Abstract

BACKGROUND CONTEXT: Occipital condyle screws appear to be a novel technique that demands biomechanical consideration. It has the potential to achieve fixation anterior to the axis of rotation while offering a point of fixation in line with the C1/C2 screws.

PURPOSE: To compare the segmental stability and range of motion (ROM) of standard occipitocervical (OC) screw/rod and plate constructs versus a new technique that incorporates occipital condyle fixation.

STUDY DESIGN: Human cadaveric biomechanical analysis.

METHODS: After intact analysis, 10 fresh-frozen human cadaveric OC spine specimens were instrumented bilaterally with C1 lateral mass screws and C2 pedicle screws. Additional occipital instrumentation was tested in random order under the following conditions: standard occipitocervical plate/rod system (Vertex Max; Medtronic, Inc., Minneapolis, MN, USA); occipital condyle screws alone; and occipital condyle screws with the addition of an eyelet screw placed into the occiput bilaterally. After nondestructive ROM testing, specimens were evaluated under computed tomography (CT) and underwent destructive forward flexion failure comparing Group 1 to Group 3.

RESULTS: There was no significant difference in OC (Occ–C1) axial rotation and flexion/extension ROM between the standard occipitocervical–C2 rod system (Group 1) and the occipital condyle screws with one eyelet screw bilaterally (Group 3). Furthermore, the occipital condyle screws alone (Group 2) did allow significantly more flexion/extension compared with Group 1. Interestingly, the two groups with occipital condyle screws (Groups 2 and 3) had significantly less lateral bending compared with Group 1. During CT analysis, the mean occipital condyle width was 10.8 mm (range, 9.1–12.7 mm) and the mean condylar length was 24.3 mm (range, 20.2–28.5). On destructive testing, there was no significant difference in forward flexion failure between Groups 1 and 3.

FDA device/drug status: none.

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* Corresponding author. Department of Orthopaedics and Rehabilitation, Walter Reed Army Medical Center, 1528 Blue Meadow Rd, Potomac, MD 20854, USA. Tel.: (202) 782-7817; fax: (202) 782-6845. E-mail address: armyspine@yahoo.com (R.A. Lehman)

Investigation performed at the Walter Reed Army Medical Center, Washington, DC, USA.

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CONCLUSIONS: With instrumentation across the mobile OC junction, our results indicate that similar stability can be achieved with occipital condyle screws/eyelet screws compared with the standard occipitocervical plate/rod system. © 2011 Elsevier Inc. All rights reserved.

Keywords: Occipitocervical; Occipital condyle; Keel plate; Instrumentation; Biomechanics

Introduction

The occipitocervical (OC) junction is the most mobile section of the cervical spine, with 50% of flexion and axial rotation occurring at the atlanto-occipital and atlantoaxial joints, respectively. The OC junction is stabilized only by capsuloligamentous structures and is thus prone to instability in a multitude of conditions to include infection, trauma, tumor, inflammatory conditions, and other degenerative conditions [1,2]. Treatment of OC instability is further complicated by the unique musculoskeletal, neurologic, and vascular anatomy, as well as the need to restrict motion in all three physiological planes [3].

Occipitocervical fusion was first described by Foerster in 1927. Initial fusion attempts included decortication and bone grafting, without internal fixation. This required prolonged external immobilization and often bed rest, with fusion achieved 75% to 90% of the time [2]. In the 1970s, the addition of supplemental wire fixation to onlay bone grafts improved stability. This was followed by contoured rods fixed with wires, but neither of these techniques were rigid enough and still required halo immobilization. As postoperative immobilization is not without risk, and is poorly tolerated by patients, the advent of plate/screw and rod/screw constructs provided immediate stability with fusion rates exceeding 95% and obviated the need for external fixation. Initial plate designs led to suboptimal lateral occipital screw placement, where the bone is thinner and screw purchase is weaker. Newer modular systems allow for more central occipital screw placement and improved fixation [4,5]. However, even with recent changes in fixation options, placement of screws into the midline occipital bone requires significant soft-tissue dissection and frequently results in prominent and symptomatic instrumentation. Additionally, unique oncologic cases or extensive OC decompressions occasionally necessitate creative fixation techniques.

To combat the disadvantages of occipital fixation and offer an additional fixation option, La Marca et al. [6] described a technique for the placement of occipital condyle screws in which the screws were placed rostral to the OC joint, but caudal to the hypoglossal canal (Fig. 1). Using morphometric analysis, they determined the starting point to be located 3 mm inferior to the condylar emissary vein foramen and angled 30° inferior and 10° medial to avoid the hypoglossal canal and jugular foramen, respectively. In their small study of six cadaveric specimens, they did not show any evidence of neurovascular violation with at least a 3-mm clearance between the screw heads and the vertebral artery. With the increased availability of three-dimensional navigation, surgeons are able to avoid these important neurovascular structures.

In our present study, we compared standard OC fixation with this recently described occipital condyle technique [6]. Occipital condyle screws have the potential advantage of avoiding the dramatic rod contouring necessary in standard techniques, providing an additional fixation point in line with the C1–C2 screws and less prominent hardware.

Materials and methods

Nondestructive testing

Ten fresh-frozen cadaveric specimens were obtained from the State of Maryland Anatomy Board (Baltimore, MD, USA). In preparation for the biomechanical testing, specimens were secured at the occiput proximally and C3 vertebral body distally using polyvinyl chloride containers and a polyester resin. Biomechanical analysis was performed using an MTS 858 Bionix Testing System configured with a custom-built six degree-of-freedom spine simulator (MTS Corporation, Minneapolis, MN, USA) allowing pure and unconstrained multidirectional load

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Fig. 1. Occipital condyle screw placement: Starting point—caudal to the condylar emissary vein foramen (appears as black circle marked by the black arrow) (condylar canal) and rostral to the occipital–C1 joint; Trajectory—30° caudal and 10° medial (demonstrated by the probe and red arrow). The vertebral artery as it courses along the cephalad aspect of the C1 dorsal arch is marked by the dashed black line. Deep to the vertebral artery is the occipital–C1 joint.
application (Fig. 2). Intersegmental motion evaluation included the use of specialized markers consisting of three non–colinear infrared light-emitting diodes. One marker was rigidly attached to the occiput and to each cervical level (C1 and C2) and oriented to permit detection by an optoelectronic motion analysis system (OptoTrak Certus; Northern Digital, Inc., Waterloo, Ontario, Canada). The intact OC spinal segments were nondestructively loaded in axial rotation (Y-axis, 1.5 Nm), flexion/extension (X-axis, 1.5 Nm), and lateral bending (Z-axis, 1.5 Nm). Each test was repeated for two loading and unloading cycles, with data from the second cycle used for computational analysis. For nondestructive multidirectional flexibility analysis, operative-level peak range of motion (ROM) for each loading mode was calculated as the sum of motions (maximum rotation for torsion, flexion/extension, and left+right bending [degrees]) observed in the neutral and elastic zones at the second loading cycle (ROM = neutral zone + elastic zone).

After intact analysis, all specimens were instrumented bilaterally with C1 lateral mass screws and C2 pedicle screws. Three different techniques of occipital fixation were tested in random order along with the C1/C2 fixation:

1. Standard occipitocervical plate/rod system (Fig. 3) (Vertex Max; Medtronic, Inc., Minneapolis, MN, USA);
2. occipital condyle screws alone;
3. occipital condyle screws with the addition of an eyelet screw placed into the occiput bilaterally (Fig. 4).

Computed tomographic analysis

After the multidirectional flexibility analysis, all specimens underwent thin-cut computed tomography (CT) scanning performed at 1-mm intervals (GE VCT 64 slice CT; GE Medical Systems, Milwaukee, WI, USA). This allowed for an accurate measurement of the condylar length and width. The position of the condylar screws in reference to the hypoglossal canal and the emissary vein foramen was also noted. Any ventral cortical screw violations were recorded.

Destructive testing

After CT analysis, specimens were prepared for destructive loading in the forward flexion plane. For failure testing, we compared the standard occipitocervical plate/rod system to the occipital condyle screws with eyelet screws (Groups 1 and 3). To ensure failure occurred at the occiput, and not distally at the C2 pedicle screws, the specimens were repotted with the polyester resin incorporating the C2 pedicle screws and distal rods. The distal container was then secured to a fixed platform, and the destructive moment applied to the occiput at a loading rate of 1/s. During each test, special care was taken to center the axis of rotation around the OC junction.

Results

Multidirectional flexibility testing

During ROM testing, all reconstructions significantly reduced OC ROM compared with intact specimens under all
Unlike flexion/extension and axial rotation, Group 1 (1.27°±0.53°) had significantly more lateral bending ROM (±Z-axis) than Group 2 (0.59°±0.42°) and Group 3 (0.33°±0.23°) (p=.038 and p=.025, respectively). Interestingly, after plate fixation, there was more lateral bending across Occ–C1 than flexion/extension, and both groups containing occipital condyle screw fixation had decreased lateral bending compared with occipital plate fixation. Furthermore, there was no significant difference in lateral bending with the addition of an eyelet (Group 3) compared with occipital condyle fixation alone (Group 2) (p=.648).

Computed tomographic analysis

During CT analysis, the mean occipital condyle width was 10.8 mm (range, 9.1–12.7 mm) and the mean condylar length was 24.3 mm (range, 20.2–28.5) for the 10 tested cadaveric specimens. The hypoglossal canal was not violated with any occipital condyle screws; however, 40% (8 of 20) of the condyle screws appear to be adjacent to or penetrating the ventral cortex, causing bicortical fixation.

Forward flexion failure

On destructive testing, there was no significant difference in forward flexion failure between Groups 1 and 3 (p=.348). The mean moment to failure was 30.3±6.1 Nm in Group 1 and 39.7±20.2 Nm in Group 3. With regard to the mechanism of failure, all specimens in Group 2 failed through the occipital and condylar screw pullout, whereas all plate failures in Group 1 occurred when bilateral rods disengaged from the plate via the locking set screw failure.

Discussion

At the OC junction, occipital condyle screws offer the potential advantages of decreased soft-tissue dissection, lower profile, and obviate the need for a sharp-angle contour of the rods [6]. While proposing this as a viable option for occipital fixation, La Marca et al. [6] did recommend that further biomechanical studies be performed before attempts at clinical application. Because of the obvious difficulty with skeletonizing the vertebral artery and placement of the occipital condyle screws, biomechanical validity must be supported before expanding the use of this relatively new fixation option into clinical application. Therefore, the purpose of this biomechanical study was to evaluate the ability of occipital condyle fixation to reduce motion across the OC junction.

When evaluating the OC junction, the primary plane of motion is flexion/extension. Our data indicate that occipital condyle screws alone do not decrease motion across the joint and occipital plate fixation. Although not the primary plane of motion at the OC junction, occipital condyle screws did significantly reduce lateral bending compared with plate fixation. There was no difference in motion...
between occipital plates (Group 1) and occipital condyle/eyelet screws (Group 3) in flexion/extension or axial rotation; however, Group 3 did have significantly less lateral bending. Additionally, there was no significant difference between Groups 1 and 3 with destructive forward flexion failure. The addition of a single eyelet screw has the potential advantage of avoiding the extensive soft-tissue disruption compared with an occipital plate but still requires a sharp bend in the rod, potentially serving as a weak point in the fixation.

Although no previous biomechanical studies have been performed evaluating occipital condyle fixation, Oda et al. [7] suggested occipital plate/rod fixation with C2 pedicle screws as the stiffest construct in flexion extension. The authors compared occipital plate/rod instrumentation to four other constructs, including a wiring technique, occipital screws with hooks/rods, occipital/foramen magnum screws, and C1/2 transarticular screws, and a Y-plate with two occipital screws and C1/C2 transarticular screws. The five different methods of instrumentation were evaluated before popularization of the Harms technique for instrumenting C1 and C2 with lateral mass screws and pedicle screws. The increased use of C1 lateral mass screws makes occipital condyle screws appealing given directly cephalad location and the ability to place a short rod to connect the screws.

Similar to Oda et al. [7], we found that the occipital plate/rod instrumentation technique performed the best under flexion extension. Interestingly, our data also suggest that the plate fixation is inferior to the occipital condyle construct in lateral bending. Although there have been no biomechanical studies on occipital condyle screws, one anatomic feasibility study has been recently published. Comparable to La Marca et al. [6], on CT analysis, we found the occipital condyle to be of sufficient size to accept a screw. Based on radiographic measurements, our mean occipital length and width was 24.3 and 9.9 mm, respectively, compared with 24.2 and 9.3 mm, respectively that was reported previously [6].

A limitation of our study is that it is a cadaveric, in vitro design, which does not truly reflect clinical application. However, this type of design is necessary to adequately test and validate the biomechanical principles of the various constructs. Although we do provide radiographic and computed tomographic data to support the occipital condyle as an osseous structure large enough to support fixation, surgeons must maintain a thorough understanding of the anatomy and morphometry of the occiput to safely place these screws clinically. Additional neurovascular structures remain a concern, including the vertebral artery, which should be carefully assessed before considering in vivo use. A thorough understanding of the unique anatomy is paramount if considering clinical use, and, therefore, consideration of preoperative CT imaging (with sagittal/coronal reconstructions) is warranted. A potential technical weakness of our study is the placement of eight screws bicortically. Although the screws did not appear to be through the ventral cortex enough to cause significant concern to adjacent structures, they would have the potential to affect the biomechanical evaluation. The use of navigation systems may allow surgeons to place screws near the ventral cortex clinically, but the tendency would likely be to place screws well short of the cortex. Obtaining purchase of the ventral cortex would provide the screw with increased strength of fixation; it likely is not necessary to obtain a biomechanically stable construct.

In conclusion, with instrumentation across the mobile OC junction, our results indicate that similar stability can be achieved with occipital condyle screws/eyelet screws compared with a standard occipitocervical rod/plate instrumentation technique performed the best un-
system. The occipital condyle screw constructs have the potential for decreased dissection and prominence postoperatively while offering similar biomechanical stability. The results of this study suggest that with similar biomechanical stability to the occipital plating systems, the use of occipital condyle screws and an eyelet could be considered in the surgeons’ decision-making process.

References

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