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Computed Tomography-Based Occipital Condyle Morphometry in an Indian Population to Assess the Feasibility of Condylar Screws for Occipitocervical Fusion

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Study Design: A retrospective computed tomography (CT)-based morphometric study of 82 occipital condyles in the Indian population, focusing on critical morphometric dimensions with relation to placing condylar screws

Purpose: This study focused on determining the feasibility of placing occipital condylar screws in an Indian population using CT anatomical morphometric data.

Overview of Literature: The occipital condylar screw is a novel technique being explored as one of the options in occipitocervical stabilization. Sex and ethnic variations in anatomical structures may restrict the feasibility of this technique in some populations. To the best of our knowledge, there are no CT-based data on an Indian population that assess the feasibility of occipital condylar screws.

Methods: We measured the dimensions of 82 occipital condyles in 41 adults on coronal, sagittal, and axial reconstructed CT images. The differences were noted between the right and left sides and also between males and females. Statistical analysis was performed using the *t*-test, with a *p*-value of <0.05 considered significant.

Results: Mean sagittal length and height were 17.2±1.7 mm and 9.1±1.5 mm, respectively. Mean condylar angle/screw angle was 38.0°±5.5° from midline, with mean condylar length and width of 19.6±2.6 mm and 9.5±1.0 mm, respectively. Average coronal height on the anterior and posterior hypoglossal canal was 10.8±1.4 mm and 9.0±1.4 mm, respectively. The values in females were significantly lower than those in males, except for screw angle and condylar width. Based on Lin et al.'s proposed criteria, eight of 82 condyles were not suitable for condylar screws.

Conclusions: Preliminary CT morphometry data of the occipital condyle shows that condylar screws are anatomically feasible in a large portion of the Indian population. However, because a small number of population may not be suitable for this technique, meticulous study of preoperative anatomy using detailed CT data is advised.

Keywords: Occipital condyle; Occipitocervical junction; Craniocervical junction; Occipitocervical fusion; Craniocervical fusion; Occipital condyle screws

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Introduction

Occipitocervical fusion is indicated in various pathological conditions that may cause instability in this area. The technique of occipitocervical fusion has evolved from a simple structural bone graft placement without any instrumentation to using occipital plates and condylar and cervical screws with bone graft. To enhance the immediate postoperative stability and the fusion rates, various fixation techniques have come into use. The most popular methods include cervical lateral mass/pedicle screw combined with occipital plate or rod constructs [1-3]. Occipital fixation in this construct relies on midline bony purchase. The disadvantage of this technique is a very limited area available for bony purchase with a chance of complications, such as a transverse sinus injury, epidural hematoma, brain parenchymal injury, and cerebrospinal fluid leak [4]. Moreover, the occipital plate is very bulky, which reduces the available area for graft, in turn compromising fusion and possibly the outcome [5]. A newer technique using occipital condyles as a sole anchor point for cranial fixation has been described [6]. However, wide anatomical variability in morphometric dimensions of occipital condyles has been reported in cadaveric studies [7-10]. Hence, we planned computed tomography (CT)-based anatomical analysis of the condyles in preoperative workup. Moreover, the anatomical dimensions are subject to ethnic variations as reported for other anatomical structures, such as lumbar and thoracic pedicles [11]. A few CT-based studies have assessed the morphometry of occipital condyles for feasibility of occipital condyle screw fixation [12,13]. None of these studies is based on an Indian population. The primary aim of our study was to identify the ethnic differences in morphometry, which can influence the feasibility of condylar screw application, in an Indian population, thereby helping in preoperative decision making.

Materials and Methods

Study from Indian Spinal Injuries Centre and Mahajan Imaging and Research Centre, New Delhi, India. After the approval of Institutional Review Board of Indian Spinal Injuries Center (ISIC/RP/2014/003), 57 random volumetric adult occipitocervical CT scans with a minimum slice thickness of less than 1 mm (range, 0.5–1 mm) were retrospectively taken and analyzed from the database of a single center based in New Delhi, a major referral center in northern India. The raw volumetric axial images were taken, and CT reconstructions in sagittal and coronal planes were performed using software (RadiAnt DIACOM viewer 4.0.2, Medixant, Poznan, Poland). Incomplete scans of the occipital condylar region were excluded from the study, as were those showing a demonstrable lesion in the craniocervical area in the form of a fracture, tumor, infection, inflammatory disease, previous surgery in the occipital area, and congenital malformations. Therefore, 16 CT scans were excluded based on the abovementioned criteria, leaving 41 CT scans that were finally included in the study. The measurements were performed in the axial, coronal, and sagittal reconstructions using bone window settings of the software after the image section was select-

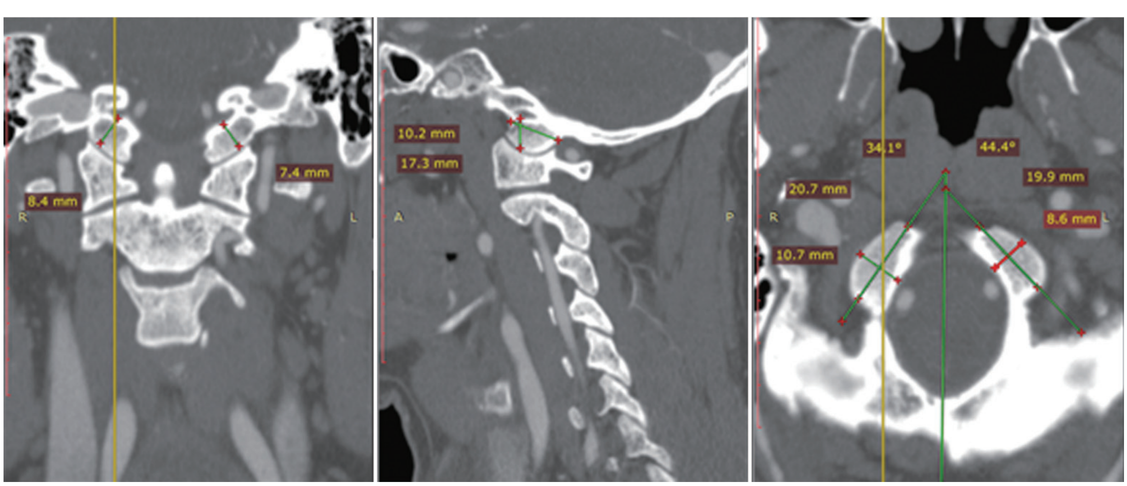

Fig. 1. Coronal, sagittal, and axial computed tomography images with sagittal and coronal height, condylar width, screw angle, and screw length as measured in our study: example 1.

ed and agreed upon by the two authors.

The condylar anteroposterior (AP) length, transverse width, height, projected screw angle, and projected screw lengths along the long axis of the condyle were measured (Figs. 1–3). Length was measured as the longest axis in the AP orientation on a sagittal plane. The transverse width was a line perpendicular to the midpoint of the long axis on an axial plane. Height was measured in the sagittal and coronal planes perpendicularly from the hypoglossal canal to the condylar cartilage. The method of coronal height measurement was not consistent in the literature; therefore, we measured the height using the techniques described by Lin et al. [12] and Le et al. [13], with a line descending from the hypoglossal canal to the condylar cartilage in the coronal section. The projected screw trajectory was along the long axis of the condyle, which was placed in the center of the condyle, directed anteromedially in the longest axis to maximize the length and safety of the screw. The condylar sagittal angle was measured in the axial plane between the midline and a line drawn through the condyle mimicking ideal screw placement. The screw length was measured from the outer cortex of the posterior wall to the outer cortex of the anterior wall. All measurements were collected and analyzed using an Excel spreadsheet (Microsoft Corporation, Redmond, WA, USA). The means of various measured parameters and standard deviations were calculated for all parameters.

The data were statistically analyzed using SPSS ver. 22 (SPSS, Inc., Chicago, IL, USA). Significance testing was performed between the right and left side condylar dimensions along with sex variations using Student's *t* -test. Correlation was also determined between various dimensions. Significance was considered if $p<0.05$. As per the study by Lin et al. [12], a 3.5-mm condylar screw was feasible only if the condylar height was ≥6.5 mm and the condylar width was ≥8 mm. Therefore, we kept these reference values as our criteria to decide the feasibility of condylar screws.

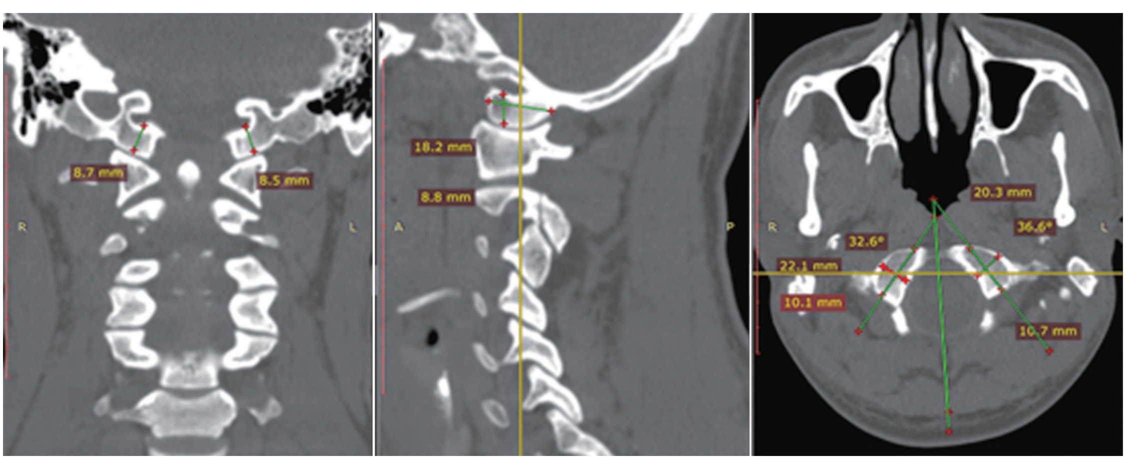

Fig. 2. Coronal, sagittal, and axial computed tomography images with sagittal and coronal height, condylar width, screw angle, and screw length as measured in our study: example 2.

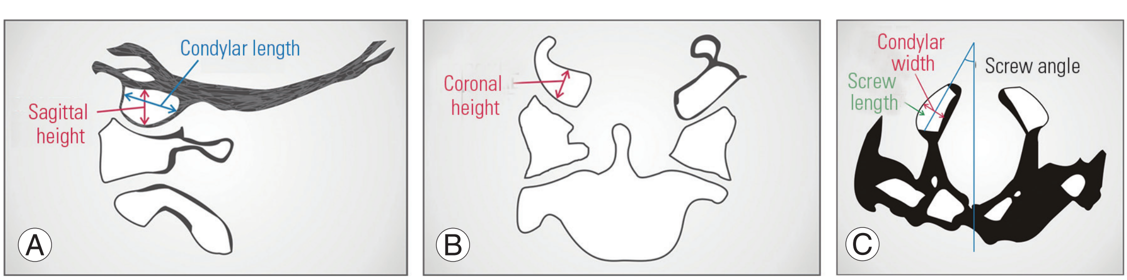

Fig. 3. Pictographic representation of condylar measurements taken on sagittal **(A)**, coronal **(B)**, and axial **(C)** reconstructions of a computed tomography scan.

Table 1. Mean values for sagittal length, sagittal height and coronal height in anterior and posterior parts of the hypoglossal canal on the right and left sides in males and females respectively

Sex	Coronal height (mm)						Sagittal length (mm)			Sagittal height (mm)		
	Right anterior	Left anterior	Total	Right posterior	Left posterior	Total	Right	Left	Total	Right	Left	Total
Male	11.4±1.2	11.2±1.5	11.3±1.4	9.7±1.4	9.0±1.5	9.3±1.5	17.8±1.6	17.9±1.5	17.8±1.5	9.6±1.7	9.3±1.4	9.5±1.5
Female	10.1±1.2	10.2±1.4	10.2±1.3	8.6±1.1	8.6±1.2	8.6±1.1	16.4±1.9	16.6±1.2	16.5±1.6	8.6±1.3	8.6±1.3	8.6±1.3
All	10.8±1.4	10.7±1.5	10.8±1.4	9.2±1.4	8.8±1.3	9.0±1.4	17.2±1.9	17.3±1.5	17.2±1.7	9.1±1.6	9.0±1.4	9.1±1.5

Values are presented as mean±standard deviation.

Table 2. Mean values for condylar axial width, length and condylar angle on the right and left sides in males and females respectively

Sex	Condylar axial width (mm)			Condylar length (screw length in mm)			Condylar angle/screw angle (mm)		
	Right	Left	Total	Right	Left	Total	Right	Left	Total
Male	9.8±1.1	9.6±1.1	9.7±1.1	20.8±2.2	19.8±3.1	20.3±2.7	38.7±5.8	37.2±5.9	38.0±5.8
Female	9.0±0.9	9.5±0.9	9.2±0.9	18.9±2.3	18.9±2.1	18.9±2.2	37.2±4.5	38.8±5.7	38.0±5.1
All	9.4±1.1	9.5±1.0	9.5±1.0	19.9±2.4	19.4±2.7	19.6±2.6	38.0±5.2	38.0±5.7	38.0±5.5

Values are presented as mean±standard deviation.

Results

Among 57 randomly selected retrospective CT scans, 41 (from 22 males and 19 females) were appropriate for the analysis. The various parameters measured are shown below with their standard deviations and means. The individual values are depicted in Tables 1 and 2.

The right and left side dimensions were tested for significance, and no significant differences were noted. However, the parameters in females were significantly lower than those in males, except for screw angle and condylar width.

Based on the criteria proposed by Lin et al. [12] for the feasibility of condylar screw (condylar height and width, ≥6.5 and ≥8 mm, respectively), four of 44 condyles in males and four of 38 condyles in females were unsuitable for condylar screw fixation in the Indian population.

Discussion

Since its introduction in 1927 [14], occipitocervical fusion has remained a challenge for surgeons. This has led to continuous modifications in the technique, which began with stabilization using wiring instead of bone graft alone, to enhance fusion rates and impart some postoperative stability. There was a need for postoperative immobilization with the halo fixator or Minerva cast because of the weakness of the construct. The technique evolved, and plate and rod constructs became the gold standard for occipitocervical fusion. However, some technical issues remained with using the occipital plate. The occipital bone is thickest at the center at the occipital protuberance and becomes thinner in the lateral or inferior direction, which leaves a very small area for application of the plate. Multiple screws are required to obtain sufficient purchase in the occiput to prevent implant failure. Moreover, because of the bulkiness of the implant, very little area is left for bone grafting. Despite all these problems, it remains the gold standard procedure. To minimize these problems, an alternative novel technique involving fixation of the occipital condyle was described by Uribe et al. [6]. This technique proposes several advantages in the form of a decreased length of lever arm, enhanced bone screw interface due to longer screw length, low profile of the construct, and more bone surface for placing graft or additional implant supplementation if needed [15]. A recent study has shown that the biomechanical strength of occipital condyle screw constructs is comparable with the traditional plate–screw occipitocervical constructs [16].

However, Uribe et al. [6] and others [12-14] have reported significant variability in condylar dimensions. This variation can further amplify if ethnic considerations are

Table 3. Ethnic variance in condylar morphometry among various populations

Study	Coronal height (mm)	Sagittal length (mm)	Axial width (mm)	Sagittal angle (°)
Lin et al. [12]	9.0	21.3	9.8	27.2
Le et al. [13]	9.92	22.38	11.18	20.30
Frankel et al. [17]	10.5	20.3	11.1	32.8
Current study	8.99	17.22	9.48	37.98

taken into account. Hence, before considering its wider clinical application in the Indian population, we performed a preliminary feasibility study.

The occipital condylar morphometry has been previously studied by Le et al. [13] and Frankel et al. [17] including 340 and 80 condyles, respectively. They extensively investigated adult condylar dimensions with focus on the placement of occipital condylar screws. The length of screw is usually determined by the sagittal AP length and axial condylar length along the long axis of the condyle. In our study, the sagittal AP length was 17.22±1.67 mm, which was lower than that reported by Frankel et al. [17] and Le et al. [13] (20.3±2.1 mm and 22.4±2.2 mm, respectively). It is notable that this value was even lower than the mean sagittal length of 19.4±1.9 mm reported in a Chinese pediatric population aged 2–5 years, as reported by Lin et al. [12]. The mean condylar length on axial scans in our study was 19.62±2.57 mm, which was slightly lower but comparable to values reported by Le et al. [13] (20.3 ±2.2 mm). The length of occipitocervical was 23.9±3.4 mm (right) and 24 ±3.3 mm (left) in a study of cadaveric morphometry of a Turkish population by Ozer et al. [18], which was higher than those in our study for right and left condyles (20.8±2.2 mm and 19.8±3.1 mm, respectively). The ethnic variations among different populations have been described in Table 3 [12,13,17].

The screw angle measured in axial scans showed wide variability, and the mean value was 38°±5.5°. Le et al. [13] reported a mean angulation of 20.3°±4.9° and Frank et al. [17] reported a mean value of 32.8°±5.2°. Our measurements showed more medial angulation than those in the study by Le et al. [13]. This observation can explain the overall higher value of axial length compared with sagittal AP length in our study. A converged trajectory in line with significantly medially angulated condylar axis is likely to give a longer screw length compared with a straight AP trajectory measured in sagittal AP length. This observation is in contradiction with other published studies, which can be due to anatomical ethnic variations among different population groups.

The condylar width was an important factor in assessing the feasibility of screw placement and was reported to have an overall mean value of 9.48±1.04 mm (range, 7.3–12 mm) in our study. This was adequate to accommodate a 3.5-mm screw as described in the original technique. Overall, the mean condylar width in the Indian population also followed the general trend and was smaller compared with the values reported by Le et al. [13] and Frank et al. [17] (11.2±1.4 mm and 11.1±1.4 mm, respectively). Right (9.8±1.1 mm) and left (9.6±1.1 mm) condylar widths were smaller compared with those reported by Ozer et al. [18] (11.9±2.3 mm and 10.7±2.3 mm, respectively).

The hypoglossal canal is a critical anatomical structure in relation to the placement of condylar screws. Screw trajectory should not violate the hypoglossal canal, which has devastating consequences. The coronal height in the posterior canal was consistently and significantly smaller compared with the measurements obtained from the anterior hypoglossal canal (9±1.4 mm vs. 10.8±1.4 mm). Overall, the results obtained were smaller compared with those reported by Frank et al. [17], who measured coronal height possibly from the posterior hypoglossal canal (mean value, 10.5±1.3 mm). Le et al. [13] used the anterior hypoglossal canal for coronal height measurements and reported higher mean values of 9.9±1.3 mm. Similarly, the sagittal height measurement from the hypoglossal canal to the condylar cartilage (9.1±1.5 mm) was lower compared to that reported by Frank et al. [17] (10.5±1.3; range, 7.6–13.5 mm).

Our study confirms variability in anatomical morphometry of occipital condyles in the Indian population. This is based on the observation by Lin et al. [12] that if the condylar heightis ≥6.5 mm and condylar width is ≥8 mm, it is safe to accommodate a 3.5-mm condylar screw. Approximately 10% of condyles were unsuitable for screw

Table 4. Demographics and statistical analysis

Measurement	Male	Female	P (≤) two-tail
Coronal height (mm)			
Anterior	11.3±1.4	10.2±1.3	0.0004
Posterior	9.3±1.5	8.6±1.1	0.0128
Sagittal length (mm)	17.8±1.5	16.5±1.6	0.0002
Sagittal height (mm)	9.5±1.5	8.6±1.3	0.0068
Condylar axial width (mm)	9.7±1.1	9.2±0.9	0.1565
Condylar length (screw length in mm)	20.3±2.7	18.9±2.2	0.9991
Condylar angle/screw angle (mm)	38.0±5.8	38.0±5.1	0.0117

Values are presented as mean±standard deviation.

placement in the Indian population. This rate was slightly higher in females than in males. The demographics and statistical differences in the measurements for various parameters are shown in Table 4. Therefore, the failure rate was approximately 10% and the main limiting factor for failure was smaller condylar width rather than height. This pattern mimics the trend seen by Lin et al. [12] in a Chinese population aged 6–9 years and is in contradiction with other published studies that noted universal feasibility of occipital condylar screws in adults.

The limitations of the study are primarily related to the sample, which was drawn from a single center based in northern India and may not be representative of all ethnic variations prevalent in India. Moreover, the measurements were taken once by a single observer only, whereas evaluation at different times by different observers may have given more accurate values. This is a radiological study and must be validated further by clinical studies. Feasibility test by radiological evaluation may have overestimated the values in comparison with a possible clinical study. Last, age has not been considered as a confounding factor in our study.

Conclusions

Our study confirmed the wide variability in occipital condylar morphometry. Therefore, we advise caution and meticulous preoperative morphometric assessment when using this technique in the Indian population, as up to 10% of condyles may not be suitable for screw placement. Overall, morphometric dimensions demonstrated smaller occipital condyles with more medial orientation in the Indian population compared with other published CT-based morphometric studies in the Chinese and Western populations.

Conflict of Interest

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

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