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The cervical end of an occipitocervical fusion: a biomechanical evaluation of 3 constructs

Laboratory investigation

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Object. Stabilization with rigid screw/rod fixation is the treatment of choice for craniocervical disorders requiring operative stabilization. The authors compare the relative immediate stiffness for occipital plate fixation in concordance with transarticular screw fixation (TASF), C-1 lateral mass and C-2 pars screw (C1L-C2P), and C-1 lateral mass and C-2 laminar screw (C1L-C2L) constructs, with and without a cross-link.

Methods. Ten intact human cadaveric spines (Oc–C4) were prepared and mounted in a 7-axis spine simulator. Each specimen was precycled and then tested in the intact state for flexion/extension, lateral bending, and axial rotation. Motion was tracked using the OptoTRAK 3D tracking system. The specimens were then destabilized and instrumented with an occipital plate and TASF. The spine was tested with and without the addition of a cross-link. The C1L-C2P and C1L-C2L constructs were similarly tested.

Results. All constructs demonstrated a significant increase in stiffness after instrumentation. The C1L-C2P construct was equivalent to the TASF in all moments. The C1L-C2L was significantly weaker than the C1L-C2P construct in all moments and significantly weaker than the TASF in lateral bending. The addition of a cross-link made no difference in the stiffness of any construct.

Conclusions. All constructs provide significant immediate stability in the destabilized occipitocervical junction. Although the C1L-C2P construct performed best overall, the TASF was similar, and either one can be recommended. Decreased stiffness of the C1L-C2L construct might affect the success of clinical fusion. This construct should be reserved for cases in which anatomy precludes the use of the other two.

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Key Words • Harms technique • occipitocervical stabilization • transarticular screw • translaminar screw

Craniocervical instability can be caused by various pathological conditions, including trauma, inflammatory arthropathies, neoplasms, infectious disease, or congenital anomalies, and can result in severe pain or neural damage. When instability is recognized, an effective means of reduction and stabilization is needed to decompress neural elements and eliminate instability.

Surgical stabilization of the occipitocervical junction has been difficult because of the unique anatomy and dynamics of the region. More than 50% of flexion/extension and rotation of the head and neck occurs over the Oc–C2 region,[38] making the achievement of immobility difficult. The angle between the occiput and the spine, which is 50–70°, additionally acts as a lever arm, the force of which must be resisted by any applied construct.

Significant advancement has been made in the methods of craniocervical stabilization since the first attempts were reported by Foerster[9] in 1927. Early onlay techniques sequentially gave way to bone wiring,[5,13,18] rod wiring,[24,25,34] and eventually screw-based rigid segmental techniques.[33,36] Each step along the course of evolution of these constructs has increased biomechanical stability, resulting in higher fusion rates and decreased reliance on rigid external orthoses, and has allowed for the fixation of fewer segments.[1,7,17,26,28,31,35]

Recent clinical and biomechanical reports on the use of screw fixation of the craniocervical junction have examined either TASF or C1L-C2P or pedicle screw fixation as a means of securing the first 2 cervical vertebrae.[11,27] Although these methods have shown biomechanical equivalence in craniocervical fixation,[31] their application is technically demanding and their use may be precluded by

Abbreviations used in this paper: C1L-C2L = C-1 lateral mass and C-2 laminar screw; C1L-C2P = C1L and C-2 pars screw; ROM = range of motion; TASF = transarticular screw fixation; VA = vertebral artery; VB = vertebral body.

anatomical variations, especially with regard to the location of the VA.[2,30,32]

Another technique of atlantoaxial fixation has recently been described in which screws placed in the lamina of C-2 are attached to C-1 lateral mass screws.[39] The technique is easy to use, because all critical structures at risk can be visualized during surgery, and it avoids risk to the VA. It has additionally been demonstrated to have biomechanical equivalence or near equivalence to TASF and C1L-C2P constructs[10,21] but has yet to be biomechanically tested in occipitocervical constructs. Additionally, the use of cross-links has been demonstrated to enhance biomechanical rigidity in segmental pedicle screw constructs in the thoracic and lumbar spine,[3,15] but there have been no biomechanical reports on their effect in occipitocervical constructs. The purpose of this study is to compare these 3 methods of occipitocervical stabilization in the human cadaveric spine and analyze the contribution of cross-links to each of these constructs.

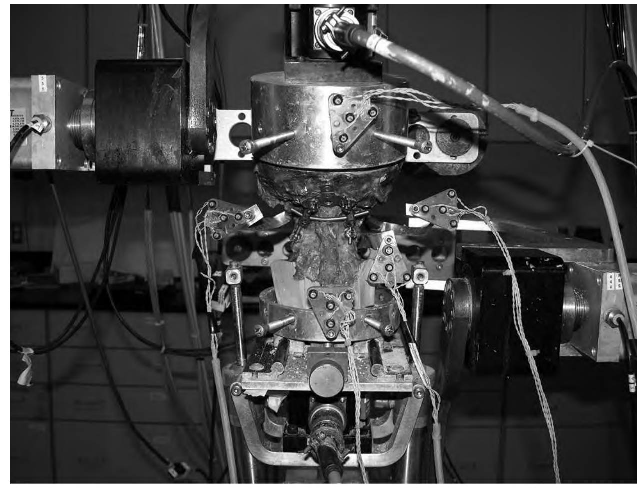

FIG. 1. Photograph of a cadaveric specimen placed in the 7-axis spine simulator. This specimen is instrumented with a C1L-C2P construct with cross-link.

Methods

Cadaveric Specimens

Ten human cadaveric spine specimens (Oc–C4) were used in the study. Each specimen was removed from a cadaver < 65 years old and was screened visually and with anterior–posterior and lateral radiographs to exclude signs of neoplasm, trauma, severe degeneration, or other factors that could affect the mechanical properties. Additionally, dual x-ray absorptiometry scanning (General Electric Medical Systems) was performed on each specimen, and those with bone densities > 1 standard deviation below the pool of specimens were eliminated.

The specimens were kept frozen at −20°C in sealed plastic bags and were thawed in a refrigeration system for 12 hours prior to testing. On the day of testing, the specimens were prepared by removing all remaining skin and most of the paraspinal cervical musculature; care was taken to keep all ligaments, joint capsules, osseous components, and intervertebral discs intact. To supplement the potting fixation, 3 drywall screws were inserted into the occiput and radially into the VB and lateral masses of C-4 of each specimen. The occiput and the C-4 VB were then placed into 4-cm-deep polyvinyl chloride potting fixtures and were embedded in the middle of the vertebra in a 2-part filler compound (Bondo Body Filler, Bondo Corp.).

Biomechanical Testing

Specimens were tested in the 7-axis spine simulator with infrared-emitting diodes screwed into the anterior arch of C-1 and the VBs of C-2 and C-3 to monitor angular motion between these vertebrae (Fig. 1). Infrared-emitting diodes were additionally secured to the pots to record motion at the occiput and C-4. All specimens were initially tested in the intact condition in load control with applied moments of 1.5 Nm in each respective plane of motion. Before any data were recorded, each spine was preconditioned with 30 cycles in each plane of motion. A second trial of 5 cycles in each axis was then used, with data recorded on the fourth and fifth cycles to determine the ROM of segments Oc–C4. Motion was tracked using the OptoTRAK 3D (Northern Digital) tracking system. The specimen was then removed from the machine for destabilization and instrumentation.

The specimen was destabilized by transecting the outer Oc-C1 joint capsule, posterior atlantooccipital membrane, tectorial membrane, apical ligament, and alar ligament and creating a cut across the base of the odontoid. A DePuy Mountaineer (DePuy Spine, Inc.) occipital plate was secured to the occiput with 2 (4.5 × 10–mm) screws in a standard midline position inferior to the superior nuchal line. Each specimen then received instrumentation under fluoroscopic guidance. A 2.8-mm drill was used to create tracks for each screw trajectory under fluoroscopic guidance: the C1–2 transarticular screws, the C-1 lateral mass screws, and the C-2 laminar screws, as described elsewhere.[12,14,39] A 3.5-mm polyaxial transarticular screw was then placed to achieve bicortical purchase of C-1. Rods of 3.5-mm diameter were then bent to connect to the occipital plate, and the construct was secured with set screws (TASF construct). A cross-link consisting of a 3.5-mm rod and 2 caps was placed between the 2 rods. The specimen was then placed back in the spine machine for testing (Fig. 1).

For instrumented tests, the spine simulator was placed in load control and tested under a 1.5-Nm force in each plane as we have outlined. The parameters for the ROM of Oc–C4 from the initial instrumented test were recorded and used to test the remaining specimens under position control. Each was subjected to 5 cycles in each axis of motion. Data were collected on the fourth and fifth cycles of each axis.

After the TASF construct with cross-link was tested, the cross-link was removed and testing was repeated as we have described. The TASF screws were then removed and 3.5-mm-diameter C-1 lateral mass screws were placed to achieve bicortical purchase along with 4 × 14–mm C-2 pars screws placed in the same trajectory as the C1–2 transarticular screws. Testing was conducted as described earlier with and without cross-link. For the final construct, the C-2 pars screws were removed and 3.5 × 20–mm laminar screws were placed. Testing was again performed with and without cross-links.

Data Collection and Statistical Analysis

Torque data from the 7-axis spine simulator and rotation data from the OptoTRAK were recorded, processed, and analyzed on a personal computer with a National Instruments AT-MIO-64E-3 board and LabView Software (both from National Instruments) that generated torque-rotation plots. Stiffness was determined from the LabView graphs by measuring the linear slope of the elastic zone from the torque-rotation plots. All data were analyzed using the Student t-test, with probability values < 0.05 considered statistically significant. Data were reported as percentage of intact, with intact being 100%. Comparisons between constructs include each construct with the cross-link in place for uniformity.

Results

The intact specimens had an average stiffness of 0.80, 0.97, and 0.11 Nm/° in flexion/extension, lateral bending, and rotation, respectively. All constructs demonstrated significantly increased stiffness when compared with intact specimens in all moments. In flexion/extension, the TASF construct demonstrated the greatest stiffness (5.98 ± 5.80 Nm/°) but with large variability (range 2.62–20.41 Nm/°; Fig. 2). The C1L-C2P and C1L-C2L constructs were less stiff (3.68 ± 2.04 Nm/° and 2.37 ± 1.52 Nm/°, respectively), although the difference between these and the TASF construct did not reach significance ($p = 0.263$ and $p = 0.099$, respectively). The C1L-C2P construct was, however, significantly stiffer than the C1L-C2L construct in flexion and extension ($p = 0.013$). That a significant difference was detected between the C1L-C2P and C1L-C2L constructs, whereas the TASF construct had higher average values for stiffness but no significant difference, is attributable to the larger degree variance between samples instrumented with the TASF construct.

In lateral bending, the TASF construct again demonstrated the greatest degree of stiffness (6.42 ± 2.33 Nm/°; Fig. 3). This was significantly greater than the C1L-C2L construct (1.90 ± 0.79 Nm/°; $p < 0.001$) but was not significantly different when compared with the C1L-C2P construct (4.73 ± 1.33 Nm/°; $p = 0.111$). The stiffness difference between the C1L-C2L and C1L-C2P constructs in lateral bending was significant ($p < 0.001$).

In axial rotation, the C1L-C2P construct demonstrated significantly greater stiffness (1.51 ± 0.98 Nm/°) than the C1L-C2L construct (0.85 ± 0.60 Nm/°; $p = 0.011$) and equivalence to the TASF construct (1.27 ± 0.57 Nm/°; $p = 0.33$; Fig. 4). The difference between the TASF and C1L-C2L did not reach significance ($p = 0.107$). The addition of a cross-link did not significantly alter the stiffness or the allowed ROM in any construct in any moment.

Discussion

Surgical stabilization of the craniocervical junction has been fraught with difficulty because of the complex anatomical relationships and unique dynamics of the region. The evolution of stabilization constructs has allowed for rigid segmental fixation of unstable elements, with high fusion rates and a reduced need for rigid external orthoses. These newer constructs, however, are technically demanding and not universally applicable because of individual anatomical variations.[2,30,32] The use of C-2 laminar screws in conjunction with C-1 lateral mass screws has recently been described as an atlantoaxial fixation construct and has the benefit of ease of use with reduced risk of VA injury.[39] This construct has been demonstrated to be of similar biomechanical strength to other screw-based constructs in atlantoaxial stabilization,[10,21] but studies examining the use of this technique as part of an occipitocervical construct are lacking.

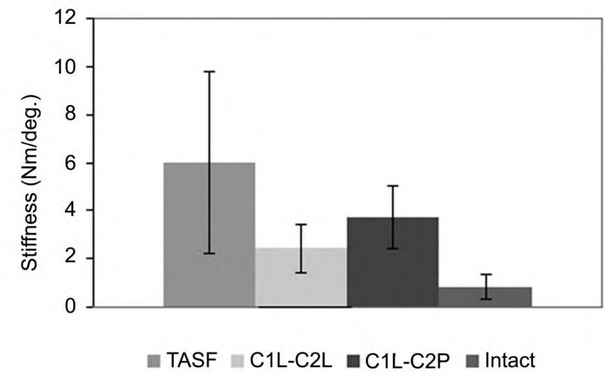

FIG. 2. Bar graph showing stiffness of intact spines and constructs in flexion/extension. deg. = degree.

Prior biomechanical studies of the occipitocervical instrumentation have demonstrated the advantage of rigid screw-based segmental constructs when compared with nonrigid wire and rod or wire and bone constructs.[6,7,17,28,31,35] These studies demonstrate that, although subtle differences in stability may exist when alternative methods of occipital or atlantoaxial fixation are used, screw-based constructs offer the greatest degree of stability and may reduce or eliminate the need for supplemental external orthosis. Clinical studies corroborate laboratory findings that greater fusion rates are obtained with screw-based techniques.[22,27,37] Although the new C1L-C2L technique is a rigid segmental construct, its use in occipitocervical stabilization may be compromised by the need to use a rod with a more acute bend than the other devices. Such a bend may weaken the rod, especially after repeated stresses are applied. The importance of the rod strength has been demonstrated by Anderson et al.,[1] who showed that stability correlates with the area moment of inertia of the rod. Demonstration of equivalency of this technique is therefore needed before its use can be recommended interchangeably.

Our data indicate that the C1L-C2P construct was equivalent to the TASF in all moments tested. The C1L-C2L was significantly weaker than the C1L-C2P in all moments and significantly weaker than the TASF in lateral bending. Close examination of the data reveals a nonsignificant trend toward greater stiffness of the TASF compared with the C1L-C2P construct in flexion/extension and lateral bending. A small sample size and greater degree of variability may have precluded the detection of a difference between these groups. The relative weakness of the laminar screw construct in this study is somewhat surprising given its demonstration of equivalence[4,16] or near equivalence[21]

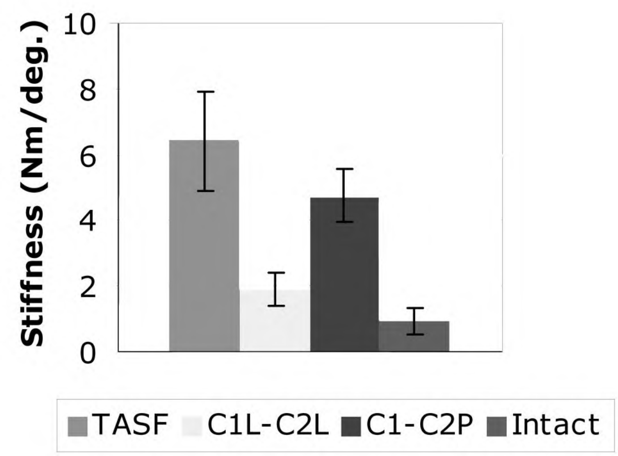

FIG. 3. Bar graph showing stiffness of intact spines and constructs in lateral bending.

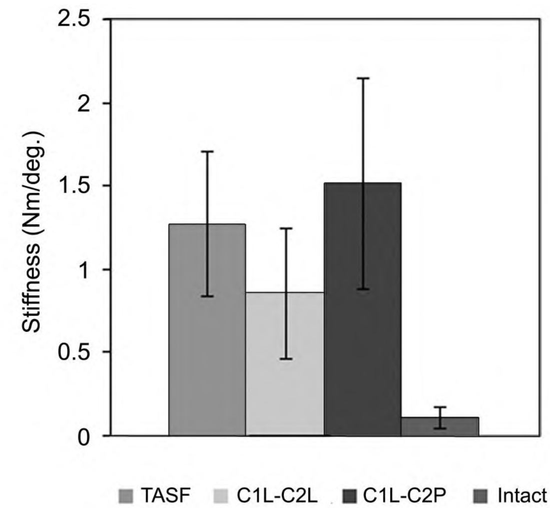

FIG. 4. Bar graph showing stiffness of intact spines and constructs in axial rotation.

to the other 2 constructs in studies of atlantoaxial fixation alone.[10,21] It is possible that the relatively acute, U-shaped bend of the rod that is needed to attach the screws to the occipital plate with this construct reduces some of the mechanical stability, because the rod may be more compressible in this configuration. Because titanium is notch sensitive, the acute bend needed to connect the fixation points may weaken this construct. In any case, all constructs offered a significant increase in stiffness over intact specimens, and it is not known whether these differences might lead to different clinical outcomes. It is also possible that pars screws and transarticular screws, which are directed ventrally toward the body of C-2, may produce a biomechanical advantage with a greater lever arm than translaminar screws, which remain only within that lamina in a dorsal position.

It is also noteworthy that the use of translaminar screws reduced the amount of bone on the dorsal surface of the C-2 lamina that was available for fusion material. The clinical relevance of this has not yet been borne out in studies, but the combination of this factor with reduced rigidity makes it the least appealing of these 3 options.

The addition of a cross-link did not affect stiffness to a significant degree in any construct in any moment tested. It has previously been shown that cross-links increase torsional stability in pedicle screw constructs[2,3] and increase the rigidity of nonsegmental pedicle screw constructs if placed over "skip" areas where no screws have been placed.[15] It is likely that no difference was shown in our study because all constructs were short and segmental. Although not tested here, cross-links may be of value in occipitocervical constructs that are long and that skip levels.

There are several limitations of the current study. First, only immediate stability was tested and no construct was tested to failure. Thus, no conclusions can be drawn about any construct's ability to withstand repeated loads.[29] Additionally, all specimens were tested in the same order, with TASF being tested first, followed by C1L-C2P, and then by C1L-C2L. This was done because of the difficulty of securing accurate transarticular screw placement while the spine was placed in the simulator and to avoid the need to remove and replace the spines in the simulator more than necessary. This constant sequence might introduce some bias, because the final specimens may be subject to damage from the prior tests, with a resultant loss of stability. Fatigue protocols, however, generally involve the application of much greater forces over several hundred cycles,[19] or similar, nondestructive forces over thousands of cycles.[17,20]

Along these lines, a test comparing TASF and C1L-C2P constructs revealed no change in stability after 5000 cycles of 1-Nm cyclic testing. It is therefore unlikely that 5 cycles in each moment would significantly weaken each specimen with sequential testing.[20] Additionally, greater variability in the TASF construct was noted than in the other constructs, a factor that made statistical significance difficult to reach. For example, although this construct had the highest average stiffness in flexion/extension and lateral bending, a significant difference between this and the C1L-C2P construct was not reached. A significant difference may have been extracted with further testing of more specimens. Finally, testing of a C-2 pedicle screw construct would have been interesting because these screws have greater anterior purchase of the C-2 vertebrae than do C-2 pars screws. Testing of this construct, however, was prohibited by the limited number of screw trajectories that could be undertaken in a single specimen. With a different trajectory and insertion point, C-2 pedicle screw placement after a transarticular or pars screw (or vice versa) would run an even greater risk of significantly weakening the screw–bone interface and biasing the data.[8]

Conclusions

All 3 constructs applied in the destabilized spine demonstrated a significant increase in stability over intact specimens. The TASF and C1L-C2P constructs demonstrated the greatest stability, with the C1L-C2P being slightly stiffer in axial rotation. These constructs can be recommended for interchangeable use, depending on surgeon preference and patient anatomy. The C1L-C2L construct was weaker than the others. Although it is difficult to say whether this difference would result in clinically different outcomes, we recommend that the use of this construct be reserved for situations in which the others are precluded.

Disclaimer

The authors do not report any conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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