Biomechanical impact of C2 pedicle screw length in an atlantoaxial fusion construct

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Abstract

Background: Posterior, atlantoaxial (AA) fusions of the cervical spine may include either standard (26 mm) or short (16 mm) C2 pedicle screws. This manuscript focused on an in vitro biomechanical comparison of standard versus short C2 pedicle screws to perform posterior C1-C2 AA fusions.

Methods: Twelve human cadaveric spines underwent C1 lateral mass screw and standard C2 pedicle screw (n = 6) versus short C2 pedicle screw (n = 6) fixation. Six additional controls were not instrumented. The peak torque, peak rotational interval, and peak stiffness of the constructs were analyzed to failure levels.

Results: The peak torque to construct failure was not statistically significantly different among the control spine (12.2 Nm), short pedicle fixation (15.5 Nm), or the standard pedicle fixation (11.6 Nm), P = 0.79. While the angle at the peak rotation statistically significantly differed between the control specimens (47.7° of relative motion) and the overall instrumented specimens (P < 0.001), the 20.7° of relative rotation in the short C2 pedicle screw specimens was not statistically significantly higher than the 13.7° of relative rotation in the standard C2 pedicle screw specimens (P = 0.39). Similarly, although the average stiffness was statistically significantly lower in control group (0.026 Nm/degree) versus the overall instrumented specimens (P = 0.001), the standard C2 pedicle screws (2.54 Nm/degree) did not differ from the short C2 pedicle screws (1.69 Nm/degree) (P = 0.30).

Conclusions: Both standard and short C2 pedicle screws allow for equally rigid fixation of C1 lateral mass-C2 AA fusions. Usage of a short C2 pedicle screw may be an acceptable method of stabilization in carefully selected patient populations.

Key Words: Atlantoaxial, biomechanics, C1, C2, pars, pedicle
INTRODUCTION

Spinal C2 screw fixation utilizing a shorter versus a longer screw may minimize neurovascular injuries.\(^6,7\) Although the C2 pedicle screws are an acceptable means of instrumenting the axis, few studies have compared the relative efficacy and strength of the short versus standard C2 pedicle screws in C1-C2 atlantoaxial (AA) cantilever fusion constructs.\(^2,3\) Here, we present a biomechanical analysis of C1-C2 AA fusions. While all specimens underwent C1 lateral mass fixation, the objective of this study is to compare the standard versus short C2 pedicle screws.

MATERIALS AND METHODS

Fresh frozen human cadaveric spines (occiput-T6) were obtained from the Maryland State Anatomy Board. All spines underwent radiographic inspection via anterior-posterior and lateral X-ray in addition to Dual Energy X-Ray Absorptiometry (DEXA) scanning. Apparent bone mineral density and absence of osteoporosis (t scores greater than -2.5) were confirmed with Dual Energy X-ray Absorptiometry (Discovery QDR Series, Hologic Inc., Bedford, Massachusetts). Any spines demonstrating fractures, tumors, abnormal radiolucency, or other pathologies that may compromise the structural integrity of the specimens were discarded. All spines were stored in sealed plastic bags at -20°C until 1 day before testing, at which time they were thawed overnight to room temperature [Figure 1a].

C1-C2 Instrumentation

Posterior C1-C2 cantilever fusion constructs (without hemilaminotomy) followed the technique described by Harms and Melcher.\(^4\) Specimens were randomly assigned to receive either no instrumentation \((n = 6)\), C1 lateral mass and standard (26 mm) C2 pedicle screws \((n = 6)\) [Figure 1b], or C1 lateral mass and short (16 mm) C2 pedicle screws \((n = 6)\) [Figure 1c]. Both lateral mass and pedicle screws were 3.5 mm in diameter; only poly-axial titanium screws (16 mm length, DePuy Inc) were utilized.

Assessment of spinal rigidity

The superior and inferior aspects of the specimens were potted in polyvinyl chloride pipe using polymethylmethacrylate bone cement (FastTray, Bosworth Co., Skokie, Illinois) [Figure 1d]. All biomechanical examinations were carried out with the materials testing machine (MTS Bionix x 858 Test System, MTS, Eden Prairie, Minnesota) [Figure 2a and b]. Reflective marker triads (SMART motion capture system, eMotion, Padova, Italy) were placed in the spinous processes of C1 and C2 [Figure 2c], with the accuracy of the motion capture system as 0.2 degrees.

The weight of the caudal fixture provided an axial load equivalent to 50N. Theses caudal forces replicated the degree of flexion (approximately 11°) at the AA joint.\(^8\) Spines underwent 20 degree range of motion cycles just prior to actual measurements being taken. In all spines, 20 cycles were run to confirm that the correct moment was being applied to the spine and that the fixture was settled. Spines were then twisted by rotating the superior (occiput) pot relative to the inferior fixed pot at a rate of 1°/s while simultaneously recording reaction torque and tracking the reflective marker positions. The effect of treatment (standard vs short C2 pedicle screw) on failure (peak) torque, stiffness, and angle at peak torque was recorded [Figure 2d].
Statistical analysis

The objective in assessing spinal rigidity was primarily focused on peak torque; that is, rotational movements until failure. In a seminal publication on biomechanical evaluations of C1-C2 posterior constructs, Sim et al. determined that the mean range of motion for an intact spine was 47.5° ± 9.6.[9] We determined a priori that a 10° difference would represent a clinically significant restriction. With a power analysis at an α (P value)=0.05 and β (power)=0.08, we sought to compare a previously established control with a 47.5° ± 9.6 range of motion to a hypothesized fusion constructed restricted to a 37° range of motion. A total sample size of 12 specimens would be necessary to detect a statistically significant difference of 10°.

Following the biomechanical study, crude data was described with summary statistics. We used a generalized linear latent and mixed regression model in STATA 10 (StataCorp LP, College Station, TX) to analyze the effect of covariates (noninstrumented, short C2 pedicle screw, and standard C2 pedicle screw) on failure (peak) torque, stiffness, and angle at peak torque to generate 95% confidence intervals. We also analyzed our data via analysis of variance (ANOVA) with Tukey post-hoc analysis, wherein significant effect was defined as P < 0.05.

RESULTS

The peak torque to construct failure was not statistically significantly different among the control spine, short pedicle fixation, or the standard pedicle fixation, P = 0.79. The mean peak torque (95% confidence interval) to failure was 12.2 Nm (5.7-18.7 Nm) in the control cohort, 15.5 Nm (7.6-23.4 Nm) in the short pedicle screw cohort, and 11.6 Nm (9.8-13.4 Nm) in the standard pedicle screw cohort [Table 1].

However, the angle at which the peak occurred did differ significantly. Failure occurred at an average of 47.7° of relative rotation (36.459°) in the control specimens, which was significantly greater than the instrumented specimens overall, P = 0.001: 20.7° of relative rotation (13.7°-27.8°) in the short C2 pedicle screw specimens and 13.7° of relative rotation (7.1-20.2°) in the standard C2 pedicle screw specimens. Although the short C2 pedicle screw instrumentation afforded spines a higher degree of rotational range of motion, the treatments were not significantly different from each other, P = 0.39.

Although standard C2 pedicle screws afforded spines a higher average stiffness than short C2 pedicle screws, this was not statistically significant, P = 0.30. The measured stiffness was 0.026 Nm/degree (0.014-0.038 Nm/degree) for the control group, which was significantly less than the treated specimens, P = 0.001: 1.69 Nm/degree (1.08-2.30 Nm/degree) in the short pedicle screw group and 2.54 Nm/degree (1.43-3.66 Nm/degree) in the standard pedicle screw group.

DISCUSSION

As the placement of C2 pedicle screws is technically challenging due to the proximity of the vertebral artery laterally and the spinal canal medially, some spine surgeons opt for the placement of short pedicle screws.[1,6,7] In our study, we fluoroscopically verified the placement of each screw to ensure accurate placement [Figures 3 and 4]. Lehman et al. previously determined that the short pedicle screws do not provide optimal purchase into the C2 vertebra, and are, therefore, not as biomechanically stable as the long screws.[3]

Our results demonstrate that the short C2 pedicle screw was able to achieve comparable rigidity to the standard C2 pedicle screw in a test to failure of a C1-C2 segmental screw-rod fusion system. The short C2 pedicle screw was able to significantly increase the angle at peak torque and maximum stiffness compared to noninstrumented controls. Compared with the standard C2 pedicle screw, the short C2 pedicle screw exhibited slightly higher rotational degrees of freedom and a lower degree of stiffness to failure, although these comparisons were not statistically significant. Taken together, our results suggest that short C2 pedicle screws afford similar levels of postinstrumentation rigidity compared with standard C2 pedicle screws.

Literature review

Although no study in the literature has directly examined the effect of C2 pedicle screw length on a biomechanical test to failure model, Sim et al. compared a short C2 pedicle screw (14-16 mm) to a standard long C2 pedicle screw (24-28 mm) in a C1-C2 AA fixation study.[9] They too found no statistically significant difference between the long versus short pedicle screws in regard to both range of motion and neutral zones.

| Table 1: Biomechanical results |
|-------------------------------|
| Control | Short pedicle screw | Standard pedicle screw |
| Mean peak torque to failure | [12.2 Nm] | [15.5 Nm] | [11.6 Nm] |
| Relative rotation to failure | [47.7°] | [20.7°] | [13.7°] |
| Measured stiffness | [0.026 Nm/degree] | [1.69 Nm/degree] | [2.54 Nm/degree] |

S345
Clinically, our findings are also supported by other studies that show excellent results utilizing the short C2 pedicle screws and C2 pars screw, both of which allow for C1-C2 fixation without a standard length pedicle screw. Nitising et al. demonstrated no permanent complications in 10 patients undergoing C1 lateral mass-C2 pars screw instrumentation; in all cases, rigid fixation was confirmed on postoperative radiographs and maintained on follow-up radiographs.\cite{7} Mummaneni et al. reported clinical outcomes on 42 consecutive patients who received C1 lateral mass fixation, of which 38 were fused at C2 using the pars screw; after 2 years of follow-up, the visual analog scale neck pain score improved by a mean of 3 points and by 1 grade in the Nurick score.\cite{6} Notably, no postoperative complications were encountered for these C1-C2 construct cases, and of the 42 patients in the study, only 1 patient developed pseudoarthrosis (2.38%).

Bransford et al. retrospectively reviewed a series of 633 screws placed in 328 patients. Of the 77 pars screws in that series, Bransford et al. demonstrated excellent intraoperative and postoperative outcomes, with no neurologic complications.\cite{1}

**Limitations**

As an in vitro biomechanical model, our results cannot fully replicate the in vivo fusion process replete with paraspinal muscles and endogenous bone turnover. Therefore, this study does not provide incontrovertible proof of long-term stability. Nonetheless, our biomechanical data provides mechanistic insight into the clinical observations by Mummaneni et al. and may serve to enhance our understanding of the value of the short C2 pedicle screw. Our biomechanical study was also limited regarding testing to failure; fatigue and quasistatic testing may provide additional data with postfatigue comparative analyses and force displacement in multiple planes, respectively.

**CONCLUSIONS**

This study showed that a shorter C2 pedicle screw provided equally rigid fixation of a C1 lateral mass-C2 segmental fusion construct in a biomechanical test to failure model. The short C2 pedicle screws (coupled with C1 lateral mass screws) may, therefore, serve as a biomechanically sound stabilizing method of fusion of the AA joint. Additional prospective studies in patient populations are warranted in order to corroborate these biomechanical findings.

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