Three-dimensional Analysis of the Occipital Condyle Considering the Internal Hypoglossal Canal Structure

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Introduction: The occipitocervical junction (OCJ) presents a unique, complex, biomechanical interface among the occipital bone, the atlas, and the axis. OCJ fusion is indicated in craniocervical instability. It is a highly rewarding, but also a highly challenging procedure because of the complex anatomy and biomechanics of this region. Currently, the main fixation difficulty is at the cranial side. The midline occipital keel plate is currently considered the mainstay method. However, in some circumstances when the suboccipital bone is not available, this method is not feasible. Recently, two novel techniques, the occipital condyle screw (OCS) [1, 2] and the C0-C1 transarticular screw [3-5], using the occipital condyle as a novel cranial anchor point, are introduced to address these problems. As the occipital condyle is small and very close to some vital neurovascular structures, a thorough study of the occipital condyle anatomy, especially determination of the space available for the implant is necessary. Therefore, in this study we establish a 3-D model of the occipital condyle and measure the mean height of the occipital condyle with/without the hypoglossal canal.

Methods: Twenty-one fresh frozen human cadaveric cervical spines were used, with segments of C0-C1 being the level of interest. The donor sample consisted of 10 men and 11 women with an average age of 56.2 years (range, 43-68). CT (Volume Zoom; Siemens Medical Solutions USA, Inc., Malvern, A) scans were obtained to exclude cadavers that had anatomical abnormalities or pathological changes such as fracture, severe deformity, and metastatic disease. CT was acquired in the axial plane from the occiput to C2 in 1.0-mm contiguous slices (120kV, 100mA, 1.0 sec duration, 20 cm field of view, 512 × 512 matrix). Finally, the CT data were used to create high resolution three-dimensional computer models. The models were segmented utilizing Mimics software (Materialise; Leuven, Belgium), including the occipital condyle, the hypoglossal canal and the atlas vertebra. These segmentations were output as point cloud data. Software programs created in Microsoft Visual C++ with Microsoft Foundation Class (MFC) programming environment (Microsoft Corp.) were used to calculate the mean height of the occipital condyle with/without the hypoglossal canal.

Creation of occipital condyle surface model: Least distances between C0 and C1 were calculated and the areas on C0 with the least distance less than 5 mm were determined as occipital condyle joint surfaces.

Determination of cranio-caudal direction at C0-C1 junction: The internal contour of the foramen magnum was manually segmented and eigenvectors of the border were calculated. An eigenvector oriented perpendicular to the border of the foramen magnum was used to determine the cranio-caudal direction.
Measurement of height distribution in reference to the occipital condyle joint surface: Least distances between the occipital condyle joint surface and internal surface of cranial cavity or a hypoglossal canal were calculated. Vectors were created by connecting an occipital condyle joint surface point and points consisting of the internal surface of cranial cavity or the hypoglossal canal with an angle from the cranio-caudal axis less than 5 degrees. Among these vectors, the vector with the least distance was selected and the distance was defined as the least distance at the joint surface point. This procedure was repeated through all points on the occipital condyle joint surface (Figure 1).

Determination of the projected area on the occipital condyle joint surface underneath the hypoglossal canal: When the aforementioned measurement of the height distribution was conducted with the presence of the hypoglossal canal, the points of the occipital condyle joint surface with the least distances to the hypoglossal canal were registered. These points were defined as the projected area on the occipital condyle joint surface underneath the hypoglossal canal.

Statistics: The least distances between the points in the projected area underneath the hypoglossal canal and the skull-base were calculated as the height of the occipital condyle at the area without the presence of the hypoglossal canal ($h_{oc}$). The mean height was compared with the mean height with the presence of the hypoglossal canal ($h_{hc}$). The differences in dimensions of the occipital condyle with and without the hypoglossal canal were determined by using a paired Students’ t-test, using $p < 0.05$ as the level of significance. The results are presented as mean ± SD in mm.

Results: We successfully established the 3-D models of the occipital condyle, including the hypoglossal canal inside it (Figures 2, 3). These models give insights into the highly irregular shape of the hypoglossal canal, similar to a tube with trumpet-like openings at either end. The mean height of the occipital condyle with the hypoglossal canal in the left side was found to be 10.4±1.1 mm and the right side dimension was 10.3±1.2. When the hypoglossal canal was not considered the dimensions for left and right sides were 17.9±1.6 mm and 17.7±1.8 mm, respectively. Symmetry was verified between left and right sides in both measurement types ($p>0.611$), and there were significant differences by method of measurement ($p < 0.0001$).

Discussion: The 3-D understanding of the anatomy of the occipital condyle and the hypoglossal canal inside it is crucial to the placement of the OCS and the C0-C1 transarticular screw. The C0-C1 junction provides the largest ROM in flexion and extension and the geometry of the joint surface at C0-C1 junction is convex and concave at C0 and C1, respectively, in the sagittal plane (Fig. 1). Therefore, the height of the occipital condyle measured from the occipital condyle joint surface to the internal surface of cranial cavity is largest at the center of the occipital condyle (Figs. 1, 3B). As previous reports indicate, the geometry of the hypoglossal canal is complex with features branching inside the occipital condyle. The present study confirmed its complex geometry in 3D and found the trumpet shape at the orifices. Therefore, the hypoglossal canal is a major structure, rather than a simple canal, located at the center of the occipital condyle having large projected area on the occipital joint surface (Figs. 2, 3C). Due to the presence of the hypoglossal canal, the zone available for screw fixation is curved zone parallel to the occipital condyle joint surface except posterior one third (Fig. 3A). Consequently, evaluation of the 3D geometry of the occipital condyle geometry including the hypoglossal canal is essential for preoperative planning of the C0-C1 fixation using transarticular screw and occipital condyle screw.

Significance: Appropriate pre-surgical planning is better served by accurate 3D methods that can provide patient-specific measurements. If complex geometries like that of the hypoglossal canal can be
correctly described with clinically-available imaging resources like in this report, surgeries that involve them decrease their risk profile.

**Figure 1** Ideal sagittal cross-section of the occipital condyle showing the dimensions calculated for the suboccipital bone: $h_{oc}$ is the height of the entire condyle and $h_{hc}$ is the height until the hypoglossal canal (blue cavity) inferior edge. The directions of these dimensions are within $\pm 5^\circ$ of the foramen magnum direction ($k_{FM}$).

**Figure 2** A Anterior-Posterior and B Posterior-Anterior views of the 3-D models of the occipital condyle, bilateral hypoglossal canals and the C1 vertebra (light blue). The left hypoglossal canal is shown in pink and the right one is depicted in blue. The base of the cranium is shown as a transparent model.
Fig. 3 Least distance distribution between the occipital condyle joint surface and hypoglossal canal (red points) and/or internal surface of the cranial cavity (white points). A: with the presence of the hypoglossal canal. B: with the absence of the hypoglossal canal. C: Projected area underneath hypoglossal canal. Note: skull-base was partially trimmed for better visualization of the hypoglossal canal.