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# Biomechanical Evaluation of Unilateral Versus Bilateral C1 Lateral Mass-C2 Intralaminar Fixation

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## Abstract

**Study Design:** Biomechanical, cadaveric study.

**Objectives:** To compare the relative stiffness of unilateral C1 lateral mass-C2 intralaminar fixation to intact specimens and bilateral C1 lateral mass-C2 intralaminar constructs.

**Methods:** The biomechanical integrity of a unilateral C1 lateral mass-C2 intralaminar screw construct was compared to intact specimens and bilateral C1 lateral mass-C2 intralaminar screw constructs. Five human cadaveric specimens were used. Range of motion and stiffness were tested to determine the stiffness of the constructs.

**Results:** Unilateral fixation significantly decreased flexion/extension range of motion compared to intact ($P < .001$) but did not significantly affect axial rotation ($P = .3$) or bending range of motion ($P = .3$). There was a significant decrease in stiffness in extension for both unilateral and bilateral fixation techniques compared to intact ($P = .04$ and $P = .03$, respectively). There was also a significant decrease in stiffness for ipsilateral rotation for the unilateral construct compared to intact ($P = .007$) whereas the bilateral construct significantly increased ipsilateral rotation stiffness compared to both intact and unilateral fixation ($P < .001$).

**Conclusion:** Bilateral constructs did show improved biomechanical properties compared to the unilateral constructs. However, unilateral C1-C2 fixation using a C1 lateral mass and C2 intralaminar screw-rod construct decreased range of motion and improved stiffness compared to the intact state with the exception of extension and ipsilateral rotation. Hence, a unilateral construct may be acceptable in clinical situations in which bilateral fixation is not possible, but an external orthosis may be necessary to achieve a fusion.

## Keywords
C1-C2 instability, laminar screws, unilateral fixation, biomechanics

## Introduction

Numerous pathologies can cause atlantoaxial instability. These conditions include inflammatory diseases, trauma, congenital malformations, and malignancy.[1-5] Significant C1-C2 instability is a serious condition that can lead to pain, myelopathy, or death if not treated.[1-5]

Over the past century, techniques for fixation of C1-C2 have progressed. External fixation has been used, but high morbidity and nonunion rates provided the impetus to find better fixation techniques.[1-5] In 1910, Mixter and Osgood described a wiring technique using heavy, braided suture to fix the posterior arch of C1 to the spinous process of C2.[1] Additional posterior wiring techniques such as the Brooks and Gallie fusions were eventually developed.[2,3] These posterior fixation techniques, however, were shown to have limited stabilization of the C1-C2 joint in rotation and poor fusion rates.[4] Later, Grob and Magerl

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presented a technique involving transarticular screws that were placed through the C1-C2 facet joints.[5] A number of biomechanical cadaveric studies have shown that this method of C1-C2 fixation to be biomechanically superior to wiring techniques.[4,5] This technique, however, can be technically difficult and poses a high risk to the vertebral artery.[6,7]

Goel and Laheri introduced a C1-C2 screw and rod fixation technique using plates, C1 lateral mass screws, and C2 pedicle screws, which serve as posts for an interconnecting rod.[8] This technique was later popularized by Harms and Melcher using polyaxial screws.[6] Although this technique reduced intraoperative risk to the vertebral artery, the risk still remains.[9] In addition, the C2 pedicle screws could not be placed in patients with small C2 pedicles. Despite its technical challenges, this screw and rod fixation was found to be biomechanically equivalent to transarticular screws.[10,11]

In 2004, Wright described a novel technique that involved placing polyaxial screws into the C2 lamina.[9] The screws crossed at the level of the C2 spinous process. These screws were connected to C1 lateral mass screws via rods. Studies have shown that C1 lateral mass screw and C2 intralaminar screw constructs are biomechanically equivalent to C1 lateral mass screw and C2 pedicle screw constructs.[12] The lamina technique is not limited by the size of the C2 pedicle or an aberrant vertebral artery and thus may be considered in patients where this is a concern.[8,9]

However, there are instances where the anatomy of the C2 lamina precludes the placement of C2 laminar screws bilaterally. In a study by Bhatnagar et al, the authors evaluated computed tomography scans of the cervical spine in 50 consecutive patients.[13] In the study, the authors found that 10% of patients had lamina too small to accommodate a 3.5 mm screw on at least one side. In another study by Sharma et al, the authors found that 16% of the patients in their study had lamina too small to accommodate laminar screws.[14] In addition, congenital anomalies may also prohibit the placement of bilateral C2 laminar screws. In a study by Ji et al, the authors evaluated the computed tomography scans of 73 patients with occipitalization of the axis.[15] In these cases, only 45% of the pedicles and 88% of the lamina had thicknesses bigger than 3.5 mm. Furthermore, there are instances where a screw may perforate the C2 laminar cortex and compromise the purchase of the laminar screw. In these cases, the surgeon may want to consider unilateral fixation rather than risking injury to the spinal cord or compromising fixation of the intact screw with repeated attempts to obtain better purchase. Hence, there are instances where it is not possible to perform bilateral translaminar fixation and only a unilateral construct is possible. In these cases, knowledge about the relative stiffness of a unilateral versus a bilateral construct may be helpful in guiding the treatment of patients where only unilateral fixation is possible.

Although there are numerous studies that discuss and compare various bilateral fixation techniques used to stabilize the C1-C2 complex, the literature is limited in cases involving unilateral fixation. The goal of our investigation was to evaluate the range of motion (ROM) and stiffness of unilateral versus bilateral C1 lateral mass screws and C2 laminar screws relative to each other and also versus intact spines.

## Materials and Methods

### Specimen Specifications and Variables

This was a cadaveric study so no institutional review board approval was necessary. Cadaveric specimens were obtained through University of California, Irvine, willed body program. There were 3 females and 2 male specimens with an average age of 73.4 ± 9.3 years. Records of these specimens were evaluated, and specimens where the patients had a history of malignancy or metabolic diseases were excluded. These 5 fresh frozen cervical spines were stored in a −70°C freezer with the soft tissues intact and thawed overnight prior to dissection. The cervical spines were disarticulated at the level of C4 leaving C1-C3 intact for testing. Special care was taken to preserve the C1-C2 facet joint capsules. All other soft tissues were removed except for the anterior longitudinal ligament and posterior longitudinal ligament.

Following dissection, the specimens were stored at −20°C. Before testing, each specimen was thawed and potted. A 4 cm length of polyvinylchloride (PVC) pipe with a 1 cm tall window extending 120° around the pipe was removed. Plaster was poured inside the PVC pipe up to the level of the window. The plaster covered C3 and the inferior tip of the spinous process of C2 (Figure 1A). C1-C3 was potted in its natural position with the C1-C2 facet joint in the horizontal plane. After potting the inferior portion, wood screws were drilled into C3 through the PVC pipe. C1 was mounted in a custom-built jig with an anterior pressure screw placed into the center of the anterior arch and a posterior pressure screw placed into the center of the posterior arch. Hook screws were used to support the transverse foramen of C1 (Figure 1B). The superior fixation plate was screwed onto the jig. For additional stability, two ¾″ wood screws were placed into the anterolateral portion of the lateral mass of C1, with care taken to avoid bone stock required for the C1 LM screws (Figure 1C). The jig was filled with plaster to the level of the posterior arch, leaving room for the C1 LM screw placement. For the purposes of this study, it was believed that plaster was adequate fixation for these specimens. These specimens were not being loaded to failure and the loads were low enough to prevent loosening of the plaster/bone interface, particularly with the secondary fixation of screw through PVC and bone.

### Destabilization

Destabilization was achieved by creating a type II odontoid fracture. Three holes were drilled into the base of the dens and connected using an osteotome. With regard to the destabilization method, we chose to employ a worst-case scenario. Crawford et al used 3 different types of injuries for testing and
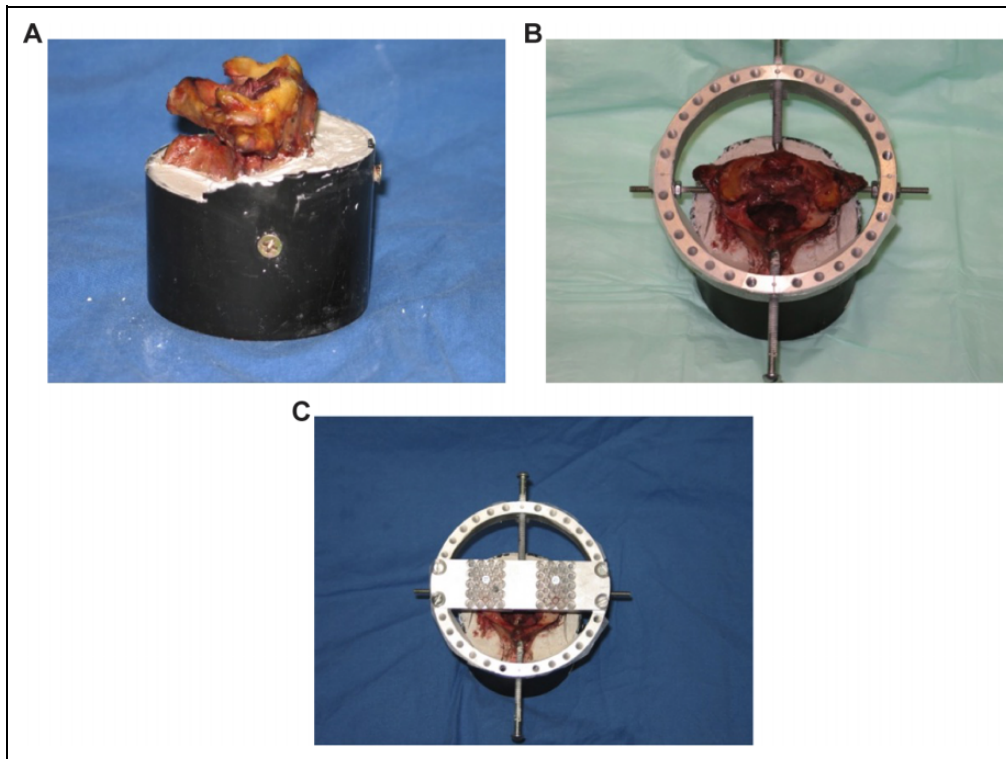
**Figure 1.** The potting sequence for the C1-C3 segments. (A) C2-C3 were potted in PVC using plaster and 2 woods screws to secure the C2-C3 joint. (B) The custom C1 mount was put in place using anterior and posterior pressure screws as well as 2 lateral hook screws through the transverse foramens. (C) Additional C1 fixation was accomplished using two ¾″ wood screws into the anterolateral portion of the lateral masses.
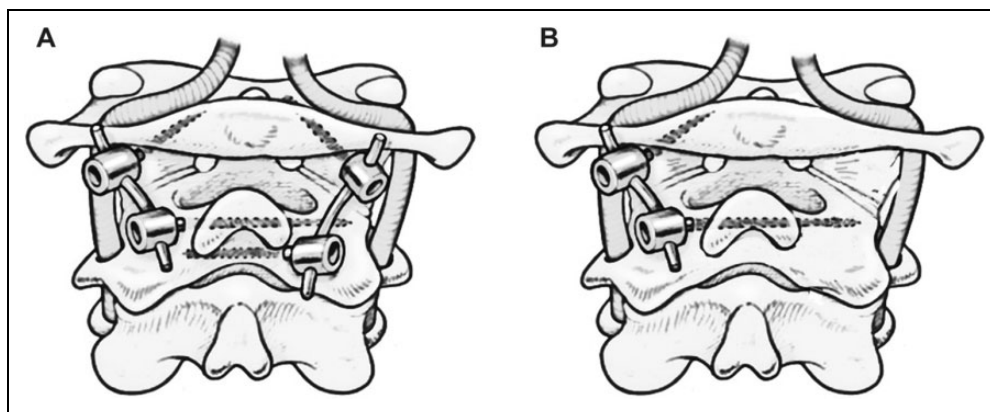


**Figure 2.** Schematic drawings representing bilateral C1 lateral mass and C2 translaminar screws (A) versus a unilateral construct (B).

showed that an odontoid fracture was a more severe injury than ligament transection.[16]

## Fixation

The surgical procedure was performed by a posterior approach. For unilateral fixation, a C1 LM screw and an ipsilateral C2 IL screw (Sierra Spinal Fixation System, SeaSpine, Vista, CA) were used. Titanium rods and set caps were placed and torqued appropriately to 35 in/lbs according to manufacturer specifications (Figure 2).

## Biomechanical Testing

First, intact testing was conducted. After destabilization, unilateral fixation was tested followed by bilateral fixation. All testing was done using a custom testing setup and an Instron machine (Instron Corp, Model #4411, Canton, MA). Each specimen was tested for ROM in flexion-extension, axial rotation, and lateral bending. The specimens were cyclically loaded for 10 cycles from 0.5 N m to 1.5 N m in each direction. Previous research has validated this range and determined it to be sufficient to produce physiologic motions without injuring the specimens.[16] All measured values were from the final cycle.
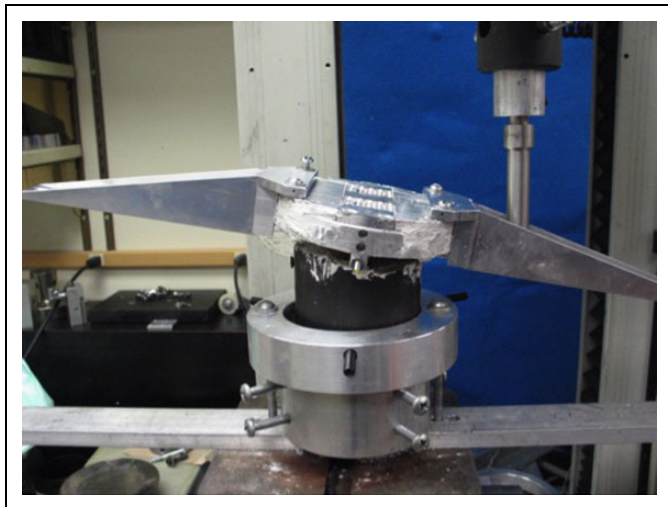
**Figure 3.** Mounted specimen with 2 wing bars attached to the C1 pot allowing application of torque via a plunger mounted to an Instron using a 10 cm moment arm. This photo depicts testing of the specimen in extension. The wing bars could be rotated around the C1 mount in order to test R/L lateral bending.

ROM for flexion-extension, axial rotation, and lateral bending were determined by the use of a video digitizing system and WinAnalyze motion tracking program (Mikromak, Berlin, Germany). The accuracy and repeatability of these measurements were within 0.06 mm and 0.03 mm respectively. The stiffness for each ROM was determined as the slope of the torque and angular displacement curve.

### Flexion-Extension

Two wing bars were attached to the superior mount and aligned with the level of the C1-C2 facet joints (Figure 3). One bar was attached to the anterior portion of the C1 mount and the other bar to the posterior portion, 180° apart. The specimen was positioned in the Instron such that the spinous process of C2 lined up with the C1 posterior arch and a plunger mounted to the Instron applied force to each bar using a 10 cm moment arm for flexion and extension.

### Axial Rotation

After flexion-extension testing, the bars were detached from the mount for axial rotation testing. The specimen was placed in the Instron such that C1 posterior arch aligns with C2 spinous process. A ring apparatus connected to a pulley system was attached to the superior part of the mount (Figure 4). The Instron applied force using a 6.5 cm moment arm for right and left axial rotation.

### Lateral Bending

The 2 bars were reattached and repositioned in alignment with the facet joints, 180° apart. The specimen was placed in the Instron such that C1 posterior arch aligns with C2 spinous
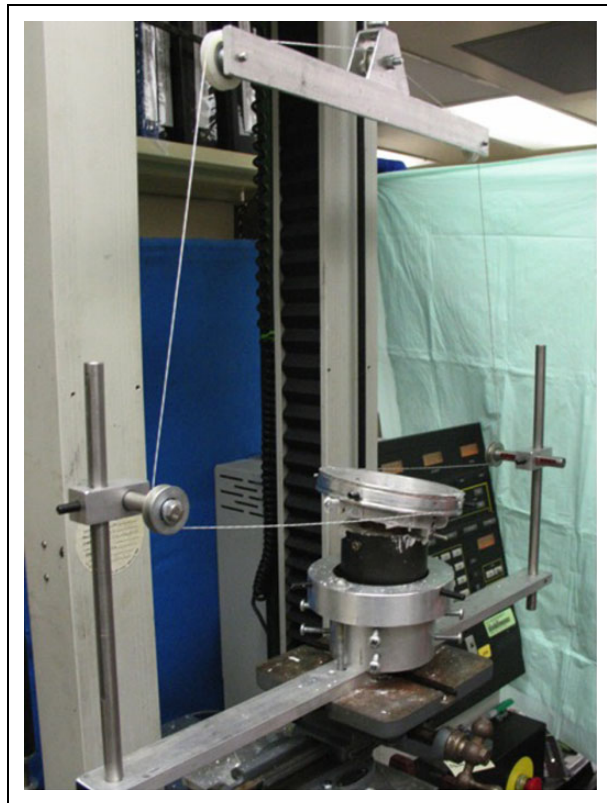


**Figure 4.** A custom ring was mounted to the C1 mount that allowed application of axial rotation torque using a 6.5 cm moment arm.

process. The Instron plunger applied force to each bar using a 10 cm moment arm for right and left lateral bending.

### Statistics

All data was tested for normality using a Shapiro-Wilk test. If data passed the normality test then a repeated-measures ANOVA was performed with significance level set to $P < .05$. If data did not pass the normality test then a Friedman repeated-measures analysis based on ranks was performed. If a significant difference was detected between the groups then a Tukey post hoc test for the individual comparisons was performed for the 3 comparisons (Intact vs Unilateral, Intact vs Bilateral, Unilateral vs Bilateral). All data is reported as a mean $\pm$ standard error of the mean.

## Results

### Range of Motion (Figure 5 and Table 1)

Unilateral fixation significantly decreased flexion/extension ROM compared to intact ($P < .001$) but did not significantly affect axial rotation ($P = .3$) or bending ROM ($P = .3$). The bilateral fixation significantly decreased axial rotation compared to the intact condition ($P = .01$) and flexion/extension and lateral bending ROM compared to both intact ($P < .001$ and $P = .01$, respectively) and the unilateral fixation ($P < .001$ and $P = .002$, respectively).
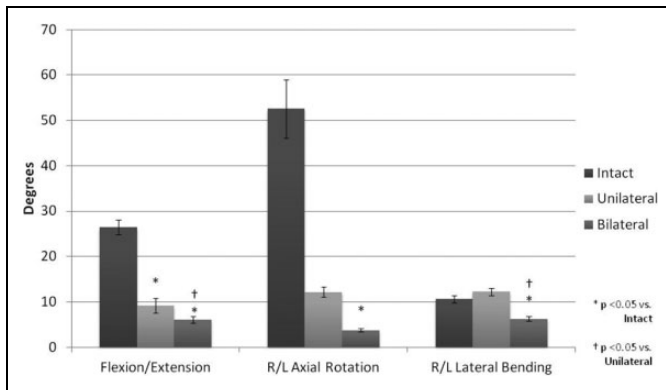
**Figure 5.** Range motion data. Unilateral fixation significantly decreased both flexion/extension and R/L axial rotation. Bilateral fixation significantly decreased range of motion in all planes, and it was significantly different from unilateral fixation in R/L axial rotation and R/L lateral bending.

**Table 1.** Range of Motion[a].

|  | Flexion/Extension (°) | Axial Rotation (°) | Lateral Bending (°) |
|---|---|---|---|
| Intact | 26.5 (1.6) | 52.6 (5.8) | 10.6 (0.8) |
| Unilateral | 9.3 (1.6) | 12.2 (1.1) | 12.2 (0.8) |
| Bilateral | 6.1 (0.7) | 3.8 (0.4) | 6.3 (0.5) |
|  | *P* Value | *P* Value | *P* Value |
| Overall *P* value | <.001 | .005 | .002 |
| Intact vs unilateral | .04 | .3 | .3 |
| Intact vs bilateral | <.001 | .013 | .01 |
| Unilateral vs bilateral | <.001 | .3 | .002 |

[a]Data is shown as mean with standard error in parentheses.

## Stiffness (Figure 6 and Table 2)

There was a significant decrease in stiffness in extension for both unilateral and bilateral fixation techniques compared to intact ($P = .04$ and $P = .03$, respectively). There was also a significant decrease in stiffness for ipsilateral rotation for the unilateral construct compared to intact ($P = .007$), whereas the bilateral construct significantly increased ipsilateral rotation stiffness compared to both intact and unilateral fixation ($P < .001$). There were no other significant differences in stiffness between intact and both fixation techniques ($P > 0.05$).

## Discussion

The primary objective of this investigation was to compare the relative biomechanical characteristics of unilateral versus bilateral C1-C2 fixation with C1 lateral mass screws and C2 intralaminar screws with an interconnecting rod. We hypothesized that the unilateral fixation would provide improved stability, although the bilateral constructs would have the greatest stability.

In our investigation, we have chosen to compare unilateral and bilateral C1-C2 fixation constructs consisting of C1 LM
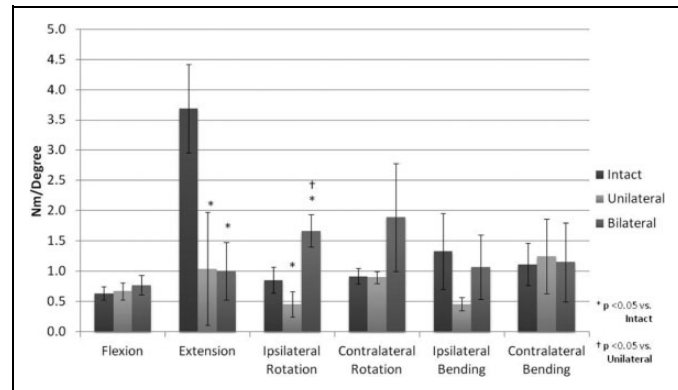


**Figure 6.** Stiffness data. There was a significant decrease in stiffness in extension for both unilateral and bilateral fixation techniques compared to intact ($P = .04$ and $P = .03$, respectively). There was also a significant decrease in stiffness for ipsilateral rotation for the unilateral construct compared to intact ($P = .007$), whereas the bilateral construct significantly increased ipsilateral rotation stiffness compared to both intact and unilateral fixation ($P < .007$).

screws and C2 IL screws. This technique minimizes risk to the vertebral artery and avoids limitations due to C2 pedicle osseous anatomy. To our knowledge, there have been no similar biomechanical studies of unilateral C1 lateral mass and C2 intralaminar fixation. Our results showed that intact stiffness was recreated with the unilateral fixation in all testing modalities, except for ipsilateral rotation and extension. Also, ROM in flexion/extension was significantly decreased from intact. These findings are similar to the results from Nichols's and Kuroki's articles comparing unilateral and bilateral fixation techniques with transarticular screws and C1 lateral mass and C2 pedicle screws.[10,17] In these articles, the biomechanical properties of bilateral fixation were superior to unilateral fixation, but unilateral fixation decreased ROM and improved stiffness. So the authors concluded that unilateral fixation may be considered when anatomical constraints precluded the placement of screws into C1 or C2. Similarly, the placement of a unilateral C1 lateral mass and C2 laminar screw construct is not as stiff biomechanically as a bilateral construct, but it is comparable to bilateral fixation with regard to stiffness in flexion and extension and contralateral bending. The biggest deficiency of the unilateral construct is with rotation and contralateral bending. Hence, if a unilateral construct is necessary, an external orthosis that limits ROM in these directions is advised. Alternatively, a C1 lateral mass and C2 pedicle (or isthmus) construct on one side could be combined with a C1 lateral mass and C2 translaminar construct on the other side in these cases. This would be ideal as long as there are no concerns about the vertebral artery on the side of the C2 pedicle screw.

By virtue of conducting an in vitro cadaveric study, the experiment has certain limitations. This includes the use of pure moments being applied to C1. These motions did not originate from muscle forces. Rather, pure moments of 1.5 N m were applied to C1, which is within limits of physiological range of 1.5 N m to 3 N m, as recommended by Goel and

**Table 2.** Stiffness[a].

| | Flexion (N m/degree) | Extension (N m/degree) | Ipsilateral Rotation (N m/degree) | Contralateral Rotation (N m/degree) | Ipsilateral Bending (N m/degree) | Contralateral Bending (N m/degree) |
|---|---|---|---|---|---|---|
| Intact | 0.64 (0.05) | 3.69 (0.42) | 0.86 (0.10) | 0.92 (0.07) | 1.33 (0.28) | 1.12 (0.16) |
| Unilateral | 0.67 (0.06) | 1.04 (0.54) | 0.46 (0.90) | 0.90 (0.05) | 0.46 (0.05) | 1.25 (0.28) |
| Bilateral | 0.77 (0.07) | 1.00 (0.27) | 1.67 (0.12) | 1.89 (0.45) | 1.07 (0.24) | 1.15 (0.29) |
| | *P* Value | *P* Value | *P* Value | *P* Value | *P* Value | *P* Value |
| Overall *P* value | .324 | .03 | <.001 | .06 | .07 | .8 |
| Intact vs unilateral | NA | .04 | .007 | NA | NA | NA |
| Intact vs bilateral | NA | .03 | <.001 | NA | NA | NA |
| Unilateral vs bilateral | NA | .9 | <.001 | NA | NA | NA |

[a]Data is shown as mean with standard error in parentheses.

Laheri.[8] Also inherent to a cadaveric study, there exist variation among the various specimens used in testing. With regard to the number of specimens used (n = 5), the authors realize that this limits the results of statistical analysis. We believe however that this did not nullify our results as we maintained consistency during data collection. Also, no attempts were made to test the long-term stability of the construct with regard to fatigue testing. The biomechanical behavior of these 2 constructs is probably quite different, especially with regard to rotational stiffness and to side bending. Last, the authors recognize that there is more than one method to connect a C1 lateral mass screw to a C2 laminar screw. In one method, the C1 lateral mass screw is connected to the C2 translaminar screw from the ipsilateral side with a straight connecting rod. In the second method, the C1 lateral mass screw is connected to the C2 translaminar screw from the contralateral side requiring the connecting rod to be bent for crossing over the midline. We chose to test only the ipsilateral C1 lateral mass and C2 translaminar fixation method because it is more commonly performed. However, the authors recognize that there is an alternative technique and the results of this study many not translate to the contralateral fixation method.

Further testing is required to elucidate the long-term stability of a unilateral construct.

## Conclusions

Atlantoaxial instability is a challenging clinical problem, which may require instrumented stabilization of the motion segment. Instrumentation, however, may prove challenging, and in some instances, bilateral fixation may not be feasible due to anatomic restrictions. Our study is the first to evaluate unilateral C1-C2 fixation employing C1 lateral mass and C2 intralaminar screws. Although the bilateral construct did show superior biomechanical properties, unilateral C1-C2 fixation using a C1 lateral mass and C2 intralaminar screw-rod construct decreased ROM and improved stiffness of the destabilized C1-C2 segments to the intact state with the exception of extension and ipsilateral rotation. Hence, unilateral fixation may be acceptable in clinical situations in which bilateral fixation is not possible or risks significant injury to the vertebral

artery or spinal cord. However, these patients may require the additional use of an external orthosis to provide the biomechanical stability necessary to achieve a spinal fusion.

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