The modified occipital condyle screw: A quantitative anatomic study investigating the feasibility of a novel instrumented fixation technique for craniocervical fusion

ABSTRACT

Study Design: Prospective human anatomical study.

Objective: Occipitocervical fusion with occipital plate or condyle screws has shown higher failure rates in those with skeletal dysplasia. The modified occipital condyle screw connects the occipital condyle to the pars basilaris of the occipital bone that may achieve fortified bony purchase and serve as a more rigid fixation point. We evaluate anatomical feasibility of a novel cranial fixation technique designed to decrease risk of pseudarthrosis.

Materials and Methods: Occipital condyles were analyzed morphologically using multiplanar three-dimensional reconstructed, ultra-thin section computed tomography. The following parameters were obtained: occipital condyle length, maximal cross section, location of hypoglossal canal, axial and sagittal orientation of the long axis, occipital condyle pedicle (OCP) diameter, maximal length of OCP screw, and entry point.

Results: Forty patients with total of 80 occipital condyles were analyzed and the following measurements were obtained: occipital condyle length 24.1 mm (20.5–27.7, standard deviation [SD]: 2.2); condyle maximum axial cross-section 12.6 mm (9–15.8, SD: 1.9); length of OCP screw 38.9 mm (29.3–44, SD: 5.7); diameter of OCP 3.4 mm (3.2–3.6, SD: 0.2); clearance below hypoglossal canal 4.5 mm (3.4–7, SD: 1.1); and distance of screw entry point from condylar foramen 2 mm (range 0-4, SD 1.6).

Conclusion: The modified occipital condyle screw connects the condyle with the clivus through the pars basilaris and represents a safe and technically feasible approach to achieve craniocervical fusion in skeletally mature individuals. This cephalad anchor point serves as an alternate fixation point of the occipitocervical junction with increased strength of construct and decreased risk of hardware failure or pseudarthrosis given cortical bone purchase and longer screw instrumentation.

Keywords: Chiari malformation, craniocervical fusion, craniocervical instability, occipital condyle pedicle, occipital condyle screw fixation, surgery

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INTRODUCTION

Fixation of the occipitocervical junction for acute or chronic instability involves technical challenge with complex anatomy of the skull base and high cervical spine.[1,2] Craniocervical fusion most commonly entails squamous occipital bone fixation with occipital plates, inside-outside occipital screws, or transarticular screws.[3-10] In select patients, craniocervical fusion and concomitant suboccipital decompression is necessary to address tonsillar ectopia or posterior basilar invagination.[11,12] In addition, variable occipital bone

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anatomy, malignancy or infection of occipital squama, or revision procedures may preclude traditional occipital plate fixation.[1,13] In such cases, occipital condyle screw fixation, rather than occipital bone fusion, has emerged as an alternative approach or salvage technique.[14,15] While fusion rates for both occipital bone and occipital condyle fixation have been reportedly high in pediatric and adult patients,[15-19] a subset of patients with skeletal dysplasia and other congenital anomalies of the craniocervical junction are at particular risk for pseudarthrosis and implant failure.[20,21]

In the present study, we aim to investigate a potential novel cranial fixation technique aimed to improve fusion rates and lower implant failure rates in individuals at higher risk for pseudarthrosis. In part, this study is based on the anatomic observation that the occipital condyle is connected ventromedially to the basiocciput, which comprises the lower clivus [Figure 1]. This connection on cross-sectional imaging consists of a "pedicle-like" structure, comprised a bony corridor with three cortical walls and cortical ridges associated with the foramen magnum rim [Figure 2]. As has been previously shown in the mobile spine, pedicle screw fixation is the most biomechanically rigid method to achieve proper fusion[14,22] when compared to techniques involving hooks or lateral plates.[23] We evaluate the feasibility of a novel "modified occipital condyle screw" trajectory for cephalad craniocervical fusion, as outlined in Figure 3, that may offer more formidable bony purchase based on an anatomic morphometric investigation with decreased risk of pseudarthrosis. Assessment of the modified occipital condyle trajectory including length, width, height, and possible medialization angle for safe and efficacious screw placement may inform future investigation.

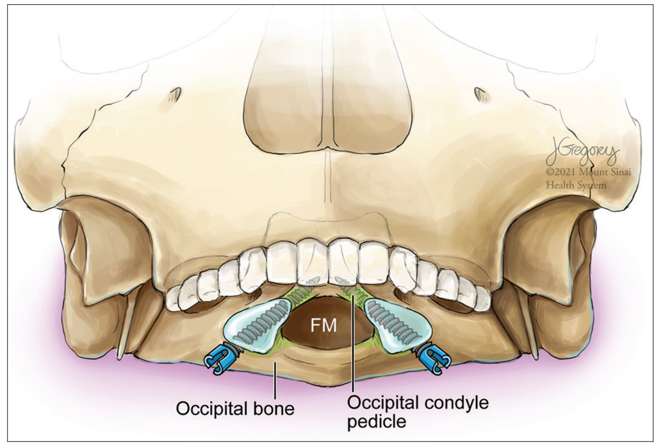

Figure 1: Artist's illustration of suggested OCP screw fixation. OCP – occipital condyle pedicle

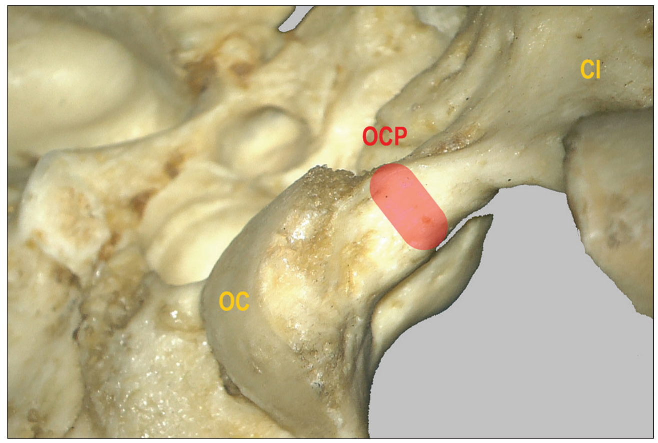

Figure 2: Right-sided medial cadaveric view of the occipital condyle. Cl – clivus, OC – occipital condyle, OCP – occipital condyle pedicle

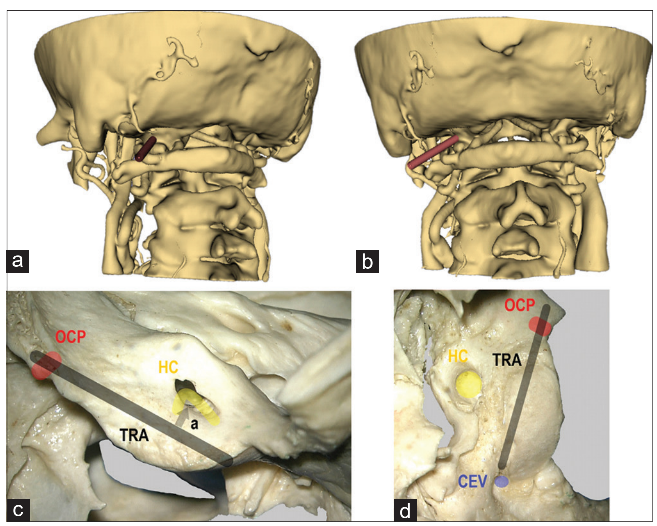

Figure 3: Proposed OCP fixation. (a and b) A 3D volume-rendered model of the left-sided OCP fixation trajectory. (c) A right-sided cadaveric view of the occipital condyle and (d) a basal view. a – clearance below hypoglossal canal, CEV – Condylar emissary vein, HC – hypoglossal canal, OCP – occipital condyle pedicle, TRA – trajectory of proposed OCP screw, 3D – Three-dimensional

MATERIALS AND METHODS

In a tertiary care neurosurgical center, consecutive patients undergoing cranial high-resolution computed tomography (CT) scans were screened for intracranial structural pathology. Informed consent was obtained from patients for the present study. No IRB approval was used for the study. Only cases without pathologic findings were included; patients with cervical or cranial fractures, neoplastic disease, deformity, and infection were excluded from the trial. For each patient, a high-resolution CT scan (slice thickness 0.625 mm) was analyzed using multiplanar reconstruction with Synedra (Synedra Information Technologies GmbH, Innsbruck/Austria), as well as three-dimensional (3D) volume-rendered reconstructions using 3D slicer (http://slicer.org). Sagittal, axial, and coronal slices were considered. Cervical CT scans of patients without structural pathology have been used to obtained the following radiographic measurements: length and diameter of the occipital condyle; maximal sagittal, coronal, and axial cross sections; maximal screw length; coronal and sagittal screw trajectory tilt angles; and entry point distance from foramen magnum. A total of 80 occipital condyles were morphometrically analyzed with each CT scan analyzed by radiologist and neurosurgeon for technical feasibility.

RESULTS

A total of 40 patients (80 occipital condyles) were analyzed and measurements for occipital condyle screw placement were considered. The average length of the condyle was 24.1 mm (standard deviation [SD]: 2.2, range: 20.5–27.7); the distance of maximal cross-section was 17.2 mm (SD: 2.8, range: 11.8–21.4); the maximal cross-section was 12.6 mm (SD: 1.9, range: 9–15.8), the axial cross-section of the occipital condyle at the hypoglossal canal 11.4 mm (SD: 2.4, range: 8.8–15.4), the coronal cross-section of the occipital condyle at the hypoglossal canal 12.7 mm (SD: 1.5, range: 10.7–14.9); and the clearance below the hypoglossal canal was 4.5 mm (SD: 1.1, range: 3.4–7). The average length of screw was 38.9 mm (SD: 5.7, range: 29.3–44) and the diameter of the occipital condyle pedicle (OCP) was 3.4 mm (SD: 0.2, range: 3.2–3.6) [Table 1]. The mean coronal plane tilt was 42° (SD: 9.1, range: 29.5–45), the sagittal tilt was 23° (SD: 10.2, range: 9.1–45), and the entry point distance from the condylar foramen was 2 mm (SD: 1.6, range 0-4).

DISCUSSION

As shown in the present anatomic, morphometric study, the occipital condyle that is anterolateral to the foramen magnum with basiocciput and precondylar extension is a reliably identified anatomic structure that may contribute to craniocervical fusion, particularly for patients at risk for pseudarthrosis and hardware failure. The modified occipital condyle screw construct meets all criteria of novel occipital cervical junction constructs described by Bosco *et al*. in (1) providing rigid segmental stability, (2) absence of canal compromise, (3) allow immediate correction of deformity, and (4) offer craniocervical fusion when an occipital plate or posterior elements are compromised.[1] Further, we maintain that this screw trajectory acts as a formidable fixation point given increased length of screw compared to the traditional occipital condyle screw[2] with improved cortical purchase and sufficient diameter for high pullout strength threshold.[24]

Table 1: Radiographic measurements. Given in mean (standard deviation, min-max)

	parameter	measurements
a	Length of occipital condyle	24.1 (2.2, 20-5-27.7)
b	distance of maximal cross section	17.2 (2.8, 11.8-21.4)
c	maximum cross section in axial plane	12.6 (1.9, 9-15.8)
d	cross section of OC at HC canal, axial	11.4 (2.4, 8.8-15.4)
e	cross section of OC at HC canal, coronal	12.7 (1.5, 10.7-14.9)
f	clearance below hypoglossal canal	4.5 (1.1, 3.4-7)
g	length of screw	38.9 (5.7, 29.3-44)
h	diameter of occipital condyle pedicle	3.4 (0.2, 3.2-3.6)
i	tilt, coronal plane	42° (9.1, 29.5-45)
	tilt, sagittal plane	23° (10.2, 9.1-45)
j	entry point distance from condylar foramen	2 (1.6, 0-4)

In a previous morphometric analysis of over 500 occipital condyles, it was shown that average condyle length was 18.6 mm, width of 10.5 mm, and height of 11 mm.[2] Medialization angle was 23° for condyle screw placement and males were observed to have significantly larger condyles with a broader angle of medialization, favoring technical feasibility. In the present study, we show that this modified occipital condyle screw trajectory could afford a markedly longer screw with average length of 38.9 mm, or 20.3 mm longer, more than double the length, than that of previous condyle measurements [Figure 4].[2] As prior biomechanical studies have shown, fixation strength increases with screw length, diameter, and cortical purchase with fewer complications such as hardware fractures and screw loosening.[24-26] Further, cortical bone trajectory of the modified occipital condyle screw, including the bony ridge of the prebasioccipital arch or basilar process that unites the condyle with the anterior rim of foramen magnum[27-29] and pars basilaris of the clivus, maximizes cephalad fixation strength.[26]

Craniocervical fusion is often indicated due to instability in the setting of acute trauma, but may also less commonly be related to pathologic fractures or destabilization from infection, neoplasm, inflammatory disease such as rheumatoid arthritis, or congenital malformations.[12,30] Overall fusion rate in occipitocervical arthrodesis with either occipital bone or condyle fixation nears 100%;[16,31] however, pseudarthrosis in the pediatric population was as high as 15%–18% with deep wound infection and skeletal dysplasias as notable risk factors.[16,20,32] Skeletal dysplasia involves a group of inherited disorders of the bone, which are frequently associated with craniocervical junction abnormities, such as odontoid dysplasia, basilar impression, basilar invagination, or atlantooccipital or atlantoaxial instability.[33] These disorders include achondroplasia, Morquio´s syndrome, osteogenesis imperfecta, and others, predisposing to hardware failure and surgical fixation complications.[20] In children, craniocervical fusion rate is similar with and without skipping of C1 and may be considered for OCP screw constructs.[31] Occipital condyle screw fixation has emerged as an alternative to occipital bone fixation with similar biomechanical properties regarding construct stiffness.[14] Indeed, some of the challenges of craniocervical fixation related to occipital plating, including epidural hematoma, wound breakdown, cerebrospinal fluid leak, and sinus injury, are avoided.[14,19,34] In a cadaveric study in 2011, Helgeson *et al*. reported that occipital condyle screws afforded increased flexion and extension movement when compared to occipital plating constructs.[19] Modified occipital condyle screw placement may represent an additional fixation method with possibly longer screw and resultant improved fusion strength and fusion rate.

All three subdivisions of the occipital bone—the supraocciput, exocciput, and basiocciput—form via primary ossificans.[29,35] The exocciput, which forms the occipital condyle is connected to the clivus, basiocciput, by the anterior intraoccipital fissure, Figure 5. In children under the age of 10, the anterior intraoccipital syncondrosis has not yet fused and may represent a cleft that crosses the occipital condyle.[29,36,37] The occipital condyle anatomy is characterized by its proximity to the occipital emissary vein, the jugular bulb, as well as the hypoglossal canal which separated the condyle from the jugular tubercle, as seen in Figure 6.[38] Previous cadaveric anatomical studies have demonstrated safe trajectory avoiding these adjacent structures with the occipital condyle screw.[14] Anatomical difficulty would require neuronavigation for safe modified occipital condyle fixation. Careful avoidance of surrounding neurovascular structures and medial breach with the nature of occipital condylar inward concavity[29] should also be considered. Commercially available navigation systems were shown to have an accuracy of 1.45 or 1.27 mm, respectively.[39] For a fusion construct utilizing OCP screw fixation, C1 could also be skipped, decreasing operative risk. Future study designs are being implemented to trial the screws in cadaveric models for further evaluation of technical feasibility and safety.

Strengths and limitations

Given the nature of the present study as a technical concept, there are no live or human cadaver trials illustrating successful placement of the modified occipital condyle screw. Future studies would need to validate the projected viability and success of the OCP screw with human or cadaver specimens and load assessment investigation as previously described for the occipital condyle screw.[14] Potential technical challenges of the OCP screw would be similar to those of the occipital condyle screw given anatomical proximity to neurovascular structures, including the hypoglossal canal, hypoglossal nerve, emissary veins, and jugular bulb. Variable craniocervical anatomy with differing cortical bone anatomy, length and diameter of condyle, gender differences, and angulation also represent surgical concerns for modified condyle screw placement, necessitating careful preoperative evaluation of imaging and intraoperative navigation.

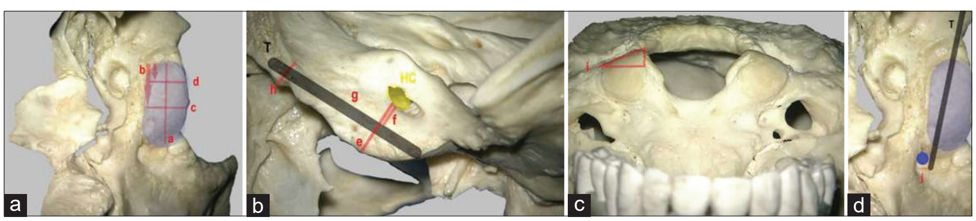

Figure 4: (a) A lateral view of the skull base with OCP and surrounding structures. (b) The trajectory of the OCP screw with hypoglossal canal shown superiorly. (c) An inferior, oblique anterior-posterior image, demonstrating the cross-sectional thickness of the proximal OCP. (d) Lateral view of the skull base, illustrating the jugular foramen and proximity to condyle pedicle screw trajectory. a – length of the occipital condyle, b – level of maximal cross-sectional area, c – maximal cross-section in axial plane, d – axial cross-section at the level of the hypoglossal canal, e – length of OCP between the inferior margin of the pedicle and the beginning of the hypoglossal canal superiorly, f – margin length between the OCP screw trajectory and the beginning of the hypoglossal canal superiorly, g – length of the occipital condyle, screw body length, h – width of the OCP, i – anterior-posterior cross-sectional width of the OCP, j – distance of trajectory from the jugular foramen, T – trajectory, HC – hypoglossal canal, OCP – occipital condyle pedicle

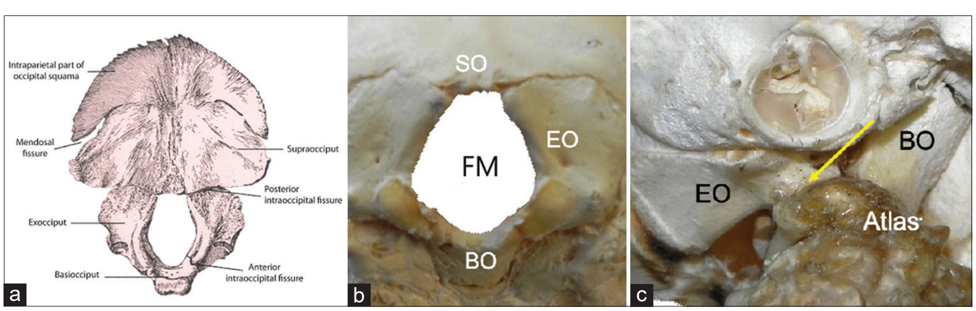

Figure 5: Embryology of the occipital bone. (a) The three occipital subdivisions: basiocciput, exocciput, and supraocciput. (b) A fetal foramen magnum. (c) A right-sided occipital condyle (yellow arrow). Bo – Basiocciput, EO – Exocciput, SO – Supraocciput

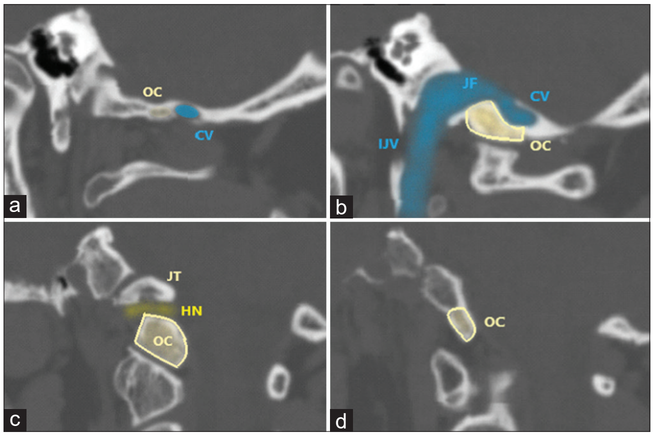

Figure 6: Reformatted thin-sectioned CT scan of the left occipital condyle. (a) section at the posterior tip of the occipital condyle, at the level of the occipital fossa, (b) section at the level of condylar vein branching off the internal jugular vein, (c) section at the level of the hypoglossal canal, (d) section at the most anterior tip of the occipital condyle. CV – condylar vein, OC – occipital vein, JT – jugular tubercle, HN – hypoglossal nerve, JF – jugular foramen, IJV – internal jugular vein, CT – Computed tomography

CONCLUSION

The modified occipital condyle screw connects the condyle with the clivus through the pars basilaris and represents a safe and technically feasible approach to achieve craniocervical fusion in skeletally mature individuals. This cephalad anchor point may potentially serve as an alternate fixation point of the occipitocervical junction with increased strength of construct and decreased risk of hardware failure or pseudarthrosis, given cortical bone purchase and longer screw for instrumentation.

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Conflicts of interest
There are no conflicts of interest.

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