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ISSN: 0015-5659

e-ISSN: 1644-3284

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DOI: 10.5603/fm.101276

Article type: Original article

Submitted: 2024-06-24

Accepted: 2024-10-09

Published online: 2024-10-21

ORIGINAL ARTICLE

Feng Yuan et al., Occipital condyle position in Chinese skulls

Morphological observation of occipital condyle position in Chinese skulls and potential clinical significance

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ABSTRACT

Background: To study the anatomy of the Chinese occipital condyle and its position relative to the occipital foramen and skull.

Materials and methods: Measurements were taken from 106 adult Chinese skulls using a Cartesian coordinate system centered on the foramen magnum. Measurements included the longitudinal diameter of the foramen magnum, distances from various points on the occipital condyles to the foramen magnum and skull landmarks, and the occipital condyle classification index (OCI) and skull-occipital condyle classification index (SOCI).

Results: OCI categorized the position of the foramen magnum and occipital condyles into three groups: OCI ≤ 0.40 (3 cases, 2.83%), 0.40 < OCI ≤ 0.50 (75 cases, 70.75%), and OCI > 0.50 (28 cases, 26.42%). SOCI categorized the relationship between the skull and occipital condyles into two groups: 0.5 < SOCI ≤ 0.6 (49 cases, 46.23%) and 0.6 < SOCI ≤ 0.7 (57 cases, 53.77%). Four relationship types were identified based on specific measurements: Type I (23 cases, 21.70%), Type II (42 cases, 39.62%), Type III (4 cases, 3.77%), and Type IV (37 cases, 34.91%).

Conclusions: Sagittal movement of the occipital condyle affects the cervical spine’s curvature. Asymmetry between the occipital condyles and the foramen magnum may misalign the skull with the body’s coronal plane.

Keywords: Chinese; occipital condyle position; anatomic measurement

INTRODUCTION

The current morphological studies of the occipital condyle primarily focus on its shape, size, and anatomical variations[1–5]. Particularly, there is a growing interest in investigating the impact of occipital condyles on craniospinal region surgical procedures [6–11], while studies regarding the positional relationship of occipital condyles relative to the foramen magnum and the skull are relatively scarce. The position of the occipital condyles relative to the foramen magnum and the skull holds potential clinical significance.

The occipital condyle is a bony anatomical structure connecting the skull to the articulation surfaces on the first cervical vertebra, determining the position of the skull relative to the cervical spine. Anterior-posterior variations in the position of the occipital condyles relative to the skull can result in anterior or posterior movement of the skull's center of gravity, with studies indicating that such changes can lead to corresponding alterations in cervical curvature [12]. Observation of occipital condyle specimens reveals asymmetry in the left and right positions relative to the midline of the foramen magnum, with one occipital condyle positioned anteriorly and the other posteriorly, potentially causing the skull to tilt left or right relative to the body. Clinical cases of skull tilt are commonly observed in patients with torticollis, although there are differing opinions regarding the causes of torticollis [13, 14], and literature reporting torticollis specifically attributed to asymmetry between occipital condyles and the foramen magnum remains scarce [15].

This study aims to analyze the positional variations of the occipital condyles relative to the foramen magnum and the skull, providing valuable data for clinical considerations regarding cervical curvature and torticollis. This will contribute to a more objective and comprehensive understanding of cervical curvature and torticollis.

MATERIALS AND METHODS

Study subjects and measurement tools

Southern Medical University, initially the First Military Medical University in Qiqihar, moved to Guangzhou in 1970 and was renamed in 2004. It has a collection of pre-1950 skulls, mostly young males, with limited detailed data. The study was conducted on 212 occipital condyles sourced from 106 normal adult Chinese dry skull specimens of unknown gender and age. The skull specimens were obtained from the Department of Anatomy at Southern Medical University. Measurements of all distance indices were conducted using a vernier caliper (Shanghai Sancun, Model: 0–300 mm, accuracy to 0.02 mm), a goniometer (Beijing Zhonglian Anhua Technology Co., Ltd., Model: ZABM-3), and assisted by a triangular ruler (Ningbo Deli), cotton thread, plumb bob, and a headrest for determining the plane of the ears and eyes.

Measurement indices and methods

Indices

The measured indices of the occipital condyles and skull are as follows (Fig. 1–3):

Longitudinal diameter of the foramen magnum (FML).

Vertical distance between the anterior border of the foramen magnum and the line of the posterior margin on both sides of the occipital condyles (AOCP).

Linear distance between the glabella and opisthokranion, representing the maximum distance from the glabella to the occipital condyles (SML).

Vertical distance between the glabella and the line of the posterior margin on both sides of the occipital condyles to the SML line level (GOCP).

Absolute value of the distance between the margo medialis of the left occipital condyle and the Y-axis (OC-ML).

Absolute value of the distance between the margo medialis of the right occipital condyle and the Y-axis (OC-MR).

Absolute value of the distance between the posterior margin of the left occipital condyle and the X-axis (OC-PL).

Absolute value of the distance between the posterior margin of the right occipital condyle and the X-axis (OC-PR).

Indexes

Classification of the occipital condyle position relative to the foramen magnum based on the Occipital Condyle Classification Index (OCI) value, calculated as OCI = AOCP/FML × 100%.

Classification of the occipital condyle position relative to the skull based on the Skull-Occipital Condyle Classification Index (SOCI) value, calculated as SOCI = GOCP/SML × 100%.

Determination of the type of left and right occipital condyle relative positions based on the values in the Cartesian coordinate system of OC-ML, OC-MR, OC-PL, OC-PR.

Methods

To accurately distinguish the positional changes of the occipital condyles relative to the foramen magnum, a two-dimensional Cartesian coordinate system was established with the long axis of the foramen magnum as the Y-axis (vertical axis) and its midpoint as the origin (O point), defining the X-axis (horizontal axis) passing through the O point.

FML: Measured using a vernier caliper. AOCP: Cotton thread was used to establish the measurement interval, and its length was measured using a vernier caliper. SML: Measured using a caliper. GOCP: A horizontal table with white paper was used. The skull was positioned on a headrest with the line connecting the glabella and opisthokranion parallel to the horizontal plane. Vertical distances from this plane to the upper edges of both external auditory meatuses were measured and made equal. Plumb bobs were used to mark the glabella and the projections of the posterior margins of both occipital condyles on the white paper. The vertical distance between the projection of the glabella and the projection of the posterior margins of both occipital condyles was measured as GOCP. OC-MR, OC-ML, OC-PR, OC-PL: a cotton thread was used to simulate the establishment of a two-dimensional coordinate system, and distances were measured using a vernier caliper.

The classification of occipital condyles relative to the foramen magnum is based on the relationship between the absolute values of OC-ML and OC-MR. To differentiate the positions of the inner edges of both occipital condyles relative to the Y-axis, OC-PL, and OC-PR represent their actual values on the Y-axis in the two-dimensional Cartesian coordinate system. OC-PL > 0 and OC-PR > 0 indicate that the posterior margin of the occipital condyles is above the X-axis; OC-PL = 0 and OC-PR = 0 indicate that the posterior margin of the occipital condyles is on the X-axis; OC-PL < 0 and OC-PR < 0 indicate that the posterior margin of the occipital condyles is below the X-axis.

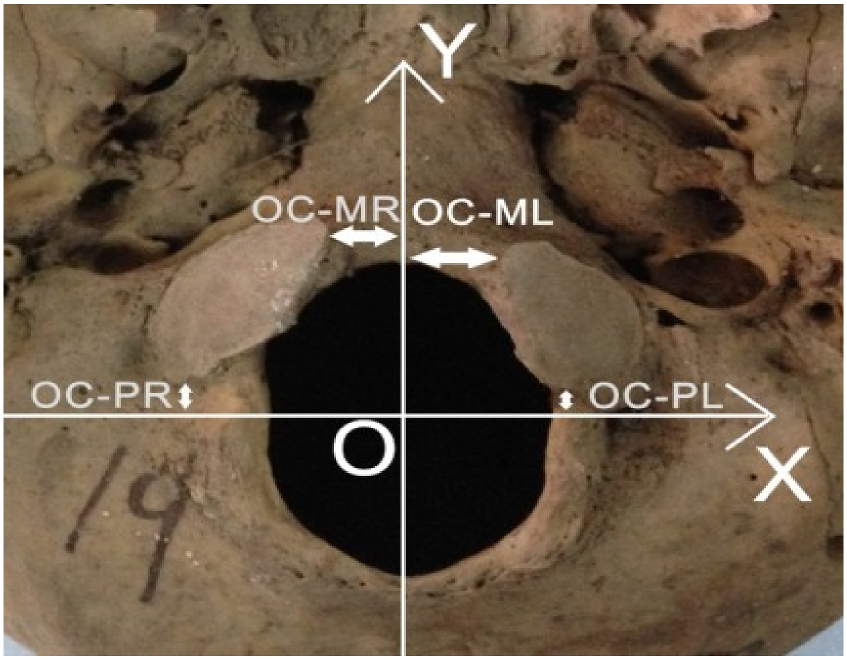

Figure 1. The absolute value of OC-ML: distance between the margo medialis of the left occipital condyle and the Y-axis. The absolute value of OC-MR: distance between the margo medialis of the right occipital condyle and the Y-axis. The absolute value of OC-PL: distance between the posterior margin of the left occipital condyle and the X-axis. The absolute value of OC-PR: distance between the posterior margin of the right occipital condyle and the X-axis.

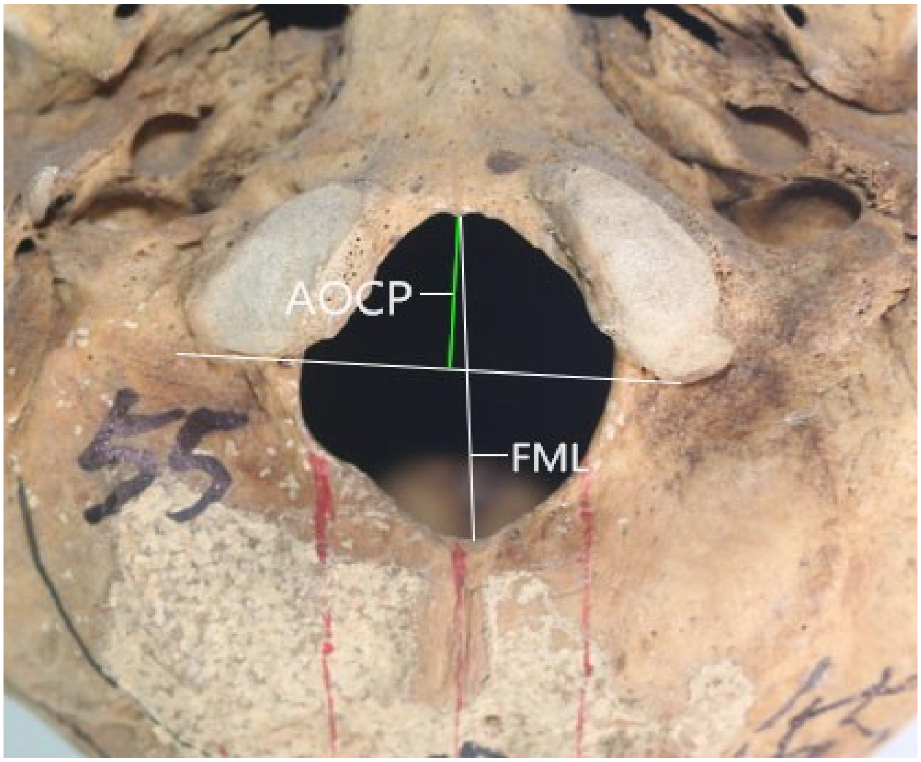

Figure 2. FML: longitudinal diameter of the foramen magnum. AOCP: vertical distance between the anterior border of the foramen magnum and the line of the posterior margin on both sides of the occipital condyles.

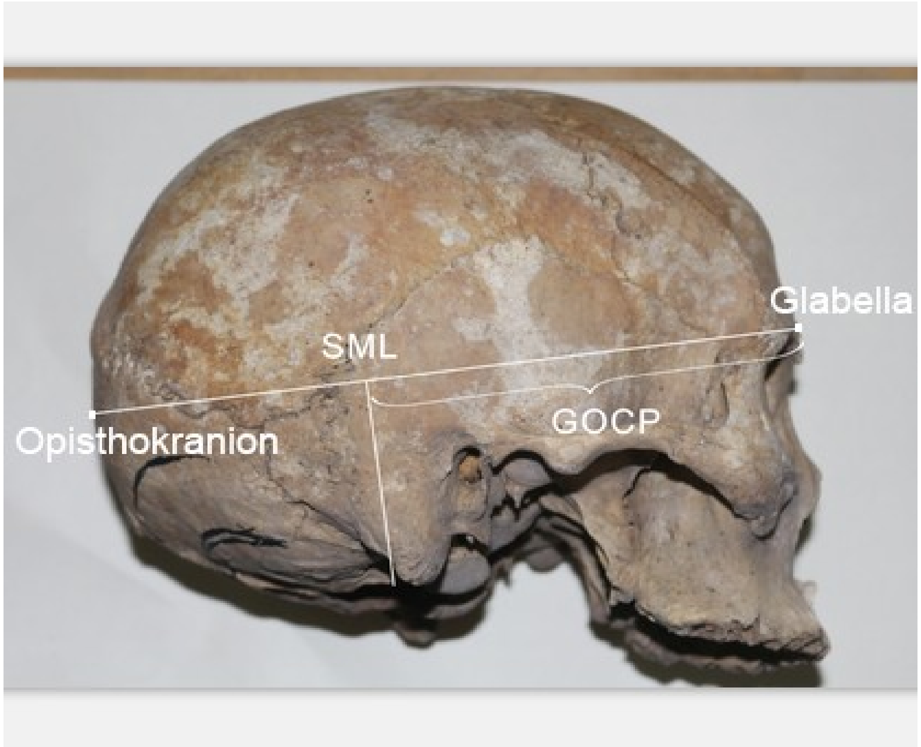

Figure 3. SML: linear distance between the glabella and opisthokranion. GOCP: vertical distance between the glabella and the line of the posterior margin on both sides of the occipital condyles to the SML line level.

Statistical analysis

The metric parameters are presented as mean ± standard deviation.

RESULTS

Table 1. Occipital Condyle Classification Index.

OCI	**Cases [n]**	**Total cases [n]**	**Percentage [%]**
OCI ≤ 0.40	3	106	2.83
0.40 < OCI ≤ 0.50	75	106	70.75
OCI > 0.5	28	106	26.42

OCI: Occipital condyle classification index; OCI = AOCP/FML; FML: The longitudinal diameter of the foramen magnum; AOCP: The vertical distance between the anterior border of the foramen magnum and the line of the posterior margin on both sides of the occipital condyle.

Table 2. Skull-Occipital Condyle Classification Index.

SOCI	Cases [n]	Total cases [n]	Percentage [%]
0.6 ≥ SOCI > 0.5	49	106	46.23
0.6 < SOCI ≤ 0.7	57	106	53.77

SOCI = GOCP/SML; SML: the linear distance between the glabella and opisthokranion; GOCP: the vertical distance between the glabella and the line of the posterior margin on both sides of the occipital condyle at the SML line level. SOCI — Skull-Occipital Condyle Classification Index.

Classification of occipital condyles relative to the foramen magnum

The relative relationship between occipital condyles and the foramen magnum is classified into four types (Fig. 4–13):

Type I (Fig. 4): OC-PL absolute value = OC-PR absolute value, OC-ML absolute value = OC-MR absolute value, indicating that the distances of the inner edges of the occipital condyles from the Y-axis and the distances of the posterior margins of the occipital condyles from the X-axis are equal on both sides.

Type II: OC-PL absolute value = OC-PR absolute value, OC-ML absolute value ≠ OC-MR absolute value, further divided into two subtypes: OC-ML absolute value < OC-MR absolute value (Fig. 5) or OC-ML absolute value > OC-MR absolute value (Fig. 6), indicating that the distances of the posterior margins of the occipital condyles from the X-axis are equal on both sides, but the distances of the inner edges of the occipital condyles from the Y-axis are unequal, with the left side either greater than or less than the right side.

Type III (Fig. 7): OC-ML absolute value = OC-MR absolute value, OC-PL > 0, OC-PR ≤ 0, indicating that the distances of the inner edges of the occipital condyles from the Y-axis are equal on both sides, with the left side above the X-axis and the right side either on or below the X-axis.

Type IV: OC-PL absolute value ≠ OC-PR absolute value, OC-ML absolute value ≠ OC-MR absolute value, further divided into six subtypes:

1. OC-ML absolute value < OC-MR absolute value, OC-PL ≥ 0, OC-PR ≤ 0, and both OC-PL and OC-PR are not equal to 0 (Fig. 8).
2. OC-ML absolute value < OC-MR absolute value, 0 ≤ OC-PL < OC-PR (Fig. 9).

3. OC-ML absolute value < OC-MR absolute value, OC-PL > OC-PR > 0 (Fig. 10).

4. OC-ML absolute value < OC-MR absolute value, 0 > OC-PL > OC-PR (Fig. 11).

5. OC-ML absolute value > OC-MR absolute value, OC-PL > OC-PR ≥ 0 (Fig. 12).

6. OC-ML absolute value > OC-MR absolute value, OC-PR > OC-PL > 0 (Fig. 13).

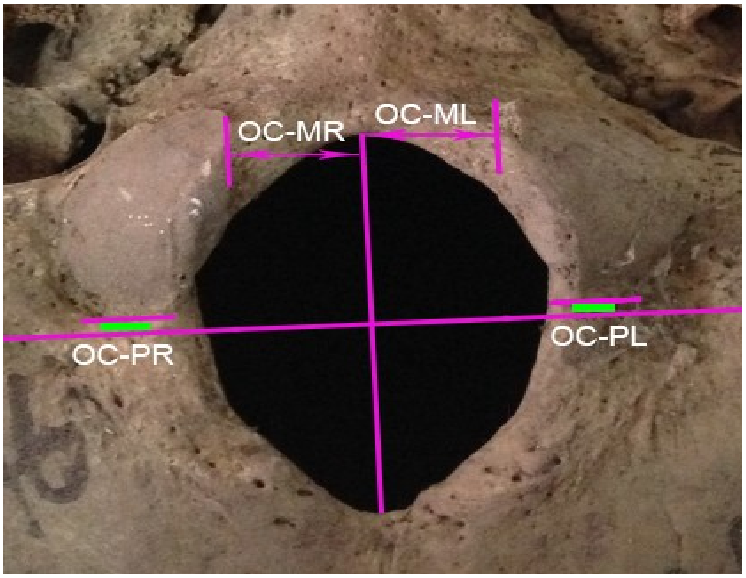

Figure 4. Type I: the distance between the margo medialis of the left occipital condyle and the Y-axis is equal to the distance between the margo medialis of the right occipital condyle and the Y-axis. The distance between the posterior margin of the left occipital condyle and the X-axis is equal to the distance between the posterior margin of the right occipital condyle and the X-axis.

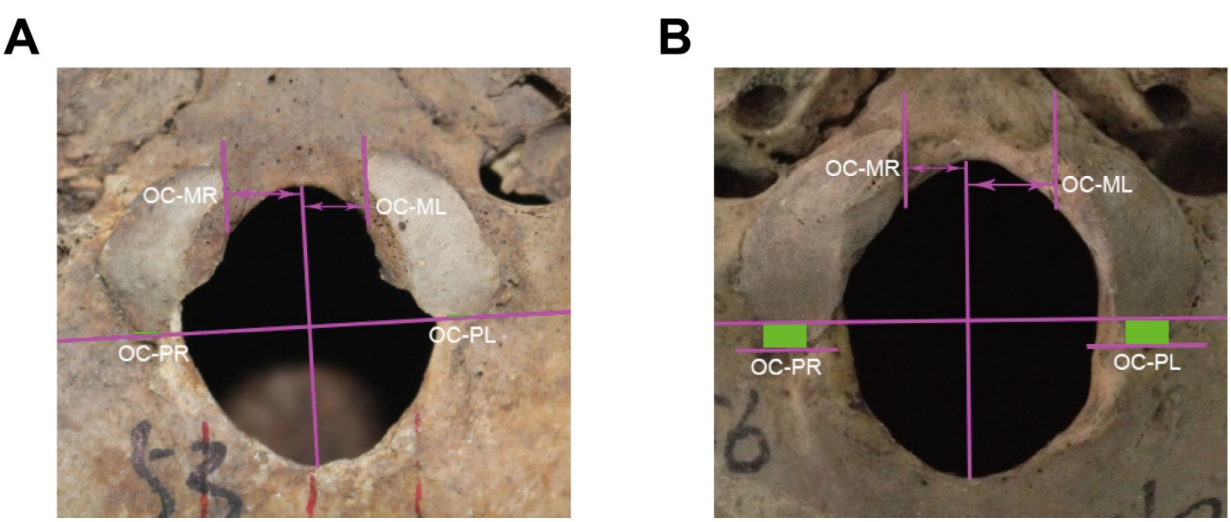

Figure 5. Type II. **A.** The distance between the margo medialis of the left occipital condyle and the Y-axis is less than the distance between the margo medialis of the right occipital condyle and the Y-axis. The distance between the posterior margin of the left occipital condyle and the X-axis is equal to the distance between the posterior margin of the right occipital condyle and the X-axis; **B.** The distance between the margo medialis of the left occipital condyle and the Y-axis is greater than the distance between the margo medialis of the right occipital condyle and the Y-axis. The distance between the posterior margin of the left occipital condyle and the X-axis is equal to the distance between the posterior margin of the right occipital condyle and the X-axis.

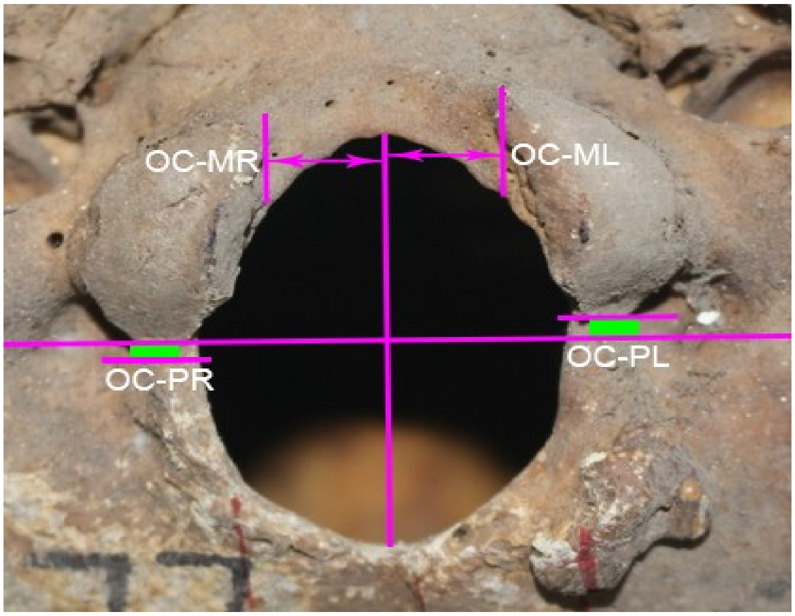

Figure 6. Type III: the distance between the margo medialis of the left occipital condyle and the Y-axis is equal to the distance between the margo medialis of the right occipital condyle and the Y-axis. The posterior edge of the left occipital condyle is above the X-axis. The posterior edges of the right occipital condyles are on or below the X-axis.

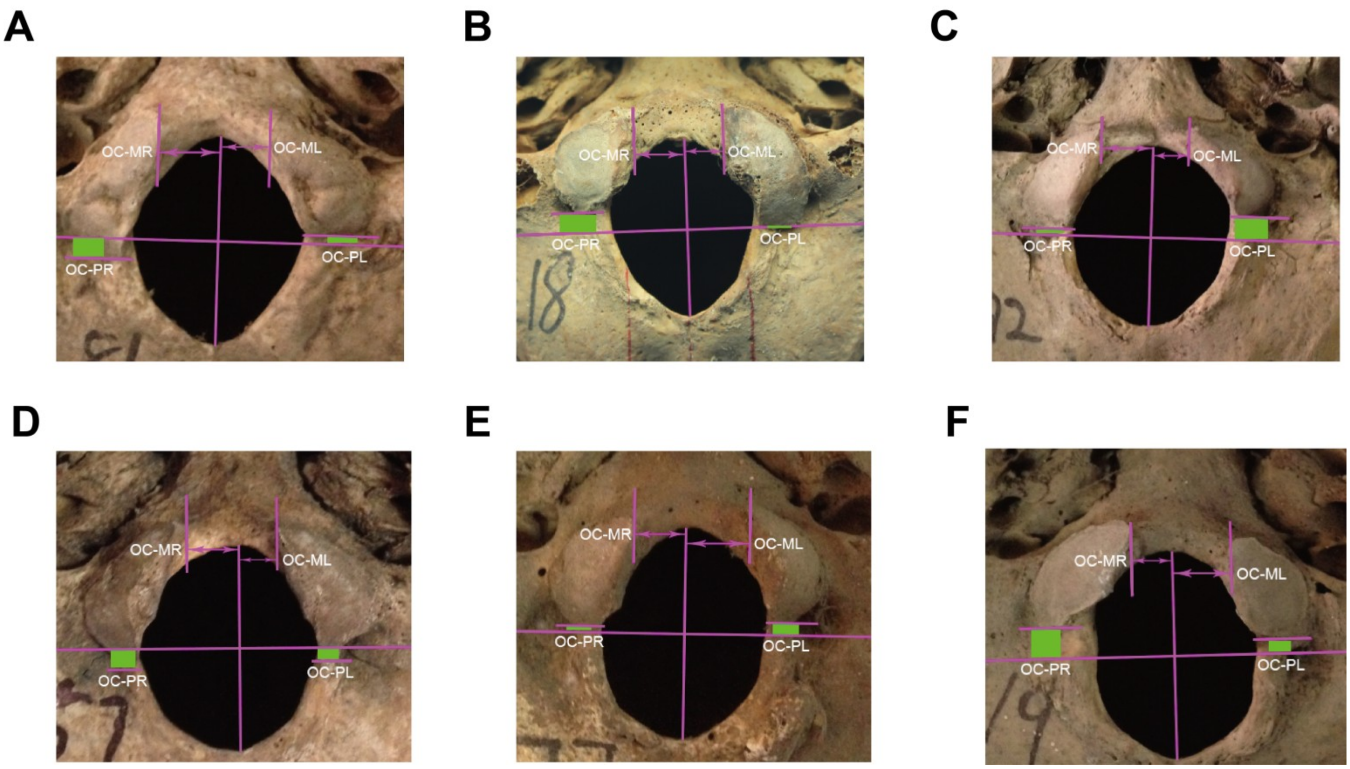

Figure 7. Type IV. **A.** The distance between the margo medialis of the left occipital condyle and the Y-axis is less than the distance between the margo medialis of the right occipital condyle and the Y-axis. The posterior edges of the left occipital condyles are on or above the X-axis. The posterior edges of the right occipital condyles are on or below the X-axis. The posterior edges of the right and left occipital condyles are not on the X-axis simultaneously; **B.** The distance between the margo medialis of the left occipital condyle and the Y-axis is less than the distance between the margo medialis of the right occipital condyle and the Y-axis. The distance between the posterior margin of the left occipital condyle and the X-axis is less than the distance between the posterior margin of the right occipital condyle and the X-axis. The left occipital condyles' posterior edges are on or above the X-axis. The right occipital condyles' posterior edges are above the X-axis; **C.** The distance between the margo medialis of the left occipital condyle and the Y-axis is less than the distance between the margo medialis of the right occipital condyle and the Y-axis. The distance between the posterior margin of the left occipital condyle and the X-axis is greater than the distance between the posterior margin of the right occipital condyle and the X-axis. Both the left and right occipital condyles' posterior edges are above the X-axis; **D.** Distance between the margo medialis of the left occipital condyle and the Y-axis is less than the distance between the margo medialis of the right occipital condyle and the Y-axis. Distance between the posterior margin of the left occipital condyle and the X-axis is less than the distance between the posterior margin

of the right occipital condyle and the X-axis. Both the left and right occipital condyles' posterior edges are below X-axis; **E.** The distance between the margo medialis of the left occipital condyle and the Y-axis is less than the distance between the margo medialis of the right occipital condyle and the Y-axis. The distance between the posterior margin of the left occipital condyle and the X-axis is less than the distance between the posterior margin of the right occipital condyle and the X-axis. Both the left and right occipital condyles' posterior edges are below the X-axis; **F.** The distance between the margo medialis of the left occipital condyle and the Y-axis is greater than the distance between the margo medialis of the right occipital condyle and the Y-axis. The distance between the posterior margin of the right occipital condyle and the X-axis is greater than the distance between the posterior margin of the left occipital condyle and the X-axis. Both the left and right occipital condyles' posterior edges are above the X-axis.

In the 106 specimens, there were 23 cases of Type I, calculated at 21.70%; 42 cases of Type II, calculated at 39.62%; 4 cases of Type III, calculated at 3.77%; and 37 cases of Type IV, calculated at 34.91%. The specific measurement parameter values for each type are detailed in Table 3.

Table 3. Types of the relative position of occipital condyle concerning the foramen magnum and metric parameters determined from 106 skull specimens.

Type	**Metric parameters**				**Cases**	**Total cases**	**Percentage [%]**
	OC-ML absolute value (mean ± SD) [mm]	**OC-MR absolute value (mean ± SD) [mm]**	**OC-PL absolute value (mean ± SD) [mm]**	**OC-PR absolute value (mean ± SD) [mm]**			
Type I	7.86 ± 1.18	7.86 ± 1.18	2.06 ± 1.52	2.06 ± 1.52	23	106	21.70
Type II	7.21 ± 1.44	8.28 ± 1.67	1.77 ± 1.28	1.77 ± 1.28	42	106	39.62
Type III	8.85 ± 0.72	8.85 ± 0.72	2.15 ± 1.18	1.80 ± 1.33	4	106	3.77
Type IV	8.73 ± 1.64	7.26 ± 1.96	2.89 ± 0.71	1.56 ± 1.03	37	106	34.91

Absolute value of OC-ML — distance between the margo medialis of the left occipital condyle and the Y-axis; Absolute value of OC-MR — distance between the margo medialis of the right occipital condyle and the Y-axis; Absolute value of OC-PL — distance between the posterior margin of the left occipital condyle and the X-axis; Absolute value of OC-PR — distance between the posterior margin of the right occipital condyle and the X-axis.

DISCUSSION

The anterior-posterior movement of the occipital condyles within the sagittal plane can lead to adaptive changes in cervical spine curvature. Previous studies have measured the relative positions of the occipital condyles and the foramen magnum, revealing significant variability in this relationship [16]. The anterior-posterior positions of the bilateral occipital condyle anterior margins relative to the foramen magnum can be categorized into three types: anterior (16%), same level (66%), and posterior (18%) [17]. Our data, as shown in Tables 1 and 2, demonstrate similar variations. Smaller occipital condyles tend to be positioned closer to the foramen magnum, creating a greater distance between the posterior margins of the occipital condyles and the posterior margin of the foramen magnum. These variations affect the positioning of the skull's center of gravity [18], which is located between the bilateral occipital condyles. Given that the cervical spine carries the weight of the skull, which averages 6.7 kg [19], the shifting center of gravity impacts the curvature of the cervical spine [20, 23].

Previous studies have utilized finite element models to simulate how anterior movement of the skull's center of gravity reduces cervical lordosis and potentially leads to kyphotic curvature [24, 25]. Posterior movement, on the other hand, increases lordosis. Satio's research [26] also confirms that pure anterior displacement of the center of gravity can lead to cervical kyphosis. Given that the weight of the skull is transmitted through the occipital condyles to the atlas [21, 22], changes in the position of the occipital condyles can significantly influence the load distribution on the cervical spine [23]. As cervical curvature changes are considered early indicators of degenerative disorders [27–29], understanding the variability in occipital condyle positioning provides new insights into cervical spine biomechanics.

In addition to the sagittal plane variations, our findings highlight significant asymmetry in the occipital condyles relative to the foramen magnum. As shown in Table 3, 78.30% of the specimens exhibited asymmetry [30]. This asymmetry suggests the potential for improper alignment of the skull in the coronal plane, although current literature does not fully address this connection. Our data suggest that this misalignment could contribute to conditions resembling torticollis, a clinical condition commonly associated with cervical spine disorders [31–33]. While X-rays are the primary tool used to rule out bony abnormalities [34], our study indicates that assessing occipital condyle positioning could add value to the diagnosis and treatment of torticollis and related conditions.

CONCLUSIONS

Variability in occipital condyle positioning, both in the sagittal and coronal planes, has significant implications for cervical spine curvature and skull alignment. Our findings suggest that anterior-posterior positional changes of the occipital condyles can affect load distribution on the cervical spine, leading to alterations in physiological curvature. Additionally, the asymmetry observed in occipital condyles may result in improper skull alignment, potentially contributing to conditions such as torticollis.

While more research is needed to fully understand these relationships, our study highlights the importance of assessing occipital condyle positioning in both biomechanical analysis and clinical diagnosis. This approach could provide valuable insights for diagnosing cervical spine disorders and improve the understanding of cervical spine biomechanics in both healthy and pathological states.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement

All the skulls come from the Anatomy Teaching and Research Department of Southern Medical University.

Ethics statement

Not applicable.

Author contributions

Yuan Feng: conducted the primary research, collected and analyzed data, and drafted the initial manuscript. **Zhong Zi-lan:** contributed to the conception and design of the study, provided critical revisions for important intellectual content, and approved the final version for publication. **Qin Rui:** assisted in data collection and analysis, contributed to the interpretation of findings, and reviewed the manuscript for scientific accuracy. **Lin Chu-hua:** provided expertise in anatomical studies, contributed to the interpretation of morphological observations, and ensured the anatomical accuracy of the manuscript. **Li Yi-kai:** shared responsibilities as a corresponding author, oversaw the research process, coordinated contributions from co-authors, and ensured adherence to ethical guidelines in research and publication.

Funding

Not applicable.

Acknowledgments

Not applicable.

Conflict of interest

The authors declare no conflicts of interest.

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