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Biomechanical Evaluation of Segmental Occipitoatlantoaxial Stabilization Techniques

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Study Design. Biomechanical study using human cadaveric cervical spines.

Objective. To evaluate the construct stability of 3 different segmental occipitoatlantoaxial (C0–C1–C2) stabilization techniques.

Summary of Background Data. Different C0–C1–C2 stabilization techniques are used for unstable conditions in the upper cervical spine, all with different degrees of risk to the vertebral artery. Techniques with similar stability but less risk to the vertebral artery may be advantageous.

Methods. Six human cadaveric cervical spines (C0–C5) (age: 74 ± 5.0 years) were used. After testing the intact spines, instability was created by transecting the transverse and alar ligaments. The spines were instrumented from the occiput to C2 using 3 different techniques which varied in their attachment to C2. All spines had 6 screws placed into the occiput along with lateral mass screws at C1. The 3 variations used in attachment to C2 were (1) C2 crossing laminar screws, (2) C2 pedicle screws, and (3) C1–C2 transarticular screws. The C1 lateral mass screws were removed before placement of the C1–C2 transarticular screws. Range of motion across C0–C2 was measured for each construct. The data were analyzed using repeated measures ANOVA. The following *post hoc* comparisons were made: (1) intact spine *versus* each of the 3 techniques, (2) laminar screw technique *versus* the pedicle screw technique, and (3) laminar screw technique *versus* the transarticular screw technique. The level of significance was $\alpha = 0.01$ (after Bonferroni correction for 5 comparisons).

Results. All 3 stabilization techniques significantly decreased range of motion across C0–C2 compared to the intact spine ($P < 0.01$). There was no statistical difference among the 3 stabilization methods in flexion/extension and axial rotation. In lateral bending, the technique using C2 crossing laminar screws demonstrated a trend toward increased range of motion compared to the other 2 techniques. CT scans in both axial and sagittal views demonstrated greater proximity to the vertebral artery in the pedicle and transarticular screw techniques compared to the crossing laminar screw technique.

Conclusion. Occipitoatlantoaxial stabilization techniques using C2 crossing laminar screws, C2 pedicles screws, and C1–C2 transarticular screws offer similar biomechanical stability. Using the C2 crossing laminar screw technique may offer an advantage over the other techniques due to the reduction of the risk to the vertebral artery during C2 screw placement.

Key words: cervical spine, C0–C1–C2 fusion, stability. **Spine 2009;34:2740–2744**

Many different conditions require stabilization of the occipitocervical junction. These conditions include trauma, congenital anomalies, neoplasm, infection, and inflammatory diseases. Different occipitoatlantoaxial (C0–C1–C2) stabilization techniques are used for these conditions, each of which has a different degree of mechanical stability and risk of vertebral artery injury.[1] Previous studies have shown that nonsegmental stabilization procedures such as wire-bone plate techniques as well as rod-loop constructs can be successful in obtaining a solid arthrodesis for these conditions.[2] However, these techniques have been shown to be inferior to procedures that offer segmental fixation (with regards to biomechanical stability).[3,4]

Currently, rod and screw fixation procedures have become readily available.[5,6] These techniques use a variety of C2 fixation possibilities along with C1 lateral mass screws; or C1–C2 transarticular screws that are then incorporated into occipitocervical segmental fixation points using occipital screws.[7] However, both of these techniques have known risks to the vertebral artery.[1,8] Techniques with less risk and similar stability may offer an advantage for this type of fixation. Recently, C2 crossing laminar screws have been used in upper cervical spine fusions, as these theoretically pose less risk to the vertebral artery.[9]

The purpose of this study was to evaluate the 3-dimensional stability of 3 different segmental C0–C1–C2 stabilization techniques. These techniques include occipital screws with (1) segmental C1 lateral mass screws with C2 crossing laminar screws; (2) segmental C1 lateral mass screws and C2 pedicle screws; and (3) C1–C2 transarticular screws.

Materials and Methods

Specimens and Experimental Set-up

Six fresh-frozen cadaveric specimens consisting of the occiput (C0) through C5 were used in this study (age: 74 ± 5.0 years, 4 males, 2 females). Lateral radiographs were taken of all speci-

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mens to ensure no radiographic evidence of a pathologic process was present between C0–C2. The spines were stored at −20°C until the day before testing. The specimens were thawed to room temperature and prepared for test by cleaning off all musculature but preserving all ligaments and joint capsules.

Crossing pins were placed through a metal fixture and drilled through C5. In addition, multiple screws were placed in C3. Polymethylmethacrylate was used to pot the specimen up to C3. A platform was then fixed to the occiput with screws. At the time of specimen mounting, the anterior wall of C3 was inclined anteriorly 20° with the base of the occiput horizontal to simulate as upright posture.[10,11]

The specimen was mounted on a 6-component load cell (Model MC3A-6–250, AMTI multicomponent transducers, AMTI Inc, Watertown, MA) at the caudal end and was free to move in any plane at the proximal end. A moment was applied by controlling the flow of water into bags attached to loading arms fixed to the occiput. The apparatus allowed for continuous cycling of the specimen between ±1.5 Nm moment endpoints in flexion/extension, lateral bending, and axial rotation.

Flexion and extension moment arms were 60 cm each. The loading arm was centered over the vertebral bodies of the specimen in the lateral view, such that the neutral posture of the specimen (with 0 Nm applied moment) corresponded to the upright posture of the cervical spine. Because of the short length of the cervical segment (C0–C3) in comparison to the long (60 cm) moment arm, the variation in the applied moment between C0 and C3 was estimated to be less than 4%. The variation was even smaller once the C0–C2 segment was instrumented.

The motions of the C0 and C2 vertebrae relative to the fixed coordinate system were measured using an optoelectronic motion measurement system and infrared targets mounted on C0 and C2 (Optotrak, Northern Digital Inc, Waterloo, Ontario, Canada). In addition, biaxial angle sensors (model 902–45; Applied Geomechanics, Santa Cruz, CA) were mounted on C0 and C2 to allow real-time feedback during testing in flexion/extension and lateral bending. Fluoroscopic imaging (GE OEC 9800 Plus digital fluoroscopy machine) was used during flexion and extension. Sequential digital videofluoroscopic images were obtained over the full range of flexion/extension motion.

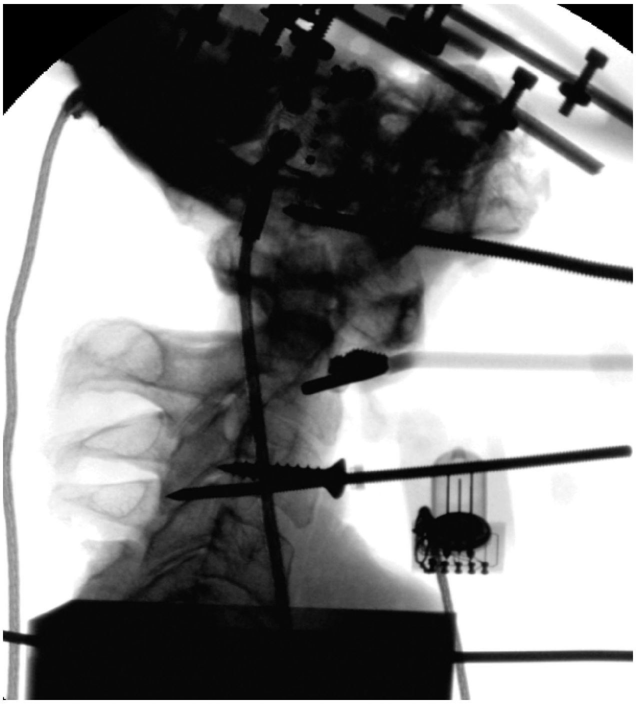

Figure 1. Radiograph showing surgical destabilization by transecting the transverse and alar ligaments. Note anterior subluxation of C1 on C2.

Experimental Protocol

Each specimen was subjected to flexion/extension, lateral bending, and torsional moments in random order. The moments used ranged within ±1.5 Nm for all loading directions and are within the range of moments used in previous biomechanical studies of human cervical spine segments. The load-displacement data were acquired until 2 reproducible load-displacement loops were obtained.

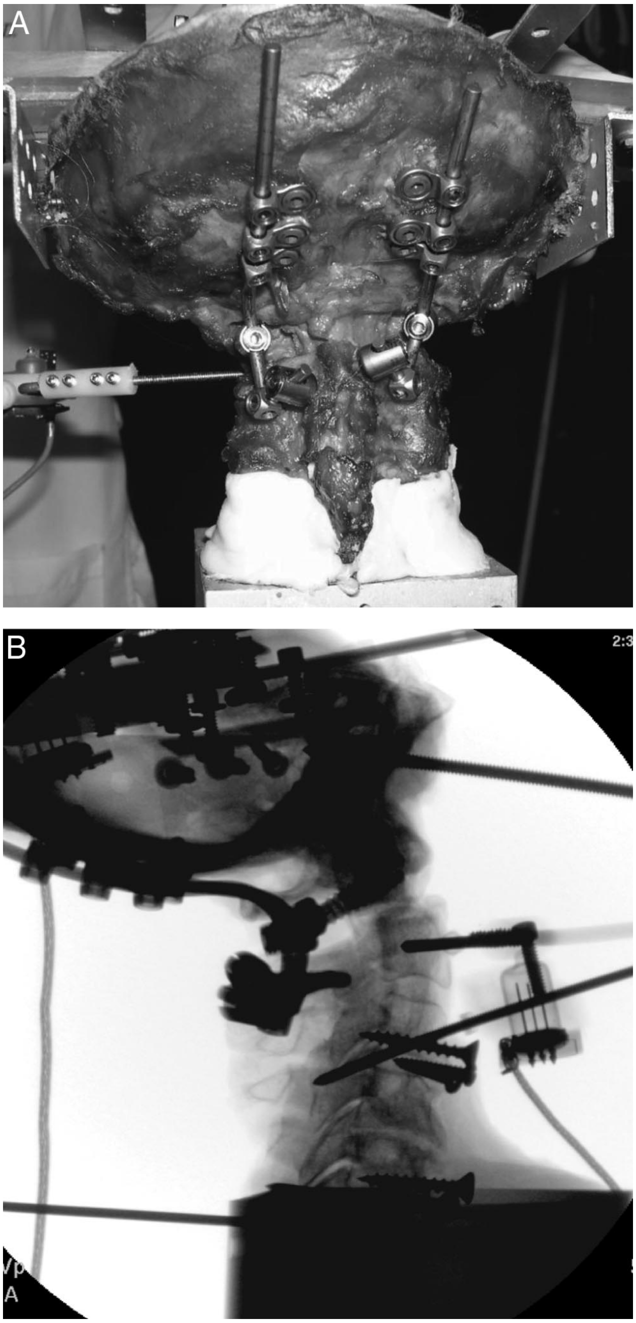

Figure 2. Laminar screw technique using C2 crossing laminar screws. **A,** Photograph, (**B**) x-ray.

After testing the intact spine, instability was created by transecting the transverse and alar ligaments. Instability was confirmed by direct visualization as well as under fluoroscopy, noting anterior subluxation of C1 on C2 (Figure 1).

The techniques with pedicle screws and crossing laminar screws were randomized and always performed in each specimen before the C1–C2 transarticular screw technique because the latter technique destroys the C1–C2 facet joints. The spines were instrumented segmentally from the occiput to C2 using 3 different techniques All spines had 6 unicortical screws placed into the occiput, and 3.5 mm C1 lateral mass screws as described by Harms *et al.*[5] The 3 variations used in C2 were (1) 3.5-mm C2 crossing laminar screws (laminar screw technique) as described by Wright[9] (Figure 2), (2) 3.5-mm C2 pedicle screws (pedicle screw technique) as described by Harms *et al*[5] (Figure 3), and (3) 4.0-mm C1–C2 transarticular screws (transarticular screw technique) as described by Magerl and Seemann[12] (Figure 4). The C1 lateral mass screws were removed before placement of the C1–C2 transarticular screws. All screws and rods were from the Vertex Reconstruction system (Medtronic, Memphis, TN).

Each construct was tested in flexion/extension, lateral bending, and axial rotation as described previously. Computed tomography scans were obtained on all 3 techniques to confirm proper screw placement relative to the bony anatomy and proximity to the vertebral artery.

Data Analysis

The load-displacement data were analyzed to obtain the angular range of motion (ROM) across C0–C2 in flexion/extension, lateral bending, and axial rotation. The statistical analysis was performed using repeated-measures analysis of variance (ANOVA, Systat Software Inc, Richmond, CA) with 4 levels of treatment (intact, laminar screw, pedicle screw, and transarticular screw). *Post hoc* tests performed were indicated by ANOVA results using Bonferroni correction for multiple comparisons. The following *post hoc* comparisons were made: (1) intact spine *versus* each of the 3 techniques, (2) laminar screw technique *versus* the pedicle screw technique, and (3) laminar screw technique *versus* the transarticular screw technique. The level of significance was $\alpha = 0.01$ (after Bonferroni correction for 5 comparisons). This was done separately for flexion/extension, lateral bending, and axial rotation because no comparisons across the 3 load types were intended.

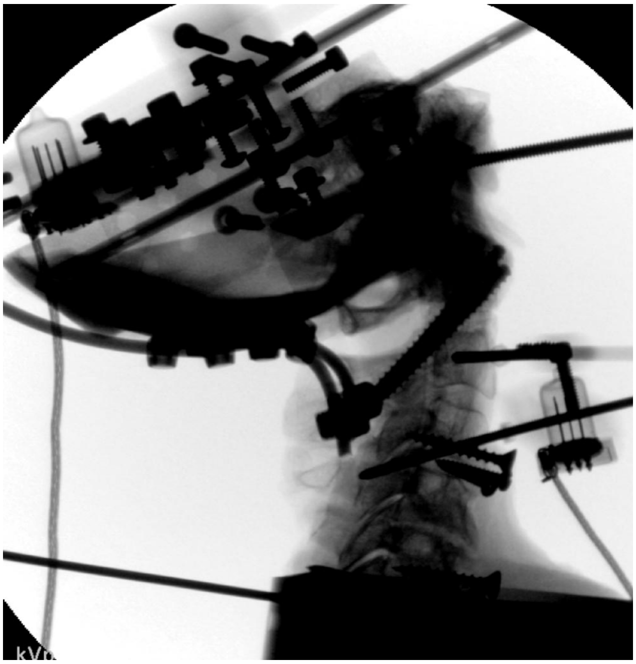

Figure 4. X-ray showing transarticular screw technique using C1–C2 transarticular screws.

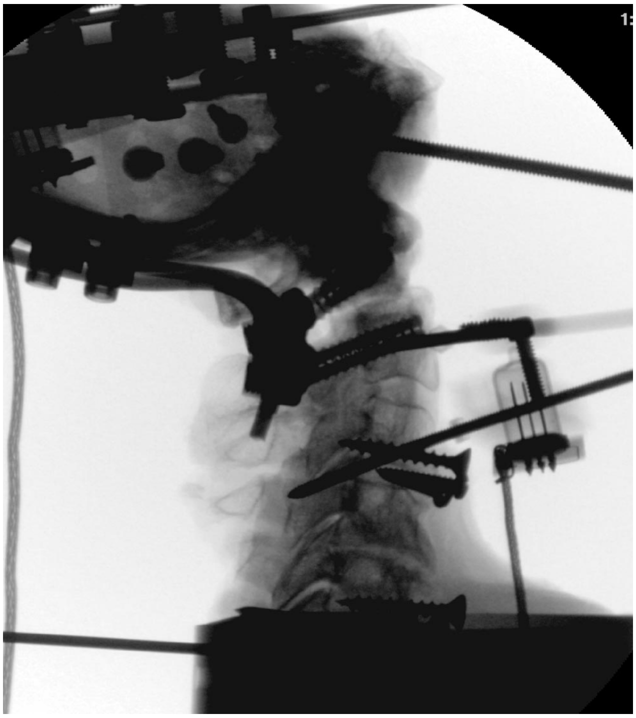

Figure 3. X-ray showing pedicle screw technique using C2 pedicle screws.

■ Results

The flexion/extension ROM across C0–C2 was 45.1° ± 11.4° in the intact spine. All 3 stabilization techniques significantly reduced ROM across C0–C2 as compared to intact ($P < 0.01$) (Table 1). The ROM reduced to 6.4° ±

Table 1. Range of Motion (°) Across C0–C2 Segments

Loading Mode	Intact	Laminar	Pedicle Screw	Transarticular
Flexion/extension	45.1 ± 11.4	6.4 ± 2.9*	4.6 ± 3.0*	4.1 ± 3.1*
Relative to intact		$P < 0.001$	$P < 0.001$	$P < 0.001$
Relative to laminar			$P = 0.104$	$P = 0.079$
Lateral bending	11.6 ± 5.6	1.5 ± 1.6*	1.0 ± 0.7*	1.0 ± 1.0*
Relative to intact		$P = 0.008$	$P = 0.002$	$P = 0.002$
Relative to laminar			$P = 0.011$	$P = 0.013$
Axial rotation	65.8 ± 18.1	3.5 ± 1.9*	1.6 ± 0.5*	2.5 ± 1.2*
Relative to intact		$P < 0.001$	$P < 0.001$	$P < 0.001$
Relative to laminar			$P = 0.030$	$P = 0.102$

Mean ± SD values are shown.
*Significantly smaller value than intact ($\alpha = 0.01$ after Bonferroni correction for 5 comparisons).

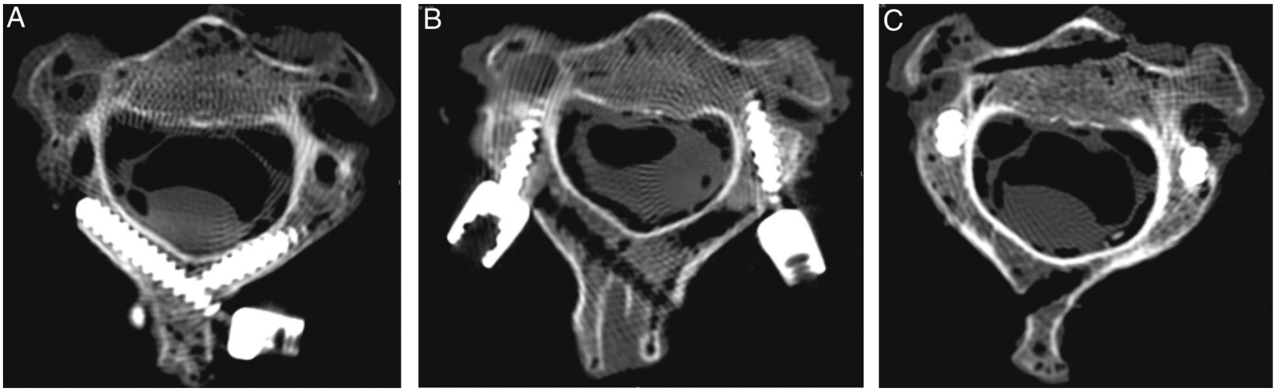

Figure 5. CT scans demonstrating proximity of C2 screws to the vertebral artery. **A,** Laminar screw technique, (**B**) pedicle screw technique, (**C**) transarticular screw technique.

2.9° for the laminar screw technique, 4.6° ± 3.0° for the pedicle screw technique, and 4.1° ± 3.1° for the transarticular screw technique. There was no statistically significant difference among the 3 stabilization methods ($P > 0.01$).

In lateral bending, ROM across C0–C2 was 11.6° ± 5.6° in the intact spine. All 3 stabilization techniques significantly reduced ROM across C0–C2 as compared to intact ($P < 0.01$), the ROM reduced to 1.5° ± 1.6° for the laminar screw technique, 1.0° ± 0.7° for the pedicle screw technique, and 1.0° ± 1.0° for the transarticular screw technique (Table 1). There was a strong trend for the stabilization with the laminar screw technique to yield larger lateral bending motion than that achieved with the pedicle screw technique ($P = 0.011$) and the transarticular technique ($P = 0.013$).

In axial rotation, ROM across C0–C2 was 65.8° ± 18.1° in the intact spine. All 3 stabilization techniques significantly reduced ROM across C0–C2 as compared to intact ($P < 0.01$) (Table 1). The ROM reduced to 3.5° ± 1.9° for the laminar screw technique, 1.6° ± 0.5° for the pedicle screw technique, and 2.5° ± 1.2° for the transarticular screw technique. There was no statistically significant difference among the 3 stabilization methods ($P > 0.01$).

CT scans in both axial and sagittal views demonstrated proper screw placement in all cases and, as expected, greater proximity to the vertebral artery in the transarticular and pedicle screw techniques compared to the crossing laminar screw technique (Figure 5).

■ Discussion

Many fixation techniques have been described to stabilize the occipitocervical junction. Among these are wire-bone plate technique described by Wertheim and Bohlman, rod-loop constructs, and screw-plate techniques.[2,13,14] Because of the need for further immobilization with a halo-vest after these fixation techniques,[2] others were developed to obviate the need for further external immobilization.

Magerl and Seemann originally described the C1–C2 transarticular screw fixation, which was subsequently used by Grob *et al* in conjunction with a plate fixed to the occiput.[7,12] Harms and Melcher later described the technique using C1 lateral mass screws with C2 pedicle screws.[5] These techniques provided more stability than previous techniques when biomechanical testing was performed.[3,4] However, placement of screws using these techniques to stabilize the occipitocervical junction has different risks to the vertebral artery.[1,16]

Understanding the vascular anatomy of the upper cervical spine is critical before undertaking fusion procedures of the occipitocervical junction. From C6 to C2, the vertebral artery ascends through the transverse foramens. At the atlas, the arteries pass through the vertebral foramen of C1 and travel posteriorly and medially behind the lateral mass and then superiorly from the posterior arch of the atlas.[17] It is in this region that there is an increased risk of injury to the vertebral artery when using C2 pedicle screws or C1–C2 transarticular screws. This is, in part, due to 20% of the population having an aberrant artery.[16] The surgeon, therefore, needs to assess the specific need for segmental fixation as well as considering the unique anatomy of each individual patient to balance the risks and benefits of each technique that may be employed. A technique that provides stability *via* segmental fixation while minimizing risk to the vertebral artery would be optimal. In the current study, all 3 of fixation techniques provided similar biomechanical stability. In addition, they have all been shown to be successful in obtaining fusion in the clinical setting.[6,9,18]

Although these techniques provide nearly equivalent reduction of motion across the C0–C2 segment, there are different disadvantages to each. In addition to being a challenging screw insertion technique, the transarticular screw technique has the greatest risk of injuring the vertebral artery during placement.[16,19] The C2 pars screw has the same high risk of vertebral artery injury without the biomechanical strength of C2 pedicle screws. The pedicle screw technique may have a slightly less risk of vertebral artery injury. The C2 laminar screw technique theoretically has the least (if not zero) risk of vertebral artery injury at the C2 level due its posteromedial location. However, difficulty in rod contouring can also present a challenge. Additionally, the presence of laminae is a prerequisite for using the crossing C2 laminar screws. These screws could not be placed in those patients who have undergone previous laminectomy. Other issues that may require consideration is the volume or bulk of the posterior construct. The C1–C2 transarticular screw represents the least volume of metal, followed by the C2 pedicle then C2 lamina screws. The C2 lamina screws also sit more dorsal and can potentially be more uncomfortable to the patient. Hence, while stability may be similar, potential risk to the vertebral artery for each construct appears to be inversely proportional to the volume of metal dorsal to the cervical spine. Clinical studies can only address the significance of this inverse relationship.

This study demonstrated similar stability following 3 different segmental occipitoatlantoaxial fixation techniques. Ultimately, the surgeon can use each of these techniques individually or in combination depending on the patient's regional anatomy as it relates to the vertebral artery, the presence or absence of a C2 lamina, the size of the C2 pedicle, and surgeon preference.

■ Key Points

- This biomechanical study evaluated the construct stability of 3 different segmental occipitoatlantoaxial (C0–C1–C2) stabilization techniques.
- C0–C1–C2 stabilization techniques using C2 crossing laminar screws, C2 pedicles screws, and C1–C2 transarticular screws demonstrated similar biomechanical stability.
- All 3 techniques significantly decreased ROM across C0–C2 compared to the intact specimen.
- CT scans demonstrated greater proximity to the vertebral artery in the pedicle screw and transarticular screw techniques compared to the crossing laminar screw technique.
- The C2 crossing laminar screw technique may offer an advantage more than the other techniques due to the reduction of the risk to the vertebral artery during C2 screw placement.

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