V.; Duarte, R. D.; Piva, L.; Pozzobon, A. Morphometric Analysis Related to the Transcondylar Approach in Dry Skulls and Computed Tomography. Int. J. Morphology. 2012; 30(2):399-404.
7. Michael Bruneau Bernard George Foramen magnum meningiomas: detailed surgical approaches and technical aspects at Lariboisière Hospital and review of the literature. Neurosurg Rev. 2007 Sep 20;31(1):19–33.
8. Tange Y, Uto A, Wachi A, Koike J. Transcondylar fossa approach to treat ventral foramen magnum meningioma--case report. Neurologia medico-chirurgica. (Tokyo), 2001;41:458–462.
9. Wen HT, Rhoton Jr AL, Katsuta T, Oliveira ED. Microsurgical anatomy of the transcondylar, supracondylar, and paracondylar extensions of the far-lateral approach. J Neurosurg. 1997;87(4):555–85.
10. Divya Mahajan, Gaurav Agnihotri, Abha Sheth, Rahat Brar An anatomical perspective of human occipital condyles and foramen magnum with neurosurgical correlates. International Journalof Experimental and Clinical Anatomy.2013, 7 (1), 29 – 33.
11. Ozer MA, Celik S, Govsa F, Ulusoy MO. Anatomical determination of a safe entry point for occipital condyle screw using three dimensional landmarks. Eur Spine Journal 2011; 20:1510-151.
12. Al-Mefty O, Borba LA, Aoki N, Angtuaco E, Pait TG. The transcondylar approach to extradural nonneoplastic lesions of the craniovertebral junction. J Neurosurg. 1996;84(1):1-6.
13. Muthukumar N, Swaminathan R, Venkatesh G, Bhanumathy SP. A morphometric analysis of the foramen magnum region as it relates to the transcondylar approach. Acta Neurochir (Wien). 2005; 147 (8):889-95.
14. Xiong Jian, Chen Guang, Zhon Fei, Wee Dong Cao, Hong Lin, Xian Zhang, et al. Morphometric analysis, and microsurgical anatomy for lateral transcondylar approach. Journal of US- China medical science, 2008; 5, 1: 27- 33.
15. Haegbulam C, Woodard EJ, Proctor M Occipitocondylar hyperplasia: an unusual craniovertebral junction anomaly causing myelopathy. Case reprt. *J* Neurosurg. 2005; 103: 379-381
16. Kalthur SG, Padmashali S, Gupta C, Dsouza AS Anatomic study of the occipital condyle and its surgical implications in transcondylar approach. J Craniovertebr Junction Spine.2014 Apr-Jun;5(2):71–77.
17. Sandeep Saluja, Sushant Swaroop Das , Neelam Vasudeva. Morphometric Analysis of the Occipital Condyle and Its Surgical Importance J Clin Diagn Res. 2016 Nov 1;10(11).
18. Prescher A., Brors D., Adam G. Anatomic and Radiologic Appearance of Several Variants of the Craniocervical Junction. Skull Base Surgery (1996); 6:83-94.93rd cond.)
19. Kizilkanat E. Morphometry of the hypoglossal canal, occipital condyle, and foramen magnum. Neurosurg Q. 2006; 16:121–5.
20. Fetouh FA, Awadalla AM. Morphometric analysis of the occipital condyle and its surgical implications in transcondylar approach. The pan arab neurosurgery society. about 15 p. http://panarabjn.org/wp-content/uploads/2013/03.
21. Barut N, Kale A, Suslu HT, Ozturk A, Bozbuga M, Sahinoglu K: Evaluation of the bony landmarks in transcondylar approach. Br J Neurosurg 2009.23:276-281.