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Biomechanical Stability of a Cross-Rod Connection with a Pedicle Screw System

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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
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Background: Surgery with pedicle screw instrumentation does not provide sufficient torsional stability. This leads to pseudoarthrosis, loosening of the pedicle screws, and, ultimately, implant failure.

Material/Methods: Functional spinal units from 18 deer were evaluated using a 6-axis material testing machine. As specimen models, we prepared an intact model, a damaged model, a cross-rod model, and a cross-link model. We measured the range of motion (ROM) during bending and rotation tests.

Results: The range of motions of cross-rod model were almost equal to those of cross-link model during the bending test. In the rotation test, the average ranges of motion of the intact, cross-rod, and cross-link models were 2.9°, 3.1°, and 3.9° during right rotation and 2.9°, 3.1°, and 4.1° during left rotation, respectively. The range of motions of the cross-rod model were significantly smaller than those of the cross-link model during the rotation test. The range of motions of the intact model were significantly smaller than those of the cross-link model during the rotation test, but there were no statistically significant differences between the range of motions of intact model and cross-rod model during the rotation test.

Conclusions: The stability of spinal fixation such as cross-rod model is equal to the fixation using the pedicle screw system during bending tests and equal to that of the intact spine during rotation tests.

MeSH Keywords: **Animal Experimentation • Spine • Surgical Instruments**

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Background

The number of spinal fusion surgeries has been increasing in recent years with advancements in spinal fixation technology, and most of these surgeries are performed using the pedicle screw (PS) system [1,2]. The purpose of fusion surgery is to stabilize the spine, but the surgery with PS instrumentation does not provide sufficient torsional stability. Consequently, this leads to pseudoarthrosis, loosening of the PSs, and, ultimately, implant failure. This is a problem that cannot be overlooked [3,4]. There have been some reports that the ROMs of the PS model were larger than those of an intact model, and the cross-link system does not provide enough stability to a damaged spine [5,6]. To explore this stability problem further, we investigated fixation methods using different rod connections. In architecture, cross-bracing is used to make a building stronger. With inspiration from cross-bracing, we diagonally connected PSs and fixed a point of intersection with resin. In this study, we used deer spines asa specimens, because deer are culled as part of a wildlife management program in our region and are readily available. Because deer and human spinal anatomies differ, it is impossible to compare the biomechanics data simply by range of motion (ROM). As described by Wasinpongwanich et al., however, when the ROM changes rate, an index is used to evaluate how the intervertebral stability will change when the normal spine of deer is injured or fixed by instrumentation, showing that the ROM change rate in the normal, damaged, and PS fixation models in deer very closely approximates that of humans [7]. In experiments exploring biomechanical tendencies, as in the present study, the spines from culled deer are therefore considered a reasonable alternative to human spines [8–10].

Material and Methods

Functional spinal units from deer that were culled as part of a wildlife management program were used as specimens. Eighteen FSU (7 from L1–2, 7 from L3–4, and 4 from L5–6) of deer were used as specimens. The lumbar vertebrae were initially preserved at –30°C. After thawing each of the frozen lumbar spines at room temperature, the muscles and fat were removed while the internal stabilizing elements were retained. The cranial and caudal portions of each specimen were fixed to a jig with dental resin. As specimen models, we prepared: 1) an intact model (INT), 2) a damaged model (DAM), 3) a cross-rod model (CR), and 4) a cross-link model (CL) (Figure 1). Internal stabilizing elements were retained in INT. DAM was prepared by drilling through-holes (3 mm in diameter) at sites 1/4, 1/2, and 3/4 of the distance from the anterior surface of the intervertebral disc and removing its supraspinous ligament, interspinous ligament, and both facet joints. CR was fixed with ϕ5.5×35 mm PSs and connecting rods (5 mm in diameter) (KISCO Co. Ltd., SUIREN®, Kobe, Japan) in the shape of an X and fixed at the point of intersection with dental resin. CL was fixed with ϕ5.5×35 mm PSs and connecting rods

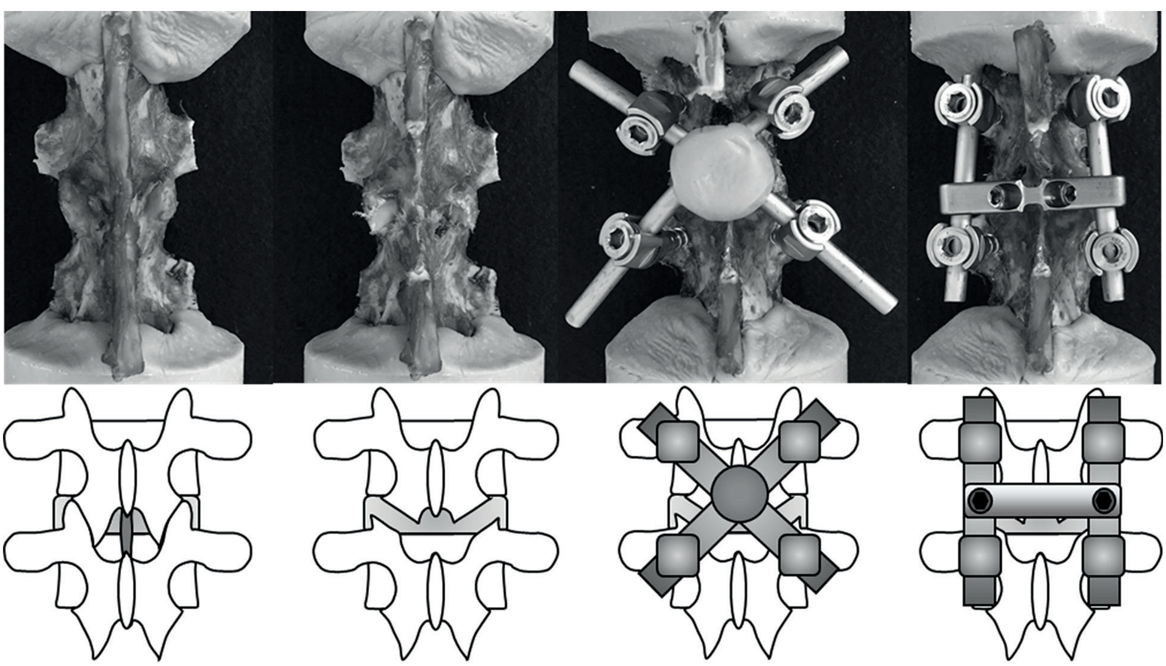

Figure 1. Scheme of each model.

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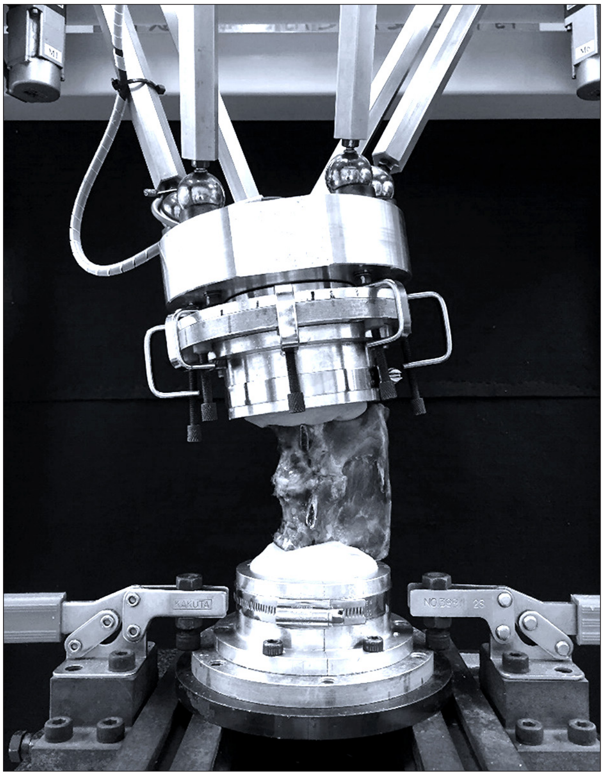

Figure 2. A six-axis material testing machine.

(5 mm in diameter) (KISCO Co. Ltd., SUIREN®), and additionally with a cross-link system (Medtronic, TSRH®RP, Memphis, TN, USA) (Figure 1).

For the biomechanical tests, a 6-axis material testing machine developed in our laboratory that allows motion with 6 degrees of freedom was used (Figure 2) [11]. In this study, we performed both a bending test (anterior, right-anterior, right, right-posterior, posterior, left-posterior, left, and left-anterior bending) and a rotation test (right and left rotation). Each test was performed for 2 cycles. The torque was set at –3.0 to 3.0 Nm for the bending test and –5.0 to 5.0 Nm for the rotation test and was loaded at an angular speed of 0.1 degrees/s. Superior vertebral body displacement/angular displacement and generated force/torque were determined in each test and recorded using a computer (sample cycle, 1 Hz). We defined the superior vertebral angular displacement as the result recorded when the maximum torque was loaded as the range of motion (ROM) and compared the ROM of each model.

We used the Friedman test to investigate intergroup differences among 3 models in each study. When the overall differences were statistically significant, a post hoc analysis was performed using the Steel-Dwass test for multiple comparisons among the 3 groups. The level of statistical significance was set at a risk ratio <0.05.

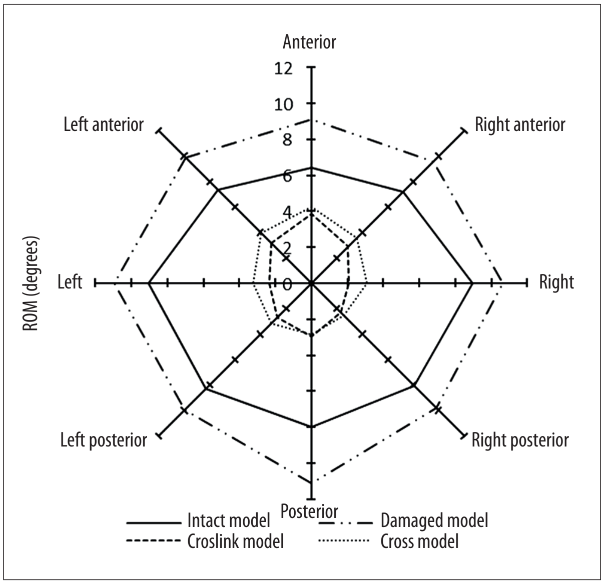

Figure 3. The chart shows average of the ROMs of each model during the bending test.

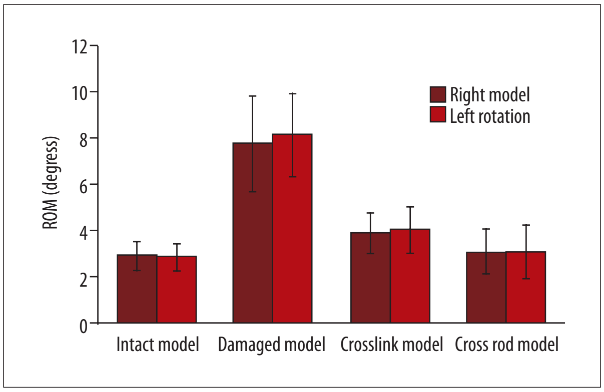

Figure 4. The chart shows average of the ROMs and standard deviations of each model during the rotation test.

Results

Figures 3 and 4 show the results of the biomechanical tests, and Table 1 shows the results of the statistical analysis.

In the bending test, the average ROMs of INT, DAM, CR, and CL were 6.4°, 9.1°, 4.3°, and 3.9° during anterior bending; 7.2°, 9.6°, 3.6°, and 2.9° during right-anterior bending; 9.0°, 11°, 3.1°, and 2.1° during right bending; 8.0°, 9.8, °, 2.6°, and 2.3° during right-posterior bending; 8.0°, 11°, 2.9°, and 3.0° during posterior bending; 8.3°, 10°, 3.2°, and 2.7° during left-posterior bending; 9.0°, 11°, 3.2°, and 2.3° during left bending; and 7.4°, 9.9°, 3.9°, and 3.1° during left-anterior bending, respectively.

In the rotation test, the average ROMs of INT, DAM, CR, and CL were 2.9°, 7.7°, 3.1°, 3.9° during right rotation and 2.9°, 8.2°, 3.1°, 4.1° during left rotation, respectively.

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Table 1. The results of multiple comparisons between Intact model, Damaged model, Crosslink model and Cross rod model.

	Anterior	Right anterior	Right	Right posterior	Posterior	Left posterior	Left	Left anterior	Right rotation	Left rotation
Intact – Damaged	**	**	*	**	**	**	*	**	**	**
Intact – Crosslink	**	**	**	**	**	**	**	**	**	**
Intact – Cross rod	**	**	**	**	**	**	**	**		
Damaged – Crosslink	**	**	**	**	**	**	**	**	**	**
Damaged – Cross rod	**	**	**	**	**	**	**	**	**	**
Crosslink – Cross rod			*						*	*

* Statistical significance (Level of significance <5%); ** statistical significance (Level of significance <1%).

The ROMs of DAM were significantly larger than those of INT in all directions during the bending and rotation tests. The ROMs of CL and CR, which used implants, were significantly smaller than those of DAM in all directions during the bending and rotation tests.

The ROMs of CR were slightly larger than those of CL during the bending test, but only the difference in ROMs during the right bending was statistically significant. Thus, the ROMs could be considered to be approximately equal. The ROMs of CR were significantly smaller than those of CL during the rotation test.

The ROMs of INT were significantly larger than those of CL during the bending test and significantly smaller than those of CL during the rotation test. In contrast, the ROMs of INT were significantly larger than those of CR, but there were no statistically significant differences between the ROMs of INT and CR during the rotation test.

Discussion

The insufficient fixation capability of the PS system during rotation is well known, even though the objective of spinal fusion surgery using this system is to stabilize the spine. Wahba et al. experimented with a burst fracture model and reported that the stiffness of the PS model was weaker than that of an intact model [5]. Lim et al. experimented with a discectomy model and reported that the ROMs of the PS model were larger than those of an intact model [11]. We also performed biomechanical experiments with a facetectomy model and concluded that the ROMs of the PS model were larger than those of an intact model during rotation tests and that insufficient torsional stability might be the cause of pseudoarthrosis and implant failure.

Reducing surgical invasion is a way to prevent destruction of stable elements. Various trials have been done to reduce operative invasion. Yang et al. reported the clinical efficacy of modified posterior vertebral resection [12] and Wang et al. reported the safety and effectiveness of the suprapedicular foraminal endoscopic approach to lumbar lateral recess decompression [13].

On the other hand, the cross-link system is a method to add instrumentation. The cross-link system has been used to increase torsional stability, but Wahba et al. reported that the stiffness of the damaged spine with the PS system and 2 crosslinks was lower than that of the intact spine.[5] These results indicate that concomitant use of the cross-link system does not provide enough stability to a damaged spine. Li et al. reported that a novel pedicle screw and plate system can provide sufficient segmental stability in axial rotation [14]. However, there was no significant difference between the unilateral pedicle screw and rod model and unilateral pedicle screw and plate model; therefore, there is room for improvement of this novel system.

In this study, we compared CL and CR. The ROMs of CR were equal to the ROMs of CL but smaller than those of INT during the bending test. The ROMs of CR were smaller than the ROMs of CL and equal to those of INT during the rotation tests. These results indicate that CR had equal stability to CL during the bending tests and equal stability to INT during the rotation tests.

Therefore, CR had equal stability to PS instrumentation during the bending tests and equal stability to INT, which is stronger than PS instrumentation. CR has strong stability, not only during bending tests, but also during rotation tests, and is a good method for stabilizing the spine as part of spinal fusion surgery. Sufficient stability reduces the load on the implant and reduces the possibility of implant failure. To the best of our knowledge, there are no reports on attempts to connect rods in the shape of an X. However, connecting rods like CR during a real operation is unrealistic, so we plan to make a new implant that is similar to CR.

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The limitations of this study include using cadaveric deer spines as specimens, not doing cycling tests, and not investigating the effect of adjacent segments. We have previously reported that it is reasonable to use cadaveric deer and boar spines in qualitative determinations of comparing each model with biomechanical experiments [7]. Kumar et al. also reported that deer spine can be used as a model for some human biomechanical experiments because of its biomechanical and material similarities to the human spine [8,9]. Liu et al. also reported that the deer lumbar spine is more similar to that of humans in anatomical form and biomechanics than the sheep lumbar spine [10]. However, experiments using human cadavers are needed for quantitative determinations.

We plan to do further experimentation with human cadavers, multilevel models, and cycling tests.

Conclusions

The stability of spinal fixation such as the cross-rod model is equal to the fixation using the pedicle screw system during bending tests and equal to that of the intact spine during rotation tests; therefore, a cross-shaped rod might be used clinically in patients with spinal rotatory instability.

Conflict of interest

None.

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