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Are pedicular screws and lateral hook screws more resistant against pullout than conventional spinal hooks and screws in terminal vertebral segment fixation?

Terminal vertebra segment tespitinde sıyrılmaya karşı pediküler vida ve lateral çengelli vidalar konvansiyonel spinal çengel ve vidalardan daha dayanıklı mıdır?

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ABSTRACT

Objectives: This study aims to biomechanically evaluate and compare four well-known types of terminal spinal constructs to a novel construct composed of a transpedicular screw with a lateral hook screw in terms of axial pullout strength in terminal vertebral segment fixation.

Materials and methods: Forty fresh-frozen lamb spines were divided into five groups with eight spines each. To stabilize the transverse process, a pedicular screw alone was used in group 1, a sublaminar hook alone was used in group 2, a sublaminar hook and a pedicular screw were used in group 3, claw hook alone was used in group 4, and a pedicular screw with a lateral hook screw was used in group 5. Biomechanical tests were performed using an axial compression testing machine and two noncontact camera systems.

Results: The mean pullout strength value was 927 N for group 1, 626 N for group 2, 988 N for group 3, 972 N for group 4, and 1194 N for group 5. Pullout strength values were statistically significantly higher in groups 3 and 4 compared to groups 1 and 2. There was no statistically significant difference between groups 3 and 4. Pullout strength value of group 5 was statistically significantly higher than the other groups.

Conclusion: Pedicular screw with a lateral hook screw had the highest fixation value. Lateral hook screw may assist to prevent pullout in patients with pullout risk and hyperkyphosis and after hyperkyphosis surgery. Further prospective clinical studies are needed to show the benefit of such a construct in reducing the risk of distal instrumentation pullout.

Keywords: Pullout strength; terminal fixation; thoracolumbar surgery.

ÖZ

Amaç: Bu çalışmada terminal vertebra segment tespitinde dört iyi bilinen terminal spinal yapı türü ile lateral çengelli vidalı transpediküler bir vidadan oluşan yeni bir yapı aksiyel sıyrılma gücü açısından biyomekanik olarak değerlendirildi ve karşılaştırıldı.

Gereç ve yöntemler: Kırk adet taze dondurulmuş kuzu omurgası her grupta sekiz omurga olacak şekilde beş gruba ayrıldı. Transvers çıkıntıyı stabilize etmek için grup 1'de sadece pediküler vida, grup 2'de sadece sublaminar çengel, grup 3'te sublaminar çengel ve pediküler vida, grup 4'te sadece pençe çengel ve grup 5'te lateral çengelli vidalı pediküler vida kullanıldı. Biyomekanik testler aksiyel kompresyon test cihazı ve iki adet temas etmeyen kamera sistemi kullanılarak yapıldı.

Bulgular: Ortalama sıyrılma gücü değeri grup 1'de 927 N, grup 2'de 626 N, grup 3'te 988 N, grup 4'te 972 N ve grup 5'te 1194 N idi. Sıyrılma gücü değerleri grup 3 ve 4'te grup 1 ve 2'ye kıyasla istatistiksel olarak anlamlı şekilde daha yüksekti. Grup 3 ve 4 arasında istatistiksel olarak anlamlı farklılık yoktu. Grup 5'in sıyrılma gücü değeri diğer gruplardan istatistiksel olarak anlamlı şekilde daha yüksekti.

Sonuç: Lateral çengelli vidalı pediküler vida en yüksek tespit değerine sahipti. Lateral çengelli vida sıyrılma riski olan ve hiperkifozlu hastalarda ve hiperkifoz cerrahisi sonrasında sıyrılmayı önlemeye yardımcı olabilir. Distal enstrümanların sıyrılma riskini azaltmada bu yapının yararını göstermek için ileri prospektif klinik çalışmalar gerekmektedir.

Anahtar sözcükler: Sıyrılma gücü; terminal tespit; torakolomber cerrahi.

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Pullout of spinal terminal instrumentation after surgical treatment for thoracolumbar pathologies is frequently encountered (Figure 1).[1-6] The incidence of distal construct failure ranges from 3% to 50%, based on previous clinical studies.[7,8] The mechanical and material properties of implants are important factors in determining the strength of the fixation and the biomechanical properties of bone-instrumentation interface.[9-11] Screws, hooks, and claws may loosen progressively over time as a result of nonunion and persistent micromotion, causing instrumentation failure due to laminar fracture or pullout of the transpedicular screws. *In vivo* cases of transpedicular screw failure due to breakage and bending have been reported in the literature.[12,13] Many biomechanical studies focused on the strength of the terminal vertebral construct in kyphosis surgery to lower the incidence of pullout phenomena and to offer a more stable anchor.[12-16] However, the literature search did not reveal a well-designed study and guidelines based on solid biomechanical information to help clinicians select the type and configuration of these anchors.

We have developed a new anchor system composed of a transpedicular screw with a lateral hook screw (which itself consists of a lateral transverse process hook augmented with a hole for a locking lateral cortical screw inserted through the corpus of the terminal vertebra) to enhance the pullout strength of the terminal vertebra construct in kyphosis surgery.

Therefore, in this study, we aimed to biomechanically evaluate and compare four well-known types of terminal spinal constructs to this novel construct composed of a transpedicular screw with a lateral hook screw in terms of axial pullout strength in terminal vertebral segment fixation. This work was also conducted to determine the modality of terminal fixation that may provide optimal biomechanical resistance to pullout in thoracolumbar spinal surgery. We hypothesized that the transpedicular screw with a lateral hook screw enhances the pullout strength of the terminal vertebral construct in kyphosis surgery.

MATERIALS AND METHODS

Forty fresh-frozen lamb spines were divided into five groups with eight spines each. To stabilize the transverse process, a pedicular screw alone was used in group 1, a sublaminar hook alone was used in group 2, a transpedicular screw augmented with sublaminar hooks via a domino connector was used in group 3, claw hook alone was used in group 4, and the novel method of a pedicular screw with a lateral hook screw was used in group 5 (Figure 2). A transverse connector was then placed between the rods at T_{12} to increase the lateral rigidity of the dual-rod construct. Instrumentation was performed by a single experienced spinal surgeon. The study was approved by the Ethics Committee of the Anatomy Department of Dokuz Eylul University Faculty of Medicine in 27/11/2014, under the reference number 235.

Lamb spines were harvested and 40 were deemed to be anatomically representative of the human spine, making them eligible for the type of instrumentation used for this study. This model was chosen because it has been reported to approximate the size and shape of human vertebrae.[17] The average age of lambs was 12.3±3.42 months. The specimens were free of macroscopic and radiological diseases.

The spine of each specimen was dissected from T_{12} to L2. All muscle tissue was dissected and cleaned from the spinal units with care to preserve the interspinous and ligamentum flavum ligaments, the facet joint capsules, and the intervertebral discs. A mechanical caliper (Mittoyoto, Japan, 0.01 mm accuracy) was used to measure the pedicle dimensions and the transverse and sagittal plane diameters of the vertebral bodies. Each specimen

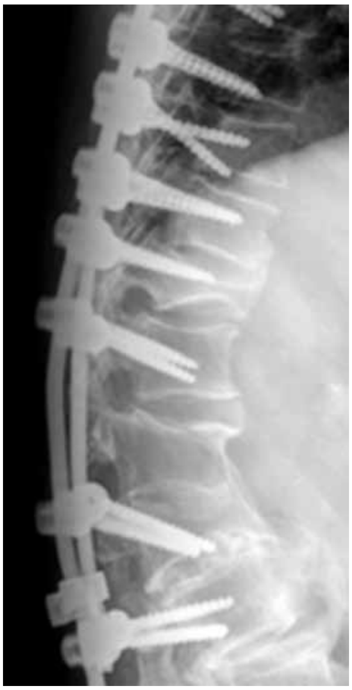

Figure 1. A degenerative thoracolumbar spine with a pullout occurrence of terminal screws.

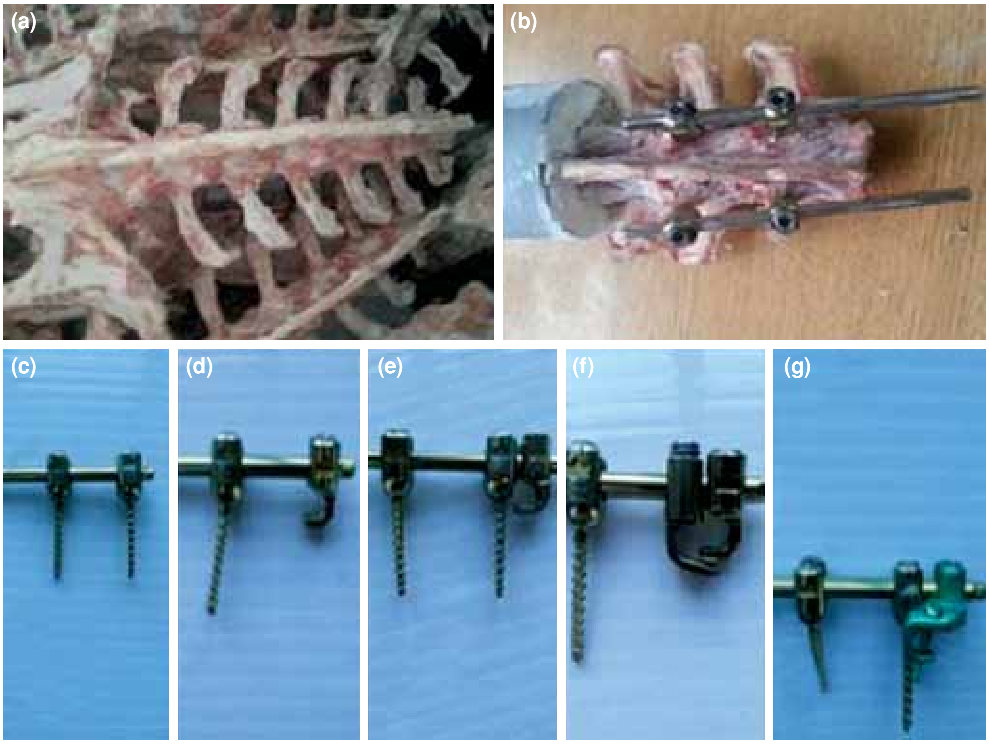

Figure 2. Different terminal fixation anchoring examples. **(a)** Lamb spine samples with thoracolumbar spine prepared for fixation. **(b)** Lamb spine (T_{12}-L_1) fixed with posterior fixation construct. **(c)** Terminal anchor performed with a single screw alone. **(d)** Terminal anchor performed with a single sublaminar hook alone. **(e)** Terminal anchor performed with transpedicular screws and sublaminar hooks. **(f)** Terminal anchor performed with claw hooks alone. **(g)** Terminal fixation performed with novel construct which is composed of a trans-pedicular screw with a lateral hook screw consisted of a transverse process hook augmented with a hole for a locking cortical screw to allow insertion through lateral aspect of distal terminal vertebra.

was wrapped in saline-soaked gauze and stored in double plastic bags at –20 °C.

Under fluoroscopic guidance, the pedicles at both T12 and L1 were instrumented with 5.5 mm diameter, 35 mm length stainless-steel polyaxial screws. Then, two high-stiffness stainless steel rods (5.0 mm in length) were seated into the heads of the pedicle screws at T12. The T12-set screws were kept loose so that the head of the screw acted as a fulcrum point.

The novel construct of distal terminal fixation was achieved by placing the transpedicular screw in the distal terminal vertebra and by orienting a lateral hook screw (composed of a lateral transverse process hook augmented with a hole) to allow a 3.5 mm locking cortical screw to be inserted from the lateral aspect through the distal terminal vertebra (Figure 3).

The study was conducted in the biomechanical laboratory of the Institute of Health Sciences. The biomechanical tests were performed using the axial compression testing machine (AG-I 10 kN, Shimadzu, Japan). The test device used TRAPEZIUM2 data processing software and charge coupled device camera extensometers (Non-Contact Video Extensometer DVE-101/201, Shimadzu, Japan); these elongation meters enabled measurement without making contact with the test specimen. The L2 vertebral body was fully embedded in polymethylmethacrylate (PMMA) to secure the entire spinal segment to the lower crosshead of the servo-hydraulic materials testing system. The T12 vertebra was supported anteriorly using a PMMA cradle (Figure 4) that had a roller bearing at its base to allow translation and rotation in the sagittal plane. Dual rods were seated in the unsecured heads of bilateral T12 pedicle screws to provide a fulcrum at a distance from L1, creating a cantilever bending moment in combination with a pullout force at L1 when a downward force was applied to the rods proximal to T12. This force simulated the load contribution of the thoracic spine and torsion in forward bending. After performing all tests, the lamb spine models underwent an indentation test to measure the bone

Figure 3. Novel terminal construct composed of a transpedicular screw with a lateral hook screw consisted of a transverse process hook augmented with a lateral screw that allows a locking cortical screw insertion in lateral aspect of corpus of terminal vertebra.

quality at L1. There was no statistically significant difference between the lamb spine samples.

Statistical analysis

For statistical analysis, the Mann-Whitney U test was used, and the level of statistical significance was set at $p<0.05$.

RESULTS

As the force was applied gradually on the proximal part of the rods, the load increased sharply until the distal construct stripped the bone; then, the load dropped rapidly (Figure 5). The construct displacement at the point of peak load was within two pitches in all the constructs, and the peak load was defined as the pullout strength. The average pullout strength of each group was 927 N for group 1, 626 N for group 2, 988 N for group 3, 972 N for group 4, and 1194 N for group 5 (Figure 6).

There was no statistically significant difference between groups 3 and 4 ($p=0.66$); group 3 had a statistically significant difference in pullout strength compared to groups 1 and 2 ($p=0.004$ and $p=0.001$, respectively). Group 4 also had a statistically significant difference in pullout strength compared to groups 1 and 2 ($p=0.004$ and $p=0.003$, respectively). Group 5 had the highest statistically significant differences in pullout strength compared to groups 1 through 4 (with p values of 0.003, 0.001, 0.006, and 0.011, respectively).

DISCUSSION

Pullout of terminal spinal instrumentation is an important complication in patients who have undergone thoracolumbar spinal surgery. In this study, we have attempted to develop some guidelines to help surgeons to select the proper terminal anchors by investigating the pullout strength of different distal fixation constructs against bending loads.

Arlet et al.[18] reported a suprapedicular claw construct at the top of the instrumented thoracic vertebra and concluded that this type of construct prevents the often-observed proximal screw pullout. Cordista et al.[19] reported that pedicle hooks should be considered when supplemental instrumentation is required in thoracic vertebrae, especially in osteoporotic bone.

Furthermore, Paxinos et al.[20] demonstrated that pedicle screws and sublaminar wires offer equally

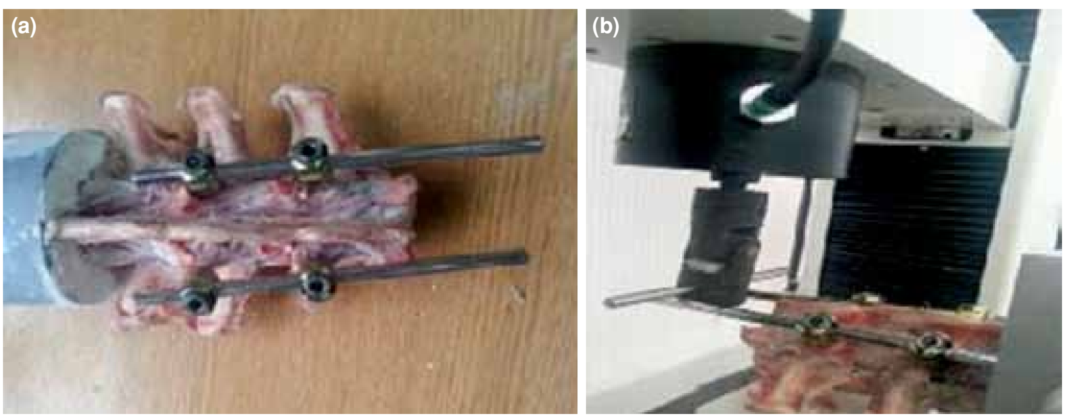

Figure 4. Preparing the lamb spine sample for biomechanical testing. **(a)** Lamb spine sample was distally embedded in polymethylmethacrylate cradle to be supported against forward flexion. **(b)** Test machine applying axial load to simulate a forward thoracolumbar flexion.

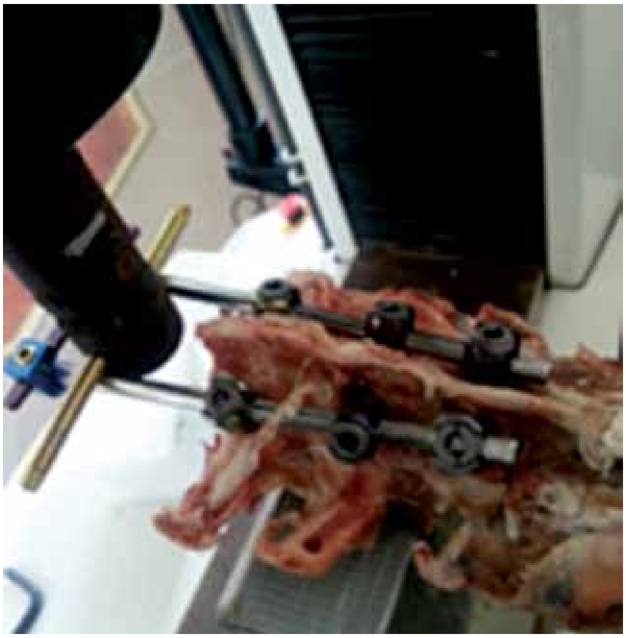

Figure 5. A gradually applied load on proximal part of rods; load increased gradually till distal construct stripped the bone and then the load dropped rapidly.

strong fixation in normal bone. In contrast, hooks tend to fail with significantly less force. In osteopenic bone, the surgeon may use any of the posterior constructs that are available for the thoracic spine because fixation strength is not related to the fixation type but to the bone strength.

Korovessis et al.[21] showed that using pedicle screws to stabilize the spine after thoracolumbar injuries was superior to using hook claws in the lumbar spine because the constructs with screws restored and maintained the fractured anterior vertebral body height better than the hooks and did so without subsequent loss of correction and while keeping a postoperatively continuous spinal canal clearance at the injury level. Moreover, Sun et al.[22] showed that the pedicle screw construct exhibited 70% greater ultimate strength and 24% greater stiffness compared with the hook construct.

Likewise, Liljenqvist et al.[23] demonstrated that average pullout strength of the pedicle screws was significantly higher than the strength in the hook group. Both screw diameter and bone mineral density had a significant influence on the pullout strength in the screw group.

Hilibrand et al.[24] demonstrated that a pedicle screw supplemented with a supralaminar hook at the same level provided significantly greater resistance to pullout than a pedicle screw alone when tested in the worst-case scenario of a stripped, senile pedicle. In the intact vertebra, no significant difference was seen in axial pullout strength when comparing the pedicle-screws-only construct and the screw-and-hook construct.

This study was intended to evaluate the strength of these anchors in a biomechanical model similar to a human spine and to compare these models with a novel method of a terminal construct fixation. The goal was to produce a more stable distal construct fixation to reduce the occurrence of pullout, which is encountered frequently in spinal instrumentation, especially in kyphosis surgery. The patient's characteristics still play a major role in determining anchor selection, and surgeons must make a final decision on what type of anchor should be used based on other clinical information. We believe, however, that the information presented in this paper will assist the surgeons in their decision-making process.

Our results revealed that a transpedicular screw in the distal vertebra and a lateral hook screw

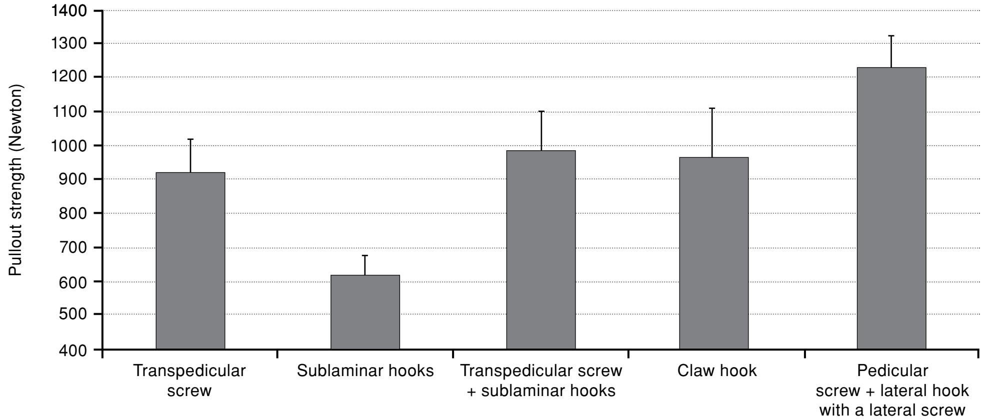

Figure 6. Graphical comparison between different types of terminal anchor pullout strengths.

(composed of a lateral transverse process hook augmented with a hole oriented to allow a 3.5 mm locking cortical screw inserted from the lateral aspect through the corpus of distal terminal vertebra) was significantly stronger in pullout failure testing than were the previously known constructs from groups 1, 2, 3, and 4. There was no obvious statistical difference between group 3 and 4. The construct using a transpedicular screw with sublaminar hooks showed a tendency to sustain higher loads before failure when compared with the claw hooks alone, but this difference did not reach statistical significance. The choice of anchors also depends on the anchor site's resistance against distraction forces and the potential for plowing the pedicle screws based on bone quality.

The study required the use of an animal model to replicate the dimensions and bone quality of a human spine. Sufficient human cadaveric tissue to adequately perform this study is virtually unobtainable. The lamb spine had similar anatomical dimensions to the human spine, and the placement of the instrumentation was similar to the human intraoperative experience. The pedicle dimensions were able to accommodate the screw placement, and the lateral-to-medial angulation of the pedicle screws did not deviate from the clinical experience. In addition, the use of animal models for evaluating spinal instrumentation is quite common.[25,26]

An obvious limitation of this biomechanical study is the direction and nature of the pullout force applied. The pullout force was directed posteriorly, continuing until acute failure occurred. A more realistic clinical scenario would involve long-term cyclical loading. However, the current method of testing was considered acceptable, as it provides a basic understanding of bone-implant behavior for this type of construct.

Furthermore, dual-energy X-ray absorptiometry was not conducted for the lamb spine specimens to create homogenous lamb spine groups; however, the indentation test was performed for all samples and no statistical significance was detected between groups. A prospective clinical study is needed to clearly demonstrate the beneficial effect of the novel construct in reducing the risk of distal instrumentation pullout.

In conclusion, our study suggests that the strongest distal fixation construct for reducing pullout is the newly described block method, which involves a transpedicular screw and a lateral hook screw. This method may be used in osteoporotic bones and conditions in which fixation strength must be enhanced.

Declaration of conflicting interests

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REFERENCES

1. Mehmanparast H, Petit Y, Mac-Thiong JM. Comparison of Pedicle Screw Loosening Mechanisms and the Effect on Fixation Strength. J Biomech Eng 2015;137.
2. Tsirikos AI, Jain AK. Scheuermann's kyphosis; current controversies. Scheuermann's kyphosis; current controversies. J Bone Joint Surg [Br] 2011;93:857-64.
3. Oto M, Shah SA, Mohammed MA, Rogers KJ, Yorgova P, Holmes L. Effectiveness and safety of posterior titanium instrumentation in children with adolescent idiopathic scoliosis: a prospective study. Eklem Hastalik Cerrahisi 2011;22:124-8.
4. Karakaşlı A, Ceçen B, Erduran M, Taylan O, Hapa O, Havıtcıoğlu H. Rigid fixation of the lumbar spine alters the motion and mechanical stability at the adjacent segment level. Eklem Hastalik Cerrahisi 2014;25:42-6.
5. Schoenfeld AJ, Wood KB, Fisher CF, Fehlings M, Oner FC, Bouchard K, et al. Posttraumatic kyphosis: current state of diagnosis and treatment: results of a multinational survey of spine trauma surgeons. J Spinal Disord Tech 2010;23:1-8.
6. Xi YM, Pan M, Wang ZJ, Zhang GQ, Shan R, Liu YJ, et al. Correction of post-traumatic thoracolumbar kyphosis using pedicle subtraction osteotomy. Eur J Orthop Surg Traumatol 2013;23:59-66.
7. Yaman O, Demir T, Arslan AK, Iyidiker MA, Tolunay T, Camuscu N, et al. The Comparison of Pullout Strengths of Various Pedicle Screw Designs on Synthetic Foams and Ovine Vertebrae. Turk Neurosurg 2015;25:532-238.
8. Sturm PF, Dobson JC, Armstrong GW. The surgical management of Scheuermann's disease. Spine (Phila Pa 1976) 1993;18:685-91.
9. Hosman AJ, Langeloo DD, de Kleuver M, Anderson PG, Veth RP, Slot GH. Analysis of the sagittal plane after surgical management for Scheuermann's disease: a view on overcorrection and the use of an anterior release. Spine (Phila Pa 1976) 2002;27:167-75.
10. Papagelopoulos PJ, Klassen RA, Peterson HA, Dekutoski MB. Surgical treatment of Scheuermann's disease with segmental compression instrumentation. Clin Orthop Relat Res 2001;386:139-49.
11. Derinçek A, Türker M, Cinar M, Cetik O, Kalaycioğlu B. Revision of the failed pedicle screw in osteoporotic lumbar spine: biomechanical comparison of kyphoplasty versus transpedicular polymethylmethacrylate augmentation. Eklem Hastalik Cerrahisi 2012;23:106-10.
12. Oshino H, Sakakibara T, Inaba T, Yoshikawa T, Kato T, Kasai Y. A biomechanical comparison between cortical bone trajectory fixation and pedicle screw fixation. J Orthop Surg Res 2015;10:125.

13. Chen HC, Lai YS, Chen WC, Chen JW, Chang CM, Chen YL, et al. Effect of different radial hole designs on pullout and structural strength of cannulated pedicle screws. Med Eng Phys 2015;37:746-51.
14. Dickman CA, Fessler RG, MacMillan M, Haid RW. Transpedicular screw-rod fixation of the lumbar spine: operative technique and outcome in 104 cases. J Neurosurg 1992;77:860-70.
15. Ebelke DK, Asher MA, Neff JR, Kraker DP. Survivorship analysis of VSP spine instrumentation in the treatment of thoracolumbar and lumbar burst fractures. Spine (Phila Pa 1976) 1991;16:428-32.
16. Esses SI, Sachs BL, Dreyzin V. Complications associated with the technique of pedicle screw fixation. A selected survey of ABS members. Spine (Phila Pa 1976) 1993;18:2231-8.
17. Smit TH. The use of a quadruped as an in vivo model for the study of the spine - biomechanical considerations. Eur Spine J 2002;11:137-44.
18. Arlet V, Shilt J, Ouellet J. The suprapedicle claw construct in anterior scoliosis surgery. Eur Spine J 2005;14:789-94.
19. Cordista A, Conrad B, Horodyski M, Walters S, Rechtine G. Biomechanical evaluation of pedicle screws versus pedicle and laminar hooks in the thoracic spine. Spine J 2006;6:444-9.
20. Paxinos O, Tsitsopoulos PP, Zindrick MR, Voronov LI, Lorenz MA, Havey RM, et al. Evaluation of pullout strength and failure mechanism of posterior instrumentation in normal and osteopenic thoracic vertebrae. J Neurosurg Spine 2010;13:469-76.
21. Korovessis P, Baikousis A, Koureas G, Zacharatos S. Correlative analysis of the results of surgical treatment of thoracolumbar injuries with long Texas Scottish rite hospital construct: is the use of pedicle screws versus hooks advantageous in the lumbar spine? J Spinal Disord Tech 2004;17:195-205.
22. Sun E, Alkalay R, Vader D, Snyder BD. Preventing distal pullout of posterior spine instrumentation in thoracic hyperkyphosis: a biomechanical analysis. J Spinal Disord Tech 2009;22:270-7.
23. Liljenqvist U, Hackenberg L, Link T, Halm H. Pullout strength of pedicle screws versus pedicle and laminar hooks in the thoracic spine. Acta Orthop Belg 2001;67:157-63.
24. Hilibrand AS, Moore DC, Graziano GP. The role of pediculolaminar fixation in compromised pedicle bone. Spine (Phila Pa 1976) 1996;21:445-51.
25. Lowe TG, Enguidanos ST, Smith DA, Hashim S, Eule JM, O'Brien MF, et al. Single-rod versus dual-rod anterior instrumentation for idiopathic scoliosis: a biomechanical study. Spine (Phila Pa 1976) 2005;30:311-7.
26. Polly DW Jr, Cunningham BW, Kuklo TR, Lenke LG, Oda I, Schroeder TM, et al. Anterior thoracic scoliosis constructs: effect of rod diameter and intervertebral cages on multi-segmental construct stability. Spine J 2003;3:213-9.