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The Trans-Spinous Crosslink Increases the Pull-Out Strength of the Pedicle Screw Instrumentation

Yunus Emre DURMUS[1], Aykan ULUS[1], Alparslan SENEL[1]

Ondokuz Mayis University Faculty of Medicine, Department of Neurosurgery, Samsun, Turkey

Corresponding author: Aykan ULUS ✉ aykanulus@gmail.com

ABSTRACT

AIM: To evaluate whether adding an extra anchoring point to the construct by passing the crosslink through a hole in the spinous process (trans-spinous crosslink technique), may prevent screw loosening by increasing the pull-out strength.

MATERIAL and METHODS: Twenty-four fresh-frozen single lumbar sheep vertebrae were instrumented with pedicle screws bilaterally, and they are connected to each other with a crosslink. All vertebrae were assigned randomly to either the experiment (trans-spinous crosslink) group or the control group. In the experiment group, the crosslink was passed through a hole within the spinous process. In the control group, the posterior part of the hole was removed. The pull-out force of the construct was determined using a mechanical testing machine.

RESULTS: The mean pull-out forces of the experiment group and the control group were 1949 ± 361.55 N and 1338.57 ± 220.26 N, respectively. The pull-out force of the experiment group was significantly higher than those of the control group with 99.9% confidence ($p < 0.001$).

CONCLUSION: The pedicle screws rigidly anchor the internal fixation devices to the vertebral colon. In classical construct design, pedicle screws share the load. Adding extra anchoring points decreases screw share and may prevent construct pull-out. This study shows that the trans-spinous crosslink can serve as an anchoring point and increases the construct pull-out strength.

KEYWORDS: Spine, Internal fixators, Pedicle screws, Crosslink, Pull-out strength

ABBREVIATIONS: N: Newton, **mm:** millimeter, **s:** second, **L:** lumbar

INTRODUCTION

Pedicle screw instrumentation has been used commonly for the treatment of unstable spine fractures and degenerative spinal disorders, since their introduction by Roy-Camille et al. (22). The pedicle screws connect stabilizing rods to the vertebra. They are the anchoring parts of the construct. As the pedicles are the strongest part of the vertebra, instrumentation with the pedicular screws can help maintain spinal alignment and stability. Screw loosening is one of the major complications of this system, with incidence that ranges from less than 1% to 15% (14), and apparently more common among patients with osteoporosis (16). Screw loosening may cause sagittal plane collapse of the spine; therefore, kyphosis, dislocation, and neurologic deficits may develop. It usually requires revision surgery. Several techniques have been proposed to prevent pedicle screw pull-out including screw augmentation with cement, using cortical bone trajectory, larger and expandible screws, etc., especially in patients with osteoporosis. The crosslinks (transverse connectors) are used to improve rotational stability in screw–rod instrumentation (9). We hypothesized that adding extra anchoring point to the construct, by passing the crosslink through a hole in the spinous process (trans-spinous crosslink technique), may increase the pull-out strength.

Yunus Emre DURMUS : 0000-0001-6331-1787 Aykan ULUS : 0000-0001-8373-7072 Alparslan SENEL : 0000-0003-3530-5480

MATERIAL and METHODS

The experimental part of the study was conducted in Ondokuz Mayis University Black Sea Advanced Technology Research and Application Center (KITAM). Ondokuz Mayıs University Local Animal Experiments Ethical Committee has confirmed that no ethical approval is required.

Twenty-four fresh-frozen lumbar vertebrae from L1, L2, or L3 lumbar levels were obtained from 1–1.5-year-old sheeps slaughtered in a local slaughterhouse. Soft tissues were removed before biomechanical testing. All vertebrae were assigned randomly to either the experiment (trans-spinous crosslink) group or the control group.

Titanium alloy pedicle screws (3.5 mm in diameter, 30 mm in length) were placed into both pedicles by a single surgeon to eliminate technical bias. All screws were inserted medially in the coronal plane and did not reach the anterior cortical bone. Two rods (6 mm in diameter) were attached to the screw heads on both sides separately and connected to each other by a crosslink. In the experiment group, a small hole was prepared in the spinous process, and the crosslink was passed from this hole (Figure 1). In the control group, the crosslink was placed at the same point, but the posterior part of the hole was removed totally (Figure 2).

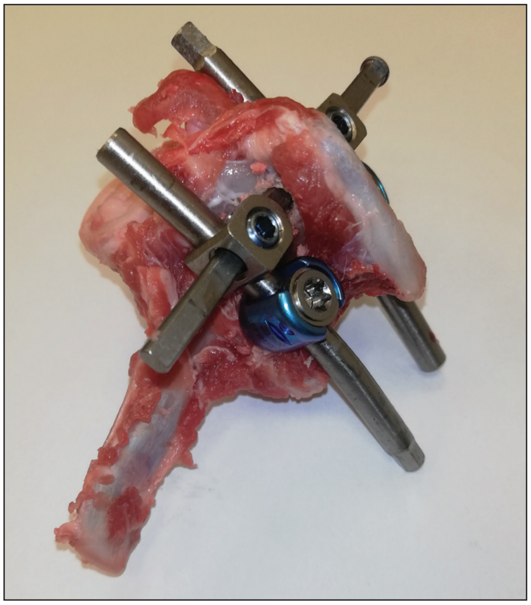

Figure 1: In the experiment group, a small hole was prepared in the spinous process, and the crosslink was passed from this hole (trans-spinous crosslink technique).

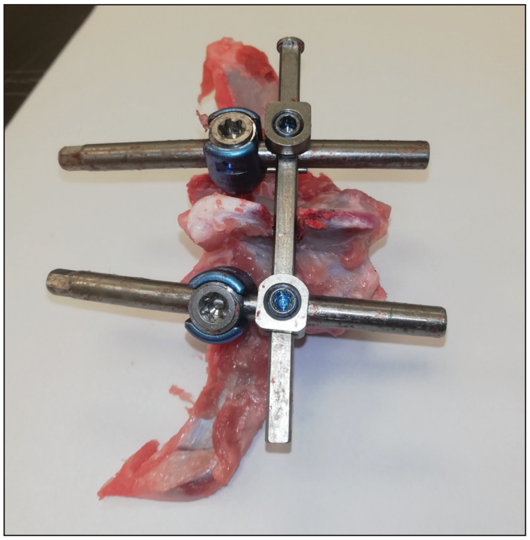

Figure 2: In the control group, a cleft was prepared in the spinous process and the crosslink was passed from this cleft.

The strength of the construct was evaluated with pull-out tests. A mechanical testing machine (Instron 5982, Illinois Tool Works Inc., USA) was used to determine the maximum pull-out force of the construct setup. A steel bar was passed through the spinal canal, and it was mounted to the lower part of the machine from both ends by using a steel chain. Bilateral rods, connected to the pedicle screws, were mounted to the upper part of the machine from their tips by using another steel chain (Figure 3). A constant pull-out displacement (0.1 mm/s) was applied to the construct–vertebra complex until failure occurred. The maximum point on the load–displacement curve was accepted as the maximum pull-out force (Figure 4).

Obtained data were evaluated with SPSS v21.0 software (IBM Corp. Armonk, NY, USA). The Shapiro–Wilk test was performed for the evaluation of normality, and the normal distribution of the data was confirmed. Data of the experiment and control groups were evaluated with independent t-tests. P values <0.05 were considered statistically significant.

RESULTS

The pull-out forces of the experiment and control groups are shown in Table I. In the control group, the maximum and minimum values were 1656.035 N, and 922.328 N respectively. The mean pull-out force in the control group was 1338.57 ± 220.26 N. In the experiment group, the maximum and minimum values were 2433.651 N and 1436.284 N, respectively. The mean pull-out force of the experiment group was 1949 ± 361.55 N (Figure 5), which was 45% higher in the experiment group than in control group. The mean pull-out force of the experiment group was significantly higher than those of the control group with 99.9% confidence (p<0.001).

DISCUSSION

The posterior pedicle screw instrumentation is a commonly used technique for the internal fixation of the vertebral colon. One of the main problems is the pull-out of the instrumentation construct. Numerous techniques and precautions were suggested to prevent pull-out of posterior spinal constructs, which are based on enhancing bone–screw purchase or adding an extra anchoring point to the construct.

Obtaining adequate purchase between the screw and bone is a major concern for a successful fusion in the instrumented spine (1). The screw diameter, screw design, screw trajectory

Figure 3: The instrumented vertebra was mounted to the upper and lower parts of the testing machine.

Table I: Pull-Out Forces of Control and Experiment Groups

Control Group		Experiment Group		
	Pull-out Force (N)		**Pull-out Force (N)**	**p**
Mean ± SD	**1338.57 ± 220.26**	**Mean ± SD**	**1949 ± 361.55**	**<0.001**
1	1375,836	**1**	1996,872	
2	1451,114	**2**	1680,005	
3	1245,409	**3**	2320,763	
4	1103,633	**4**	1660,648	
5	1610,427	**5**	1708,512	
6	1182,030	**6**	1849,054	
7	922,328	**7**	2275,764	
8	1476,957	**8**	2251,696	
9	1184,944	**9**	2318,255	
10	1656,035	**10**	2433,651	
11	1315,545	**11**	1436,284	
12	1538,576	**12**	1457,506	

***N:** Newton, **SD:** Standard deviation.*

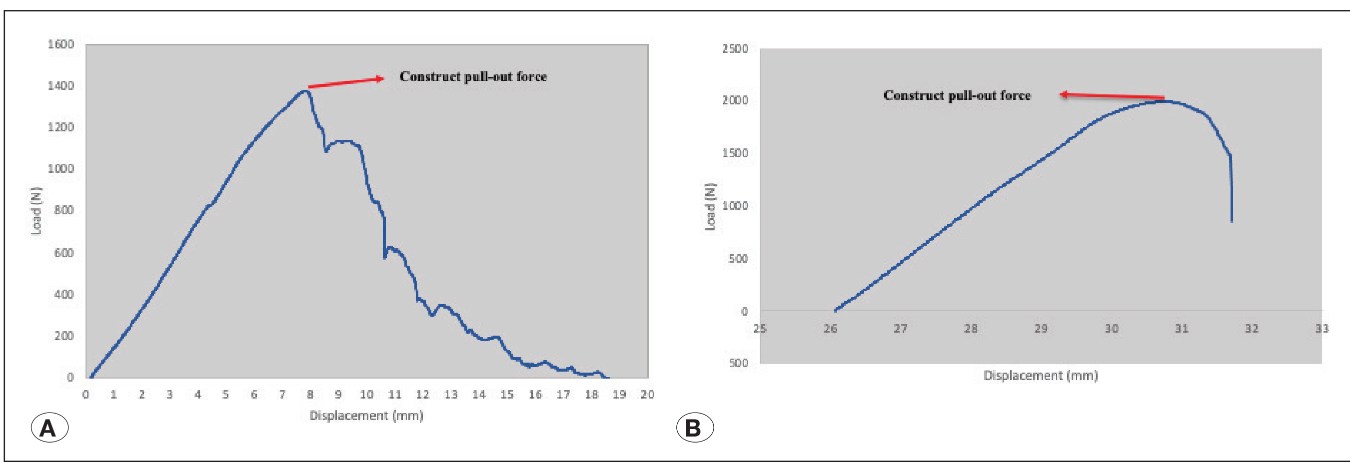

Figure 4: The maximum point on the load–displacement curve was accepted as the maximum pull-out force (**A:** A sample from the control group, **B:** A sample from the experiment group; N, Newton; mm, millimeter).

within the pedicle, and screw depth have been reported as influencing factors for screw purchase (1). Bone property is another determinant. Different screw designs have been proposed to enhance bone–screw purchase including conical screws (4), expandible screws (2,8), and coated screws (19). Pedicle screw augmentation with cement is a preferred technique inspired from vertebroplasty (3,12,13). Different screw designs and techniques for augmentation can be employed, such as augmentation with fenestrated screws (6,7,10,12), cannulated screws injected with cement through perforations (5,12), cement vertebroplasty prefilling method (6,12), and pedicle screws prefilled with cement (5,7,12).

The pedicle screws rigidly anchor the internal fixation devices to the vertebral colon. Adding extra anchoring point(s) to the construct is another option to improve pull-out strength instead of using the aforementioned bone–screw purchase-enhancing methods. Laminar hooks, intralaminar screws, and pedicular hooks are used as additional anchors (11,15). From this idea, we used a trans-spinous crosslink as an extra anchor to increase pull-out strength.

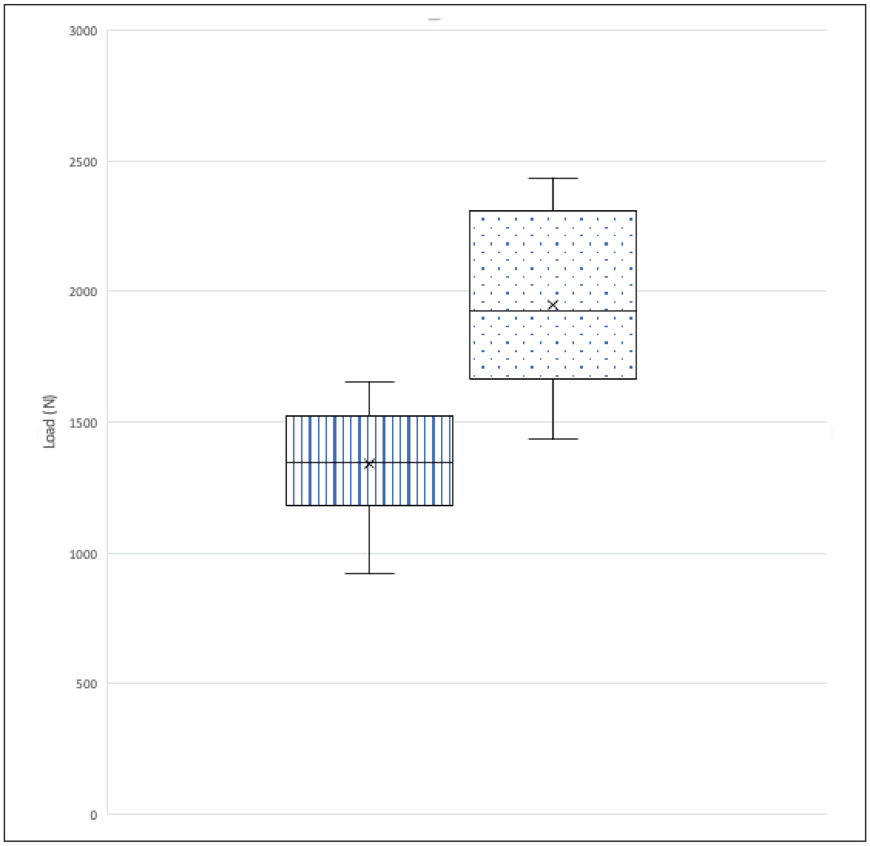

Figure 5: Box plots of the control and experiment groups (vertical stripes, control group; dotted, experiment group; N, Newton).

The mean pull-out forces of the experiment group and control group were 1949 ± 361.55 N and 1338.57 ± 220.26 N, respectively. The pull-out force of the experiment group was significantly higher than that of the control group with 99.9% confidence ($p<0.001$). These results show that the use of a trans-spinous crosslink as an extra anchor increases the pull-out force of posterior pedicle screw constructs.

The trans-spinous crosslink technique has some advantages when compared with other technique in terms of complications. As the location of the crosslink within the spinous process is not related with neural tissues, any neurologic deficit is not expected to be related to the trans-spinous crosslink technique. It may cause minor problems such as spinous process fracture during installation, which is not expected to cause a neural injury. However, laminar hooks, intralaminar screws, and pedicular hooks may cause serious complications by invading the neural canal (20). Pedicle screw augmentation may cause serious complications including neurologic deficits due to cement leakage, embolism, thermal necrosis, monomer toxicity, and adverse bone remodeling (17,18). In addition, revision of cement augmented screws may be difficult.

As the crosslinks are used routinely by most of the surgeons to enhance rotational stability, the trans-spinous crosslink technique does not cause extra cost. Even if it is added to the construct setup only for the trans-spinous crosslink technique, it is still less costly than other techniques.

Bone–screw purchase highly relies on cancellous bone properties, which is affected by osteoporosis more than the cortical bone (21). In patients with osteoporosis, the use of the spinous process, which is mostly composed of cortical bone, as an extra anchorage point would increase the pull-out strength. Besides, this technique can also be used together with the bone–screw purchase-enhancing methods such as those with different screw designs or pedicle screw augmentation technique.

Contraindications for using the trans-spinous crosslink technique are fractures of the spinous process and lamina. Performing laminectomy on the related level would also prevent such a design. However, in that case, the upper healthy vertebra has to be included to the construct design because construct failure or screw loosening usually occurs at the cranial part of the instrument. The crosslink can be mounted between upper screws. To perform this technique, the crosslink connection sites on both rods and the spinous process should be aligned properly. Pronounced downward angle of the spinous processes in the thoracic region provides suitable alignment (23). It may be difficult, but not impossible, to use a trans-spinous crosslink in the lumbar region because of short and relatively perpendicular structure of the spinous processes. We used this technique in both the thoracic and lumbar regions in selected patients (Figure 6).

The main limitation of this study is related to its use of sheep vertebra instead of human vertebra. Its spinous process has

Figure 6: The white arrow shows a trans-spinous crosslink bypassing the spinous process of a thoracic vertebra.

more cortical bone, and our data might be affected by this stronger composition. A hole in the human spinous process may easily become enlarged and deformed under load.

The results of this study show the resistance against acutely increasing force, but do not show the effects of repeating microtraumas. The fatigue test spanning over days, which simulates real-life conditions better, would be a more suitable testing design. In this construct design, the load is shared by pedicle screws and the crosslink inside the spinous process. In this study, the pedicle screw size (3.5 mm) used is smaller than those usually used in humans. The role of the trans-spinous crosslink may be augmented erroneously due to weak pedicle screws. In other words, the role of the spinous process would be much less with stronger, thick screws. Besides, in real life, a whole construct includes a minimum of four screws. Similarly, the load share of the spinous process would be less important with more screws.

As the soft tissues are removed, the effects of the ligaments and muscles are ignored. If the study is replicated in human cadavers, loading the whole construct using fatigue test design, more reliable data would be obtained.

CONCLUSION

This study shows that adding extra anchoring point to the construct, by using the trans-spinous crosslink technique, increases the construct pull-out strength with relatively low cost and without probable serious complications.

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AUTHORSHIP CONTRIBUTION

Study conception and design: AS

Data collection: YED

Analysis and interpretation of results: YED, AU

Draft manuscript preparation: AU, YED

Critical revision of the article: AU, AS,

Study supervision: AS

All authors (YUD, AU, AS) reviewed the results and approved the final version of the manuscript.

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