Biomechanical comparison of pedicle screws versus spinous process screws in C2 vertebra
A cadaveric study

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Abstract

Background: Biomechanical studies have shown C2 pedicle screw to be the most robust in insertional torque and pullout strength. However, C2 pedicle screw placement is still technically challenging. Smaller C2 pedicles or medial localization of the vertebral artery may preclude safe C2 pedicle screw placement in some patients. The purpose of this study was to compare the pullout strength of spinous process screws with pedicle screws in the C2.

Materials and Methods: Eight fresh human cadaveric cervical spine specimens (C2) were harvested and subsequently frozen to –20°C. After being thawed to room temperature, each specimen was debrided of remaining soft tissue and labeled. A customs jig as used to clamp each specimen for screw insertion firmly. Screws were inserted into the vertebral body pairs on each side using one of two methods. The pedicle screws were inserted in usual manner as in previous biomechanical studies. The starting point for spinous process screw insertion was located at the junction of the lamina and the spinous process and the direction of the screw was about 0° caudally in the sagittal plane and about 0° medially in the axial plane. Each vertebrae was held in a customs jig, which was attached to material testing machine (Material Testing System Inc., Changchun, China). A coupling device that fit around the head of the screw was used to pull out each screw at a loading rate of 2 mm/min. The uniaxial load to failure was recorded in Newton'st dependent test (for paired samples) was used to test for significance.

Results: The mean load to failure was 387 N for the special protection scheme and 465 N for the protection scheme without significant difference ($t = -0.862$, $P = 0.403$). In all but three instances (38%), the spinous process pullout values exceeded the values for the pedicle screws. The working distances for the spinous process screws was little shorter than pedicle screws in each C2 specimen.

Conclusion: Spinous process screws provide comparable pullout strength to pedicle screws of the C2. Spinous process screws may provide an alternative to pedicle screws fixation, especially with unusual anatomy or stripped screws.

Key words: C2 vertebrae, screw fixation, spinous process screws, pedicle screws

MeSH terms: Spine, cervical vertebrae, cadaver, bone screws

Introduction

Currently, several screw fixation techniques have been described for C2 fixation[1-5] These techniques include transarticular screw, pedicle screw and translaminar screw technique. Both transarticular screws and pedicle screws have been demonstrated to be effective method for C1-C2 stabilization in most patients. However, these techniques are not applicable in all patients and puts the vertebral artery (VA) to risk. Several authors[5,6] have reported up to 20% incidence of vertebral anomalies that would not allow safe placement of these screws. Alternatively, the C2 intralaminar screw technique may be a safe choice to avoid injury to the VA.[7] However, the obvious drawback to the C2 intralaminar screw technique is the spinal cord injury due to breaking of the inner cortex of the lamina. Further, there could be marked variation in C2 laminar thickness.

Appropriate C2 fixation method for a patient who has thin laminas and VA anomalies together was controversial. Nagata *et al.*,[8] reported a case of C2-T1 fixation by using a C2 spinous process screw, inserted horizontally through the base of the spinous process, as a fixation anchor. The special patient had anatomical limitations for screw

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insertion. Transarticular screw or C2 pedicle screw were not acceptable on the right side because of high-riding VA and translaminar screws trajectories could not be allowed because of thin laminas. After laminectomy posterior fixation for C2 was successfully used spinous process screw on the right side and pedicle screw on the left side. The spinous process screws technique was thought to be advantageous because of the large size of the C2 spinous process and the ability to directly visualize all relevant structures, potentially decreasing the need for intraoperative fluoroscopy or image guidance[8] However, until date, no biomechanical studies have addressed the spinous process screw in the C2. The purpose of this study was to compare the pullout strength of spinous process screws with pedicle screws in the C2 vertebrae.

Materials and Methods

Eight fresh human cadaveric cervical spine specimens (C2) were harvested and subsequently frozen to –20°C. After being thawed to room temperature, each specimen was debrided of remaining soft tissue and labeled. A customs jig was used to clamp each specimen for screw insertion firmly. Screws were inserted into the vertebral body pairs on each side using one of two methods.[9-11] The pedicle screws were inserted in usual manner as in previous biomechanical studies[9-13] The starting point for spinous process screw insertion was located at the junction of the lamina and the spinous process and the direction of the screw was about 0° caudally in the sagittal plane and about 0° medially in the axial plane [Figure 1]. Screws were placed in such a manner so that the first thread penetrated the far cortex. All spinous process screws insertion was performed without breeching the inner cortex of lamina under direct visualization. After each hole was drilled and tapped according to the manufacturer's specifications, 4.0 mm cortical screw (Vertex Fixation System, Sofamor Danek, Memphis, TN, USA) was inserted into the spinous process on one side, and pedicle screw was inserted on the other. The type of screw was randomized at each vertebrae, either left or right [Figure 2]. To grasp the screws with a coupling device, it was necessary to leave all of the screws approximately 4-6 mm outside. The screw length was defined as the actual working screw length.

Each vertebrae was held in a customs jig, which was attached to material testing machine (Material Testing System Inc., Changchun, China) [Figure 3]. A coupling device that fit around the head of the screw was used to pull out each screw at a loading rate of 2 mm/min. The motion segment was oriented so that the pullout force was collinear with the long axis of the screw. The uniaxial load to failure was recorded in Newton'st dependent test (for paired samples) was used to test for significance.

Results

The mean load to failure was 387 N for the spinous process screws and 465 N for the pedicle screws without significant difference ($t = -0.862$, $P = 0.403$). Table 1 shows the minimum, maximum, mean and standard deviation for the spinous process and pedicle screws.

In all but three instances (38%), the spinous process pull out values exceeded the values for the pedicle screws. The working distances for the spinous process screws

Table 1: Pull-out values

Techniques	Mean (*n*)	Range (*n*)	Difference (SD)	Screw length (mm)
Spinous process screws	387	134-567	137	21.4 (±1.1)
Pedicle screws	465	168-764	214	23.1 (±1.0)

SD=Standard deviation

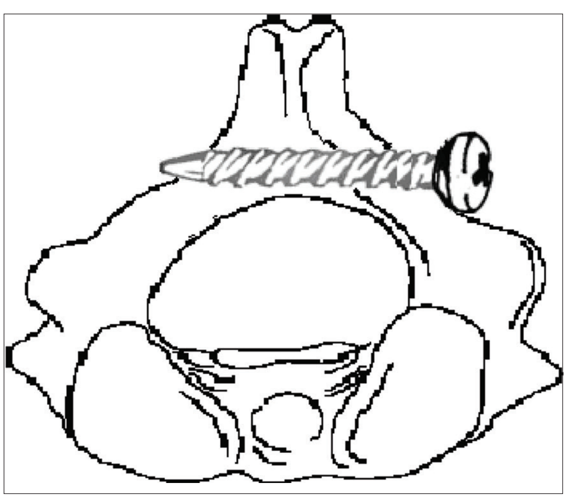

Figure 1: Artist's illustration of the technique for placing C2 spinous process screws

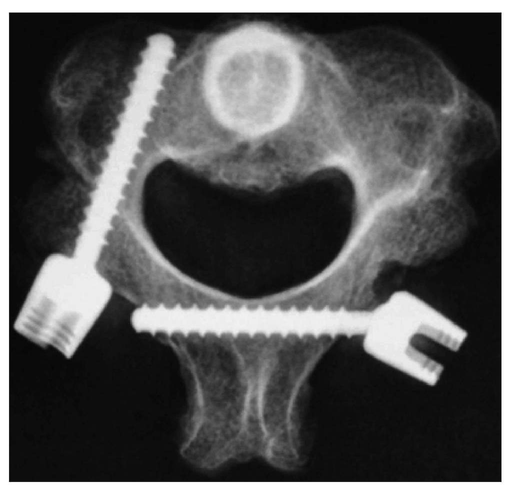

Figure 2: Computed tomography scan showing placement of C2 spinous process screw (left) and pedicle screw (right)

Figure 3: The material testing machine

was shorter than for pedicle screws in each C2 specimen with a significant difference in the working length of the screws (t = 4.368, P< 0.001).

Discussion

Advances in fixation into the upper cervical spine have continued to progress over the past decade. In 1992, Jeanneret and Magerl first described the technique of transarticular screw fixation for C1-C2[14] Biomechanical studies have shown transarticular screw fixation completely stops rotational movement at the atlanto-axial joint.[10-12] However, this procedure is technically demanding and there is a significant risk of VA, which has led many authors to advocate the use of screw-rod constructs to obtain fixation at the C1-C2 articulation. In 2001, Harms and Melcher described the technique of C1 and C2 fixation using C1 lateral mass screws and C2 pedicle screws using polyaxial screws with rods.[15] Biomechanical studies have shown C2 pedicle screw to be the most robust in insertional torque and pullout strength. However, C2 pedicle screw placement is still technically challenging and the risk of VA injury persists[10-12] Moreover, the diameter of the pedicle and the location of the foramen transversarium are variable. Cadaveric studies of the C2 pedicle have also shown high rates of violation of the foramen transversarium during attempted pedicle screw placement[4,6] Smaller C2 pedicles or medial localization of the VA may preclude safe C2 pedicle screw placement in some patients[4,6] The clinical study reported the incidence of screws breaching the pedicle of C2 was 7%.[16] C2 translaminar screw technique has some advantages[17] Gorek *et al*.,[18] also found C2 translaminar screws to be equivalent in rigidity when compared with C2 pedicle screws. However, although the risk of VA injury has been essentially eliminated, neurologic injury from breakthrough of the inner cortex of the lamina by the drill or screw is still a possibility[18] Jea *et al*.,[19] have found instances of critical violation of the inner cortical surface of the lamina as seen on postoperative computed tomography scans. Parker *et al*.,[16] retrospectively reviewed the records of 152 C2 translaminar screws in patients undergoing posterior cervical fusion, and found 2 (1.3%) translaminar screws breaching the C2 lamina and one requiring acute revision. Another drawback to the technique is its requirement for adequately sized lamina.

For these reasons, a spinous process screws technique using screws placed directly onto the spinous process of C2 was devised[8,20,21] The starting point for the C2 spinous process screw insertion was located at the base of the spinous process, posterior C2 spinous process screw implantation can be performed bilaterally under direct visualization. This technique allows incorporation of the axis into atlantoaxial or craniocervical constructs, or incorporation into the subaxial spine, without risk of VA and spinal cord injury. Liu *et al*.,[21] examined the feasibility of the C2 spinous process screw in a cadaveric study in 2010. They quantitatively evaluated the C2 spinous process and found that the C2 spinous process screw fixation has the anatomic feasibility[21] The researchers futher reported that the C2 spinous process screws were placed without impingement of spinal cord or VA and breakage of the spinous process in ten human cadaveric of cervical spine. They concluded that the C2 spinous process screw fixation had the anatomic feasibility and was easier to perform than pedicle screw fixation.[20]

Nagata *et al*.,[8] reported a case of use of C2 spinous process screw for posterior cervical fixation as substitute for laminar screw in a patient with thin laminae and thought spinous process screw could be an option of C2 fixation for patients with high-riding VA and severe degenerated cervical spines including thin C2 laminas.

The C2 spinous process screw technique described in this paper has many advantages. First, the C2 spinous process screw technique is easy to be performed because the base of the spinous process can be directly visualized. Though the screw tip could be visualized, it did not seem to gives us the assurance that the C2 screw has not entered the spinal canal. Because of the canal being triangular, the screw may enter and exit through the lamina and the tip may be still visible. The starting point for spinous process screw insertion was selected at the junction of the lamina and the spinous process and the direction of the screw was about 0° caudally in the sagittal plane and about 0° medially in the axial plane. The starting point should be located to a little caudal direction in order to get an appropriate screw length because the C2 spinous process was in a triangle shape[8,20,21] Furthermore, C2 spinous process screws can be placed with visual and tactile feedback without fluoroscopy or image guidance. In addition, should transarticular or pedicle screw fixation fail, the use of the spinous process screw technique to salvage either fixation method provide a viable alternative[20] Biomechanically, the results of this study indicate that spinous process screws provide comparable pullout strength (387 N) to pedicle screws (465 N) in the cervical spine. Thus, spinous process screws may provide an alternative to pedicle screws for the fixation of the C2. A C2 spinous process screw seems a useful alternative for fixation as a salvage technique when there is anomalous anatomy, when other spinal fixation techniques have failed or as a primary fixation technique. Some surgeons use a C2 pars screw when the vertebral artery is high riding. Su *et al.*[22] compared the pullout strength of a C2 pedicle screw and C2 pars screw after cyclical testing and found C2 pedicle screws have twice the pullout strength of C2 pars screws after cyclical loading. On the other hand, spinous process screws may have more biomechanical advantages than C2 pars screws.

The limitations of this study are first we were limited to eight specimens, but presumed these would provide at least new preliminary data. Thus the sample size is small. Second, uniaxial pullout, which has been tested, is a rare mechanism for failure in clinical practice. On the other hand, multidirectional toggle and cyclical stresses are responsible for failure and these need to be tested in future projects. Third, each specimen had one spinous process screw. If there were two screws per spinous process given the limited bone stock available for purchase the result may be different. Four, cadaveric studies that look at the accuracy of screw placement and try to quantify the applicability of C2 spinous process screw placement in the general adult population would also be beneficial. Finally, Bone density measurements were not performed because we randomly selected alternating sides of the same caderveric specimen motion segment and previous studies have not found such studies to be useful in predicting cervical screw pullout strength.[23]

Conclusion

Spinous process screws provide comparable pullout strength to pedicle screws of the C2. Spinous process screws may provide an alternative to pedicle screws fixation, especially with unusual anatomy or stripped screws.

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