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ORIGINAL ARTICLE

Load sharing properties of cervical pedicle screw-rod constructs versus lateral mass screw-rod constructs

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Abstract Lateral mass screws have a history of successful clinical use, but cannot always be used in the subaxial cervical spine. Despite safety concerns, cervical pedicle screws have been proposed as an alternative. Pedicle screws have been shown to be biomechanically stronger than lateral mass screws. No study, however, has investigated the load sharing properties comparing constructs using these screws. To investigate this, 12 fresh-frozen single cervical spine motion segments (C4–5 and C6–7) from six cadavers were isolated. They were randomized to receive either lateral mass or pedicle screw-rod constructs. After preloading, the segments were cyclically loaded with a uniplanar axial load from 0 to 90 N both with and without the construct in place. Pressure data at the disc space were continuously collected using a dynamic pressure sensor. The reduction in disc space pressure between the two constructs was calculated to see if pedicle screw and lateral mass screw-rod constructs differed in their load sharing properties. In both the pedicle screw and lateral mass screw-rod constructs, there was a significant reduction in the disc space pressures from the no-construct to construct conditions. The percentage decrease for the pedicle screw constructs was significantly greater than the percentage decrease for the lateral mass screw constructs for average pressure ($p \leq 0.002$), peak pressure ($p \leq 0.03$) and force ($p \leq 0.04$). We conclude that cervical pedicle screw-rod constructs demonstrated a greater reduction in axial load transfer through the intervertebral disc than lateral mass screw-rod constructs. Though there are dangers associated with the insertion of cervical pedicle screws, their use might be advantageous in some clinical conditions when increased load sharing is necessary.

Keywords Cervical spine · Biomechanics · Cervical pedicle screws · Lateral mass screws

Introduction

Posterior fixation of the subaxial cervical spine has traditionally been achieved using lateral mass screws. These screws have a history of successful clinical use and are commonly employed by surgeons today [7, 8, 23, 25]. However, fixation into the lateral mass can be inadequate in certain cases with poor bone quality or large defects in the posterior vertebral elements secondary to fracture, neoplasm, or revision surgery. Lateral mass screws tend to fail by loosening or avulsion, and the decreasing size of the lateral mass in the lower cervical spine can also make fixation challenging [5, 6, 9]. Cervical pedicle screws have been proposed as an alternative. The major drawback to cervical pedicle screws is a concern with safe placement of the screws [13], due in part to the small size of the pedicles [14].

The advantage of cervical pedicle screws is that they have consistently been shown to be stronger when tested

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biomechanically. They have demonstrated higher pull-out strength than lateral mass screws [11, 12]. When tested further as part of a construct in cadaveric specimen, pedicle screws have outperformed lateral mass screws. Kotani et al. [18] showed that pedicle screws are stronger in a three column injury model and with respect to primary stability and stability after cyclic loading [19]. These studies primarily looked at resistance to lateral bending, flexion/extension, and axial rotation.

The goal of our study was to investigate axial load and the load sharing properties of cervical pedicle screw-rod constructs when compared to similar constructs using lateral mass screws. Clinically, greater load sharing ability of pedicle screws is important if a surgeon wants to protect the anterior column in cases of tumor, fracture, or shielding of an anterior construct. We hypothesized that our results would be consistent with the prior literature and that pedicle screw-rod constructs would have a greater load sharing ability when compared to lateral mass screw-rod constructs.

Materials and methods

Six fresh-frozen human (3 male, 3 female, average age 71.4 years) cadaveric cervical spines were harvested from C4 to C7. The specimen were placed in double plastic bags, and stored at −20°C. Plain radiographs were taken to ensure that there were no obvious neoplastic, traumatic, or congenital conditions with the specimen used. The specimens were kept frozen until the night before instrumentation and testing.

Individual motion segments (C4–5 and C6–7) were isolated for a total of 12 segments. All muscle soft tissue were dissected from the specimen, while care was taken to preserve the ligamentous attachments. The specimens were randomized so that half of the C4–5 segments were instrumented using pedicle screws while the other half of the C4–5 segments received lateral mass screws. The corresponding C6–7 segment from the same specimen received the opposite instrumentation of its C4–5 segment. In this way, each specimen could serve as its own internal control. The specimens were instrumented using 3.5 mm polyaxial screws (Depuy Spine, Summit, Raynham, MA). The pedicle screws were placed using modified "funnel" technique as per Karaikovic et al. [15] and the lateral mass screws were placed as per An et al. [5] The holes were prepared with a 2.5 mm drill and 3.5 mm tap prior to screw insertion. The lateral mass screws were placed in a bicortical fashion. The screws were placed under direct visualization, using the previously published starting points noted above.

Screws and acrylic dental cement were then used to secure the specimen to the testing jig. The specimens were allowed to find their own neutral alignment and were not placed in a flexed or extended fashion. A 1.5 × 1.5 cm dynamic pressure sensor (Tekscan K-scan model 6900, range 0–6.894 mPa, Tekscan, Inc, South Boston, MA) was placed anteriorly through a horizontal slit in the disc space. Sensors were also placed into the facet joints.

A precision linear motor (Physik Instrumente, Germany) was used to place a non-destructive uniplanar axial load on the specimens. The axial load was delivered at the center of the vertebral body as defined by the point on the endplates where multiple diameters of the vertebral body intersected. Figure 1 shows the overall set-up.

The specimens were first preloaded for 40 cycles with a load from 0 to 40 newtons (N) as per Rhee et al. [24]. A cyclic load from 0 to 90 N was then applied at a rate of 22.5 N/s as previously described [11, 24]. Cyclic loading was chosen over static loading to closer simulate in vivo conditions. The load shape was trapezoidal. The load gradually increased to 90 N with a constant loading rate, and after reaching 90 N, maintained it for 1-s and then decreased the load back to 0 N with a constant unloading rate. The control was performed by feeding back the measured force signal. We had the desired force value at every 10 ms, and the error between the desired force and the measured force was fed back to the motor controller so that the motor controller can generate some motion to reduce the error. The sampling rate of the motor controller was 4 kHz, so the inner control loop was fast enough to track the desired force which was changing slowly. The specimens

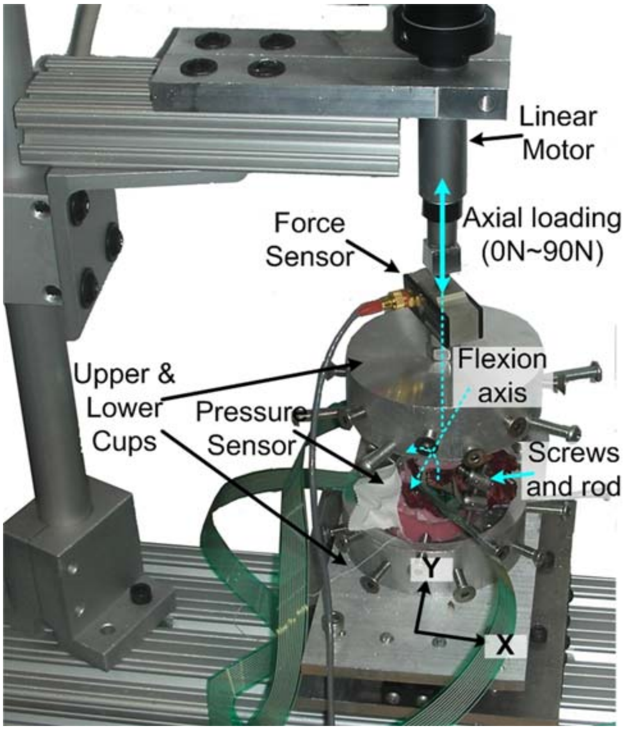

Fig. 1 Overall view of the experimental setup

were tested through 200 cycles with data continuously collected from the pressure sensor in the disc space.

The pressure sensor collected pressure data at individual points. The highest pressure recorded was the peak pressure. The sum of all of the pressures divided by the number of data points was the average pressure. The pressure data was reported in megapascals (MPa). The product of the average pressure and contact area was the force and reported in newtons (N).

Two conditions were tested. The first condition was the physiologic intact condition ("no-construct"). While the cervical screws had been placed prior to loading, the rods had not yet been secured to the screws and thus there was no functional construct in place. The second condition was the screws connected with 3.0 mm titanium rods (Depuy Spine, Summit, Raynham, MA) contoured to follow individual cervical lordosis secured in place ("construct"). This was done so that the specimen would not have to be removed from the testing jig in between conditions. In this way, the applied force and pressure sensor position would be in the identical positions for both conditions.

A paired *t* test was performed to compare the disc pressure/force with and without the constructs in place for both the lateral mass and pedicle screw groups (Microsoft Excel, Redmond, WA). An additional paired *t* test was performed to compare the percent reductions between lateral mass and pedicle screw groups. We chose to perform a paired *t* test instead of an independent *t* test because the two segments from the same specimen were paired, one receiving each construct.

Results

A total of 12 segments from six cadaveric specimens were tested. 24 pedicle screws and 24 lateral mass screws were placed. None of the specimens fractured, and there was no loosening of the screws or rods noted during the experiment. There were no major pedicle perforations, and one (4.2%) minor lateral breach was noted at one of the C4 segments.

There was difficulty obtaining pressure data from the facet joints for technical reasons, and therefore, the analysis of this data was not possible. The data reported below are from the sensor in the intervertebral disc space.

There was no statistical difference noted between the pressure or force collected at cycle 1 compared to cycle 200 for any of the conditions. For average pressure, peak pressure and force, there was a significant difference at the disc space between the no-construct and construct conditions for both the lateral mass and pedicle screw-rod constructs (Tables 1, 2, see tables for *p* values). The percentage decrease for the pedicle screw-rod constructs was significantly greater than the percentage decrease for the lateral mass screw-rod constructs for average pressure ($p \leq 0.002$), peak pressure ($p \leq 0.03$) and force ($p \leq 0.04$). Figure 2 shows a graphical representation of these percentages.

Discussion

The goal of our study was to determine the load sharing abilities of cervical pedicle screw-rod constructs when compared to lateral mass screw-rod constructs. While both constructs showed significant load sharing abilities, our biomechanical testing showed pedicle screw-rod constructs to be superior to lateral mass screw-rod constructs in sharing axial loads. We were able to demonstrate that the disc spaces are subject to significantly less pressure and force with pedicle screw constructs in place than with the lateral mass screw constructs in place. Clinically, this may

Table 1 Lateral mass screw results

No.	Segment	Average pressure			Peak pressure			Force		
		No construct	Construct	% decrease	No construct	Construct	% decrease	No construct	Construct	% decrease
1	C4–5	0.215	0.141	34.4	0.561	0.362	35.6	17.85	11.454	35.8
2	C6–7	0.283	0.232	18.0	1.178	0.934	20.8	30.091	19.402	35.5
3	C4–5	0.416	0.356	14.4	0.945	0.812	14.1	53.684	32.618	39.2
4	C6–7	0.203	0.162	20.1	0.579	0.454	21.6	17.287	12.769	26.1
5	C4–5	0.148	0.139	6.1	0.522	0.491	6.0	16.443	12.595	23.4
6	C6–7	0.110	0.089	19.1	0.312	0.263	15.7	12.75	9.026	29.2

Means of the average pressure, peak pressure and force at the intervertebral disc space with an axial load of 90 N for lateral mass screw-rod constructs. Pressure values are reported in megapascals (MPa) and force values are reported in newtons (N)

Average pressure: ** $p \leq 0.005$

Peak pressure: ** $p \leq 0.01$

Force: ** $p \leq 0.02$

Table 2 Pedicle screw results

No.	Segment	Average pressure			Peak pressure			Force		
		No construct	Construct	% decrease	No construct	Construct	% decrease	No Construct	Construct	% difference
1	C6–7	0.127	0.072	43.3	0.458	0.160	65.1	15.847	4.619	70.9
2	C4–5	0.351	0.271	22.7	1.028	0.793	22.9	36.376	20.602	43.4
3	C6–7	0.253	0.191	24.5	0.599	0.460	23.2	29.054	15.566	46.4
4	C4–5	0.257	0.198	22.9	0.898	0.652	27.3	38.341	21.472	44.0
5	C6–7	0.145	0.116	20.0	0.769	0.650	15.5	16.985	12.595	25.8
6	C4–5	0.152	0.109	28.3	0.528	0.373	29.3	14.139	8.457	40.2

Mean average pressure, peak pressure and force at the intervertebral disc space with an axial load of 90 N for pedicle screw-rod constructs. Pressure values are reported in megapascals (MPa) and force values are reported in newtons (N)

Average pressure: ** $p \leq 0.0006$

Peak pressure: ** $p \leq 0.001$

Force: ** $p \leq 0.003$

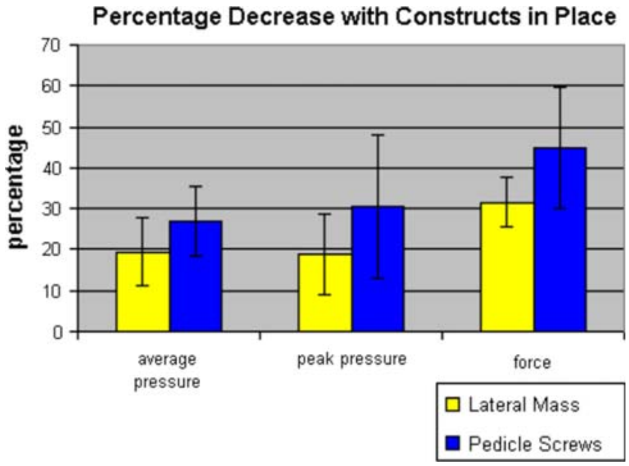

Fig. 2 Summary of results

be advantageous when the surgeon wants to protect the anterior column from increased loads, such as in the case of tumor, fracture, or simply shielding an anterior construct such as a cage or a bone graft. Conversely, this must be balanced against excessive shielding so that the bone still experiences a sufficient load to heal.

Our study is consistent with previous biomechanical testing of cervical pedicle screws. The pullout strength of cervical pedicle screws has been shown to be superior to lateral mass screws after simple [12] or after cyclic fatigue loading [11]. In a multilevel instability model, Kothe et al. demonstrated that pedicle screw fixation was superior to lateral mass fixation with respect to primary stability in lateral bending. After cyclic loading, the loss of stability for flexion/extension, axial rotation, and lateral bending was less with pedicle screw fixation than for lateral mass screw fixation [19]. Our study further confirms that pedicle screw constructs are superior in axial load sharing than lateral mass constructs.

There are legitimate safety concerns with regard to cervical pedicle screw insertion. The relatively small size of cervical pedicles, combined with the close proximity of the vertebral artery, nerve root, spinal cord, and surrounding soft tissues [16] has justifiably concerned surgeons inserting cervical pedicle screws. Anatomic studies have shown a high critical perforation rate from 8.6 to 65.5% [13, 20] depending upon the insertion technique used.

There are clinical data, however, that suggest that cervical pedicle screws can be safely and successfully used. Oda et al. [22] reported on the successful use of cervical pedicle screws for reconstruction for metastatic lesions of the cervical spine. Abumi also reported on their use in both traumatic and non-traumatic cases [1–3]. More specifically, Abumi et al. reported on 712 cervical pedicle screws and noted only one vertebral artery injury. This did not, however, cause any significant neurologic complication for the patient. This article also reported a pedicle breach in 6.7% of the screws, but only a 0.3% incidence of radiculopathy from the pedicle screws [4]. More recently, Kast et al. reported a minor pedicle breach in 21% of their pedicle screws, and 9% of the screws had a critical breach, two causing either temporary paresis or sensory loss. All critical perforations were reported at C3–5 [17]. Finally, Neo et al. reported on 86 screws and noted a 29% pedicle breach rate. However, no vertebral artery or spinal cord injuries were reported [21]. Thus, while there is clearly a high rate of pedicle perforations reported in the literature, very few clinical complications have resulted. Additionally, lateral mass screws are not without safety concerns. There have been reports of nerve root injuries by lateral mass as well as loss of fixation [7, 8, 10].

There are limitations to our study. This was a cadaveric experiment using only one motion segment at two cervical levels and may not apply to a complete cervical spine in vivo. The accuracy of pedicle screw placement was likely higher in our experiment than in a true surgical setting as we were able to remove soft tissues from the specimen and view the entire path of the pedicle quite easily. Ideally, we would have been able to perform the pedicle screw fixation and lateral mass screw fixation on the same segments for direct comparison. However, this was not possible, as the screw paths would have overlapped. Therefore, we used segments from the same cadaveric specimen to help minimize variability between the segments. We are aware of the differences in the anatomy of the different levels, but it would have been impossible to get completely identical segments and we therefore compromised by randomizing the samples. We also would have ideally had bone quality information for the specimen tested. Finally, although we attempted to let the segments find their own neutral alignment and apply a pure axial load, it is possible that small flexion/extension or lateral bending movements occurred with loading. Though we were not able to completely eliminate these small moments, they were most likely the same for both control and experimental constructs since we did not have to remove the segment from the testing apparatus in between the control and experimental constructs.

Though we attempted to measure pressure at the facet joints, the data were inconsistent. This could have been due to a mismatch between the size of the pressure sensors and the facet joints themselves. Also, there were likely individual variations in the facet-to-rod distance in the sagittal plane causing uneven loads to be placed across the facets.

Lateral mass screws remain the gold standard for posterior cervical spine fixation. As noted previously, there are situations where pedicle screws may be a viable alternative. Our study suggests that constructs using pedicle screws will decrease the load at the disc space more than those using lateral mass screws. It remains to be seen, however, if the clinical benefit of increased stiffness warrants the increased risks of pedicle screw placement.

Conclusion

Cervical pedicle screw-rod constructs demonstrated a greater reduction in axial load transfer through the intervertebral disc than lateral mass screw-rod constructs. Though there are dangers associated with the insertion of cervical pedicle screws, their use might be advantageous in some clinical conditions when increased load sharing is necessary.

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Conflict of interest statement Depuy Spine provided implants used in the study.

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