Acta Orthopaedica et Traumatologica Turcica 52 (2018) 459–463

Contents lists available at ScienceDirect

Acta Orthopaedica et Traumatologica Turcica

journal homepage: https://www.elsevier.com/locate/aott

Quantitative comparison of a laterally misplaced pedicle screw with a re-directed screw. How much pull-out strength is lost?

Murat Korkmaz [a, *], Kerim Sarıyılmaz [b], Okan Ozkunt [b], Halil Can Gemalmaz [b], Turgut Akgül [c], Mustafa Sungur [b], Fatih Dikici [b], Murat Baydoğan [d]

[a] Koc University Hospital, Department of Orthopaedics and Traumatology, Istanbul, Turkey
[b] Department of Orthopedics and Traumatology, Acibadem Atakent University Hospital, Istanbul, Turkey
[c] Istanbul University Istanbul Faculty of Medicine Department of Orthopedics and Traumatology, Istanbul, Turkey
[d] Istanbul Technical University, Metallurgical and Materials Engineering Department, Istanbul, Turkey

ARTICLE INFO

Article history:
Received 5 December 2016
Received in revised form
2 January 2018
Accepted 19 March 2018
Available online 3 September 2018

Keywords:
Pedicle screw placement
Lateral wall perforation
Pull-out strength
Free hand technique
Biomechanics

ABSTRACT

Objective: Redirecting of a laterally misplaced pedicle screw into the accurate position decreases the pull-out strength due to the reinsertion, lateral wall cortical perforation and widening of the pedicle hole. Thus, this biomechanical study was performed to quantitatively analyze the pullout strength of a redirected laterally misplaced pedicle screw into the accurate position.

Methods: Thirty pedicules of 15 bovine vertebrae were separated to 3 groups, according to the screw placement method: 1) standard flawless trajectory; 2) trajectory with lateral pedicle wall perforation; 3) trajectory with lateral wall perforation redirected to the standard trajectory. Samples were placed on a universal testing machine and pullout loads were measured. Kruskal-Wallis test was utilized within 95% confidence interval and p value <0.05 to test for the statistical significance.

Results: The mean pullout strength was 2891±654,2 N(1383-3814,5) in Group 1; 817,8±227,6 N(308,6-1144,9) in Group 2 and 2081,1±487,7 N(1583,5-2962,5) in Group 3. The results found out to be statistically significant ($p<0.05$). Inter-group comparisons revealed that lateral pedicle wall perforation significantly decreases the pullout strength ($p<0.05$) and redirection of the screw increases the strength ($p<0.05$), however it was still weaker than the screws with flawless standard trajectory but this was not statistically significant ($p>0.05$).

Conclusion: The results of this study confirm that pullout strength of pedicle screw decreases by approximately 71% when the lateral wall is perforated and decreases 28% after redirection to the accurate position.

© 2018 Turkish Association of Orthopaedics and Traumatology. Publishing services by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

The use of pedicle screws in spinal surgery has become standard which has been shown to have biomechanical and corrective advantages by means of three-column fixation.[1,2] Meanwhile, optimal placement of pedicle screws is mandatory to avoid neurological and vascular complications due to close relationship to the vital structures.[3] Furthermore, misplacement of the pedicle screw is known to result in decreased biomechanical stability.[4] In this respect, several techniques has been described to provide optimal placement of pedicle screws in the right trajectory.

The optimal placement of pedicle screws can only be achieved with one accord of several factors. These factors are known to be suitability of anatomy of the vertebral body, size of the pedicle, quality of bone, and also three-dimensional orientation of the pedicle.[5,6] Also, there are many methods to provide accuracy and safety such as guide pins to mark the pedicle, intraoperative fluoroscopy and advanced image-guided systems.[7,8]

Several authors have studied the accuracy and safety of the placement of pedicle screws in scoliosis patients. Kuklo et al disclosed 96.3% accuracy in patients with severe thoracic scoliosis.[9] Other novel studies have stated the accuracy of free-hand pedicle

* Corresponding author. Sisli Etfal Hamidiye Training and Research Hospital, Halaskargazi St. Sisli, Istanbul, Turkey. Tel.: +90 536 430 52 66.
E-mail address: mrtmkz@gmail.com (M. Korkmaz).

Peer review under responsibility of Turkish Association of Orthopaedics and Traumatology.

https://doi.org/10.1016/j.aott.2018.03.002
1017-995X/© 2018 Turkish Association of Orthopaedics and Traumatology. Publishing services by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

screw instrumentation to range from %45–85% in adolescent and adult population with scoliosis.[9,10]

Many techniques were defined to provide proper placement of pedicle screws with free-hand technique. Even with advances in conventional technique and intraoperative navigation, lateral pedicular wall perforation is not uncommon. Relatively frequent tendency of lateral wall disruption is thought to be a result of variation in anatomy, size of pedicles and especially the fact that the lateral wall is the weakest of all the walls of the pedicle.[4,11,12]

Several studies have reported that, because of the potential vascular and neurological complications, free-hand pedicle screw placement for posterior spinal instrumentation must be accurate and safe. Also it is known that, misplacement of pedicle screws with lateral wall perforation negatively effects the pullout strength. But there is no consensus about the quantitative evidence of this negative correlation despite of many reports on the accuracy of pedicle screw placement.

In this biomechanical study, we aimed to analyze the pullout strength of a redirected laterally misplaced pedicle screw into the accurate position. We hypothesized that redirecting of a laterally misplaced pedicle screw into the accurate position decreases the pull-out strength due to the reinsertion, lateral wall cortical perforation and widening of the pedicle hole.

Methods

In this biomechanical study, 15 fresh frozen thoracic vertebrae were harvested from 3 male bovine spine. Each vertebra was dissected separately and all of the soft tissue was cleaned from the bone. Fresh frozen vertebrae were kept at −20 Celsius throughout the study. Prior to the biomechanical study, vertebrae were thawed by soaking in room temperature serum physiologic for 24 h.

Thirty pedicules of 15 bovine vertebrae were separated to 3 groups, according to the screw placement. In control group (Group 1), titanium polyaxial pedicle screws 5 mm in diameter and 45 mm length (Tasarım Medical, Istanbul, Turkey) were inserted with a standard flawless trajectory without any cortical perforation. In second group (Group 2), pedicle screws were intentionally inserted perforating the lateral pedicle wall. In third group (Group 3), pedicle screws were first placed with lateral pedicle wall perforation and then they were redirected to the standard trajectory. Following the pedicle screw instrumentation plain radiographs were obtained (Fig. 1).

Biomechanical testing

For the biomechanical testing, the specimens were subjected to axial loading with a 10 kN capable Shimadzu (Shimadzu Corp., Kyoto, Japan) Autograph AGS-J model universal testing machine. A custom made metal mount was fabricated to provide stable fixation to the test machine. All specimens were adapted to the test device with a connector to align the loading direction along the longitudinal axis of the pedicle screw. All of the specimens were preloaded with 5N and the screws were pulled out at a constant velocity of 5 mm/min until the pull-out of the pedicle screws (Fig. 2).

Measurements were recorded by using Trapezium 2.0 v.2.23 (Shimadzu Corp., Kyoto, Japan) software. The peak force causing failure of the construct by means of pullout of the pedicles from the bone were noted for each sample.

Statistical analysis

Pull-out strengths were analyzed with a statistics software (SPSS for Windows, Statistical Package for the Social Sciences, version 15.0, Chicago, IL). Kruskal–Wallis test was utilized within 95% confidence interval and p value <0.05 to test for the statistical significance.

Results

The mean pullout strength for screws which inserted with a standard flawless trajectory without any cortical perforation was 2891 ± 654.2N (1383–3814.5). The mean pullout strength for screws which inserted perforating the lateral pedicle wall was 817.8 ± 227.6N (308.6–1144.9). Pullout strength for the screw with standart trajectory without any cortical perforation was 71.4% more as compared to the screw with lateral wall perforation ($p < 0.05$). The mean pullout strength for the re-directed screws was 2081.1 ± 487.7N (1583.5–2962.5). Pullout strength for correctly inserted screws was 28.1% more as compared to re-directed screws. But this difference is not significant statistically ($P > 0.05$). Pullout strength for re-directed screws was 60.8% more as compared to the screw lateral wall perforation ($p < 0.05$).

In summary, the mean pullout strength for screws which inserted with a standard flawless trajectory without any cortical perforation was superior in comparison with other groups ($p < 0.05$). Inter-group comparisons revealed that lateral pedicle

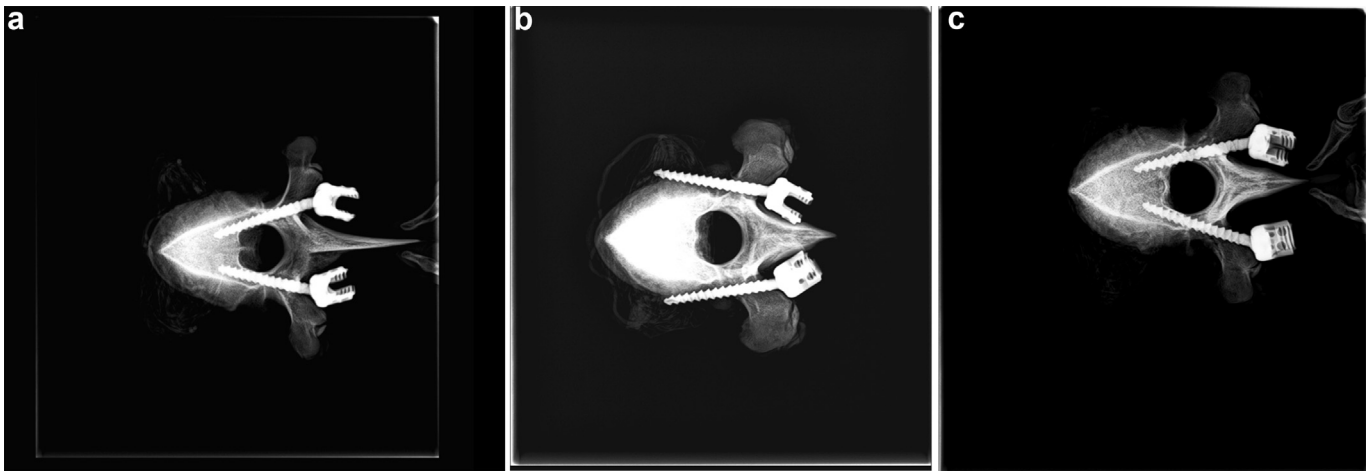


Fig. 1. **(a)** Radiography of the vertebra with pedicle screw inserted in standart trajectory. **(b)** Radiography of the vertebra with pedicle screw inserted in lateral trajectory with lateral wall perforation. **(c)** Radiography of the vertebra with pedicle screw inserted in trajectory with lateral wall perforation redirected to the standard trajectory.



Fig. 2. The pedicle screw pull-out strength was tested using the a 10 kN capable Shimadzu (Shimadzu Corp., Kyoto, Japan) Autograph AGS-J model universal testing machine at a rate of 5 mm/min.

wall perforation significantly decreased the pullout strength ($p < 0.05$), while redirection of the screw to standard trajectory restored the pullout strength significantly ($p < 0.05$). However, redirected screws were still weaker than the screws with flawless standard trajectory but this difference was not statistically significant ($p > 0.05$) (Fig. 3).

Discussion

The current study quantitatively analyzes the pullout strength of laterally misplaced and redirected to an accurate position screw. The results of our study revealed that pullout strength of pedicle screw significantly decreases when the lateral wall is perforated and redirection of the screw to the proper trajectory significantly restores the strength. However this restoration in strength does not match flawless standard trajectory screw's strength, whereas this finding was not significant.

Although pedicle screws are widely used for posterior spinal surgery, there have been some concern about potential complications resulting from screw misplacement due to the small pedicle width, altered pedicle morphology, and shift of the surrounding structures by rotation.[9] In a systematic review, Hicks et al found 4.2% screw misplacement rate.[13] However, in a recent study, Sarwahi et al[14] claimed that this rate can be misleading because of the fact that readings from X-rays are biased when compared to computed tomography. They reported 87.96% accuracy in pedicle screw placement.

Lateral pedicular wall perforation during screw insertion is not uncommon and may cause major vascular and visceral injuries. Castro et al[15] reported 11% of lateral wall penetration with CT evaluation in lumbar spinal fusion patients. Utilization of navigation and assistance techniques significantly increases lateral wall penetration rates.[16,17] Furthermore, close relationship of the rotated vertebrae to the vascular and visceral structures makes these structures prone to injury.[5,18–22]

Pedicles supply major contribution to the screw purchase therefore, perforation reduces the pullout strength of the screws. Weinstein et al[23] demonstrated that pedicles account for 60% of the pullout strength, the vertebral body accounts for 15–20% and anterior vertebral cortex accounts for the remaining 20–25%. Likewise, Hirano et al[24] revealed that 82% of the fixation strength and 57% of the pullout strength were attributable to the pedicles. George et al[25] reported that pedicle fractures decreases the pullout strength by 11% compared to intact pedicles. In a cadaveric study, Saraf et al,[26] biomechanically tested the misplaced pedicles and found that lateral misplacement reduces 47.3% of the pullout strength. Similar with latter study, we found a significant decrease in pullout strength in case of lateral wall perforation, however the magnitude was found to be greater in our study reaching 71%.

As lateral misplacement of a pedicle screw is not uncommon and leaving the misplaced screw as it is has risks, surgeons tend to correct the screw pathway to the accurate position. However, some investigators showed that reinsertion of a screw to close proximity is known to decrease the pullout strength. In a porcine biomechanical study, Chun et al[27] inserted screws parallel to the superior end plate on one side as control group. On the other side they inserted an identical screw first 10° caudal to the superior end plate, and then repositioned it parallel to the superior end plate. They found that repositioned screws were significantly weaker than controls in terms of the maximum insertional torque and pullout strength. Likewise, Wadhwa et al,[28] reported in their ex vivo biomechanical study that, revising a nonparallel screw placement decreases pullout strength in patients with decreased bone mineral density. They concluded that, if a screw is inadvertently placed nonparallel to the endplate while being within the pedicle and vertebral body with adequate bone purchase, it should not be revised and rather be left in place.

After gearshift pedicle finder insertion, the 4 pedicle walls and anterior cortex of the vertebral body has to be checked with a ball tip probe to confirm integrity in order to prevent screw misplacement during the surgery. Nonetheless, lateral wall perforation during screw placement can occur. In a cadaveric study, Nan et al[4] investigated the effect of lateral wall perforation by a gearshift probe. Maximal pullout strength in the control group and experiment group was 1320 ± 320.5 N and 1015.8 ± 249.4 N, respectively. As might be expected, redirecting a laterally misplaced pedicle screw into the accurate position decreases the pullout strength due to lack of buttress from lateral wall absence and widening of the pedicle hole. Our results revealed that lateral pedicle wall perforation significantly decreases the pullout strength, and redirection of the screw increases the strength. However, redirected screw is found to be weaker than the screw with flawless standard trajectory, but this was not statistically significant. Similar with our study, Brasiliense et al,[29] reported in their biomechanical study that, laterally misplaced screws had 21% less mean pullout strength. They compared the standard pedicle screw, screw with medial perforation, screw with lateral perforation and screw that completely missed the vertebral body. They did not test for the reinserted screw, which is the difference of our study.

This current study is not without its limitations. To begin with, this is an ex vivo study and in in-vivo conditions, the purchase of the screw may be better initially and perforated lateral wall may heal over time reducing the clinical relevance of the condition.

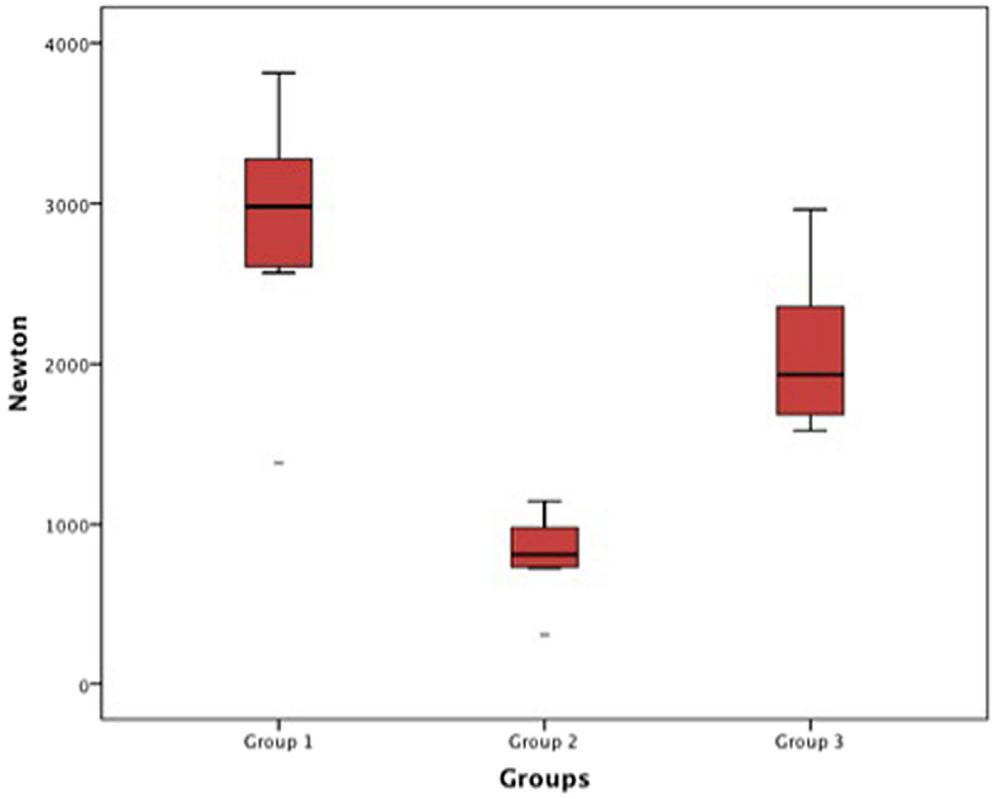


Fig. 3. Biomechanical test results.

Additionally, this is a biomechanical study and may not reflect in vivo environment. Though the vertebrae used in this experiment are real bones, bovine vertebrae used in the study may not represent human vertebrae to expected level.

Conclusion

The results of this study confirm that pullout strength of pedicle screw decreases by approximately 71% when the lateral wall is perforated and decreases 28% after redirection to the accurate position. We recommend to redirect the laterally misplaced screw into the accurate position. However, one must not forget that the first shot is the best chance to get the strongest screw purchase.

Ethical approval

This article does not contain any studies with human participants or living animals performed by any of the authors.

Acknowledgement

We thank Tasarim Medical for the supply of instrumentation devices.

References

1. Cotrel Y, Dubousset J, Guillaumat M. New universal instrumentation in spinal surgery. *Clin Orthop Relat Res*. 1988;227:10–23.
2. Eggli S, Schläpfer F, Angst M, Witschger P, Aebi M. Biomechanical testing of three newly developed transpedicular multisegmental fixation systems. *Eur Spine J*. 1992;1(2):109–116.
3. Di Silvestre M, Parisini P, Lolli F, Bakaloudis G. Complications of thoracic pedicle screws in scoliosis treatment. *Spine (Phila Pa 1976)*. 2007;32(15):1655–1661.
4. Nan Li DH, Xing Yonggang, Yanwei LV, Tian Wei. The effect of lateral wall perforation on screw pull-out strength: a cadaveric study. *J Orthop Surg Res*. 2015;10:6.
5. Ebraheim NA, Jabaly G, Xu R, Yeasting RA. Anatomic relations of the thoracic pedicle to the adjacent neural structures. *Spine (Phila Pa 1976)*. 1997;22(14):1553–1556 [Discussion 1557].
6. Vaccaro AR, Rizzolo SJ, Allardyce TJ, et al. Placement of pedicle screws in the thoracic spine. Part I: morphometric analysis of the thoracic vertebrae. *J Bone Joint Surg Am*. 1995;77(8):1193–1199.
7. Samdani Amer F, Ranade Ashish, Sciubba Daniel M, et al. Accuracy of free-hand placement of thoracic pedicle screws in adolescent idiopathic scoliosis: how much of a difference does surgeon experience make? *Eur Spine J*. 2010;19(1):91–95.
8. Amiot LP, Lang K, Putzier M, Zippel H, Labelle H. Comparative results between conventional and computer-assisted pedicle screw installation in the thoracic, lumbar, and sacral spine. *Spine (Phila Pa 1976)*. 2000;25(5):606–614.
9. Kuklo TR, Lenke LG, O'Brien MF, Lehman Jr RA, Polly Jr DW, Schroeder TM. Accuracy and efficacy of thoracic pedicle screws in curves more than 90 degrees. *Spine (Phila Pa 1976)*. 2005;30(2):222–226.
10. Fayyazi AH, Hugate RR, Pennypacker J, Gelb DE, Ludwig SC. Accuracy of computed tomography in assessing thoracic pedicle screw malposition. *J Spinal Disord Tech*. 2004;17(5):367–371.
11. O'Brien MF, Lenke LG, Mardjetko S, et al. Pedicle morphology in thoracic adolescent idiopathic scoliosis: is pedicle fixation an anatomically viable technique? *Spine (Phila Pa 1976)*. 2000;25(18):2285–2293.
12. Misenhimer GR, Peek RD, Wiltse LL, Rothman SL, Widell Jr EH. Anatomic analysis of pedicle cortical and cancellous diameter as related to screw size. *Spine (Phila Pa 1976)*. 1989;14(4):367–372.
13. Hicks JM, Singla A, Shen FH, Arlet V. Complications of pedicle screw fixation in scoliosis surgery: a systematic review. *Spine (Phila Pa 1976)*. 2010;35(11):E465–E470.
14. Sarwahi V, Wendolowski SF, Gecelter RC, et al. Are we underestimating the significance of pedicle screw misplacement? *Spine (Phila Pa 1976)*. 2016;41(9):E548–E555.
15. Castro WH, Halm H, Jerosch J, Malms J, Steinbeck J, Blasius S. Accuracy of pedicle screw placement in lumbar vertebrae. *Spine (Phila Pa 1976)*. 1996;21(11):1320–1324.
16. Silbermann J, Riese F, Allam Y, Reichert T, Koeppert H, Gutberlet M. Computer tomography assessment of pedicle screw placement in lumbar and sacral spine: comparison between free-hand and O-arm based navigation techniques. *Eur Spine J*. 2011;20(6):875–881.
17. Gelalis ID, Paschos NK, Pakos EE, et al. Accuracy of pedicle screw placement: a systematic review of prospective in vivo studies comparing free hand, fluoroscopy guidance and navigation techniques. *Eur Spine J*. 2012;21(2):247–255.

18. Sarlak AY, Buluç Levent, Sarısoy Hasan Tahsin, Memişoğlu Kaya, Tosun Bilgehan. Placement of pedicle screws in thoracic idiopathic scoliosis: a magnetic resonance imaging analysis of screw placement relative to structures at risk. *Eur Spine J*. 2008;17(5):657–662.
19. Kuklo TR, Lehman Jr RA, Lenke LG. Structures at risk following anterior instrumented spinal fusion for thoracic adolescent idiopathic scoliosis. *J Spinal Disord Tech*. 2005;18(Suppl):S58–S64.
20. Jiang J, Mao S, Zhao Q, et al. Different proximal thoracic curve patterns have different relative positions of esophagus to spine in adolescent idiopathic scoliosis: a computed tomography study. *Spine (Phila Pa 1976)*. 2012;37(3):193–199.
21. Minor ME, Morrissey NJ, Peress R, et al. Endovascular treatment of an iatrogenic thoracic aortic injury after spinal instrumentation: case report. *J Vasc Surg*. 2004;39(4):893–896.
22. Sariyilmaz K, Ozkunt O, Sungur M, Dikici F, Domanic U. Esophageal perforation caused by a posterior pedicle screw: a case report. *J Pediatr Orthop*. 2017;37(2):98–101.
23. Weinstein JN, Rydevik BL, Rauschning W. Anatomic and technical considerations of pedicle screw fixation. *Clin Orthop Relat Res*. 1992;284:34–46.
24. Hirano T, Hasegawa K, Takahashi HE, et al. Structural characteristics of the pedicle and its role in screw stability. *Spine (Phila Pa 1976)*. 1997;22(21):2504–2509 [Discussion 2510].
25. George DC, Krag MH, Johnson CC, Van Hal ME, Haugh LD, Grobler LJ. Hole preparation techniques for transpedicle screws. Effect on pull-out strength from human cadaveric vertebrae. *Spine (Phila Pa 1976)*. 1991;16(2):181–184.
26. Saraf SK, Singh RP, Singh V, Varma A. Pullout strength of misplaced pedicle screws in the thoracic and lumbar vertebrae - A cadaveric study. *Indian J Orthop*. 2013;47(3):238–243.
27. Tan CE, Fok MW, Luk KD, Cheung KM. Insertional torque and pullout strength of pedicle screws with or without repositioning: a porcine study. *J Orthop Surg (Hong Kong)*. 2014;22(2):224–227.
28. Wadhwa RK, Thakur JD, Khan IS, et al. Adjustment of suboptimally placed lumbar pedicle screws decreases pullout strength and alters biomechanics of the construct: a pilot cadaveric study. *World Neurosurg*. 2015;83(3):368–375.
29. Brasiliense LB, Theodore N, Lazaro BC, et al. Quantitative analysis of misplaced pedicle screws in the thoracic spine: how much pullout strength is lost?: presented at the 2009 joint spine section meeting. *J Neurosurg Spine*. 2010;12(5):503–508.