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Original Research

Sagittal orientation and uniform entry for thoracic pedicle screw placement with free-hand technique: A retrospective study on 382 pedicle screws

H. Bahadir Gokcen[a,*], Sinan Erdogan[b], Sidar Ozturk[c], Gurkan Gumussuyu[c], Irem Bayram[d], Cagatay Ozturk[b]

[a] Orthopaedics and Traumatology, Istinye University (Medicalpark Hospital), Bahcelievler, Istanbul, Turkey
[b] Orthopaedics and Traumatology, Istinye University (LIV Hospital), Ulus, Istanbul, Turkey
[c] Orthopaedics and Traumatology, Medicalpark Hospital, Bahcelievler, Istanbul, Turkey
[d] Department of Radiology, LIV Hospital, Ulus, Istanbul, Turkey

A B S T R A C T

Background: One of the most important factors in obtaining a successful outcome in spinal surgery is appropriate placement of the pedicle screw. A number of different techniques are used to achieve successful pedicle screw placement. The free-hand technique has the advantage of no requirement for radiation exposure, but its success is highly dependent on surgeon experience. Here, we describe our entry point and perioperative sagittal orientation method, and evaluate postoperative sagittal alignment of pedicle screws with the free-hand pedicle screw placement technique.

Materials and methods: Eighty-two patients undergoing spinal surgery between 2015 and 2016 were included in this study. Pedicle screw placement was evaluated retrospectively on postoperative anterior-posterior (A-P) and lateral load-bearing radiographs of the entire spinal column. The vertebral body was divided into five areas in the lateral plane. Sagittal orientation of the pedicle screws on lateral radiographs was evaluated by two spine surgeons with 3 years of experience and one radiologist experienced in musculoskeletal radiology, with each observer evaluating the image twice according to a 1-month interval.

Results: A total of 382 pedicle screws were evaluated. There was no statistically significant difference between the first and second measurements, performed by individual observers, and there was good concordance among the three observers.

Conclusions: Use of a uniform entry point at all levels may increase the effectiveness of the free-hand technique and decrease the pedicle screw misplacement rate. Our technique may standardize the free-hand technique, which does not require radiation exposure, and make it more practical to apply uniformly.

1. Introduction

Pedicle screw placement was first described in 1950 and has become a common technique used by spine surgeons [1]. The popularity of the pedicle screw has increased in the last two decades. It was initially used in the lumbar spine, and has since been applied to stabilize both the thoracic and lumbar regions. Increased knowledge of the anatomy and refinement of screw placement techniques have led to thoracic screw placement becoming as common as lumbar screw placement. The widespread adoption and associated advantages of pedicle screws compared to other approaches, such as the Harrington rod and Luque's instrumentation, have reinforced its superiority [1–3]. Pedicle screws have a number of advantages over other systems, including their increased stability, greater deformity-correcting ability, and lower incidence of pseudoarthrosis [4–10]. Despite these advantages, pedicle screws also carry potential risk due to the proximity of the pedicle to the spinal canal and vascular structures. Misplacement of the pedicle screw may cause irreversible and catastrophic complications. Therefore, accurate and safe pedicle screw placement is crucial for an efficient and stable surgical procedure.

The misplacement rate of pedicle screws in the thoracic spine ranges from 10% to 30%, even for experienced spine surgeons [2,11–14]. Various methods of safe pedicle screw placement have been reported [15–17]. The free-hand technique, fluoroscopy-guided methods, computer-assisted navigational surgery, and stereotactic surgery are among the approaches for screw placement. In comparison to other techniques,

* Corresponding author. Bahcelievler, E-5 / Kultur Street Number:1, 34180 Bahcelievler, Istanbul, Turkey.
E-mail addresses: bahadir.gokcen@istinye.edu.tr (H.B. Gokcen), sinan.erdogan@istinye.edu.tr (S. Erdogan), sidar.ozturk@medicalpark.com.tr (S. Ozturk), gurkan.gumussuyu@medicalpark.com.tr (G. Gumussuyu), irem.bayram@livhospital.com.tr (I. Bayram), cagatay.ozturl@livhospital.com.tr (C. Ozturk).

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the free-hand technique has the advantage of no requirement for radiation exposure during surgery. This technique is based on the experience of the surgeon. There have been several reports assessing pedicle screw placement success [18–21]. However, these studies evaluated screw misplacement and spinal canal involvement using computed tomography (CT) images in axial view, and there have been no reports regarding the sagittal orientation of the pedicle screw.

Here, we describe the entry point and perioperative sagittal orientation of our free-hand pedicle screw placement technique. We evaluated the postoperative sagittal alignment of patients undergoing spinal surgery due to various spinal disorders. Our technique and method of evaluating intraoperative sagittal orientation may standardize sagittal orientation of the pedicle screw with the free-hand technique.

2. Materials and methods

The work has been reported in line with the STROCSS criteria [22]. A total of 112 patients undergoing spinal surgery between 2016 and 2017 were included in this study. Patients with severe scoliosis (Cobb angle > 80°), and those with neuromuscular scoliosis, were excluded because rotation of the vertebrae in scoliosis may affect the results. The study population consisted of 82 patients (57 females, 25 males). The mean age at the time of surgery was 47.7 years (range: 15–82 years). Patients' diagnoses were as follows: degenerative spine ($n = 34$), scoliosis (Cobb angle range, 45–69) ($n = 14$), vertebral fracture ($n = 13$), Scheuermann kyphosis (kyphosis angle range: 70°–85°) ($n = 9$), spinal tumors ($n = 7$), and spondylodiscitis ($n = 5$) (Table 1). A total of 382 pedicle screws inserted using the free-hand technique by one surgeon with more than 10 years of experience of spinal surgery were analyzed retrospectively. Intraoperative electromyographic monitoring of pedicle screw placement was used in all cases. Early neurological examination of the patients was performed in the operating room immediately after surgery. Postoperative anterior-posterior (A-P) and lateral load-bearing films of the spinal column were taken on the second day after surgery.

The vertebral body was divided into five areas in the lateral plane. The first area was the upper disc level. The second, third, and fourth areas were one third of the vertebral body. The fifth area was the lower disc level of the vertebral body (Fig. 1). Evaluation of the pedicle screws was performed using A-P and lateral radiographs (Fig. 2). The pedicle screws were classified based on the area of the pedicle screw tip on lateral radiographs. The pedicle screw tip orientation in the A-P view was evaluated to clarify whether the pedicle screw identified on lateral view images was on the right or left side. We did not routinely perform postoperative CT to assess pedicle screws. CT was performed for patients with suspected inappropriate pedicle screw placement based on A-P and lateral radiographs. All postoperative images were examined by two spine surgeons with 3 years of experience and one radiologist experienced in musculoskeletal radiology. The collected data were independently evaluated twice each by three observers, with a 1-month interval between evaluations. Statistical analyses were performed, including intraobserver and interobserver assessments.

Table 1
Patient diagnoses.

Diagnosis	*N* (total = 82)
Degenerative spine	34
Scoliosis	14
Vertebral fracture	13
Kyphosis	9
Spinal tumor	7
Spondylodiscitis	5

Fig. 1. Illustration of Areas 1, 2, 3, 4, and 5 described in the study.

2.1. Surgical technique

The patient was placed in the prone position on an operating table with a radiolucent frame. A posterior longitudinal midline incision (tip of the superior spinous process to the spinous process of levels determined before surgery) was performed. Superficial dissection was performed. Subcutaneous fat and fascia were dissected, and the paraspinal muscles were stripped from the lamina. The spinal column was exposed from the spinous process to the lamina, facet joints, and tips of the transverse process subperiosteally. The facet joints were cleaned of soft tissues. The lateral borders of the superior and inferior facet joint were made visible. Hemostasis was carefully carried out to ensure better visualization of the landmarks.

Visualization of the lateral border of the facet joint and lamina is a critical step in the initial orientation. Medial orientation of the pedicle screw corresponded to it becoming parallel to the lateral border of the superior facet joint of the pedicle, and sagittal orientation corresponded to it being perpendicular to the lamina of the pedicle as the screw was inserted. The entry point of the pedicle screw was 2 mm caudal and 2 mm lateral to the junction of the lateral border of the superior facet joint and transverse process (Fig. 3A–D). Before entering the pedicle with a probe, the entry point was roughened with a rongeur to expose the cancellous bone. Palpation of the lateral border of the pedicle passage was performed with a pathfinder that was first directed laterally, then medially, and finally laterally. The medial, lateral, superior, inferior, and anterior walls were inspected with a probe. The pedicle was then undertapped. A final breach assessment was performed prior to screw insertion and then a screw of appropriate size was placed. No imaging methods were used during pedicle screw insertion. When pedicle screw placement was completed, pedicle screw orientation was checked once with fluoroscopy. No screws were replaced after applying this fluoroscopic control. Intraoperative electromyographic monitoring of the pedicle screw was performed at each step of screw insertion.

2.2. Statistical analysis

Continuous variables (mean, standard deviation, minimum, median, maximum) were described using descriptive statistics. Interobserver concordance for continuous variables was examined with Cronbach's alpha coefficient. The correlations between two dependent and non-normal distribution-dependent continuous variables were examined using Wilcoxon's signed rank test. In all analyses, $p < 0.05$ was taken to indicate statistical significance. Analyses were performed using MedCalc statistical software (ver. 12.7.7; MedCalc Software BVBA, Ostend, Belgium).

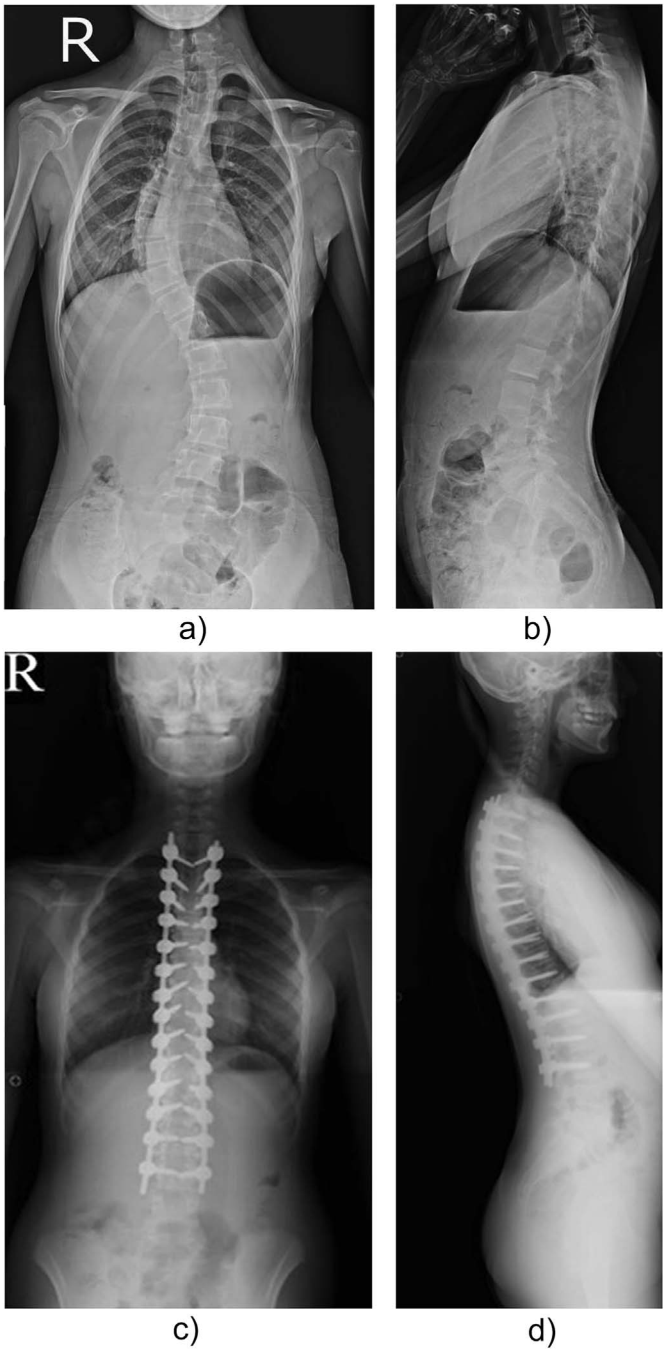

Fig. 2. a–d: Preoperative and postoperative anterior-posterior (A–P) and lateral radiographs.

3. Theory/Calculation

Pedicle screw placement is a critical step in spinal surgery. If all stages of pedicle screw placement are not performed appropriately, catastrophic complications can arise that affect the patient's life. To minimize these complications, many assistive techniques have been applied. This study was performed to improve the free-hand technique, and facilitate and standardize the sagittal orientation of pedicle screw placement using the free-hand technique.

4. Results

A total of 545 pedicle screws were inserted in the thoracic spine during the study period. One pedicle screw at T1, six at T2, six at T3, four at T4, two at T5, and two at T6 that were not clearly identified, and 141 screws at T12, for which fluoroscopy may have been used to identify the entry point, were excluded from the analysis. Therefore, 382 pedicle screws were finally evaluated. The average number of pedicle screws placed at each level, according to the first and second measurement results, were as follows: T2 = 19, T3 = 23, T4 = 29, T5 = 33, T6 = 35, T7 = 34, T8 = 38, T9 = 40, T10 = 63, and T11 = 68. There were no statistically significant differences between the first and second measurements performed by any of the three different observers at the 1-month interval (Wilcoxon's signed rank test, $p > 0.05$; Table 2). There were no statistically significant differences between the three observers in the first or 1-month measurements. There was good concordance between observers (Cronbach's alpha > 0.90; Table 3).

At levels other than T2, the pedicle screws were mostly in the third area, and at the T2 level, the majority of screws were in the second area. Postoperative CT was performed in 3 of 82 patients due to suspected inappropriate pedicle screw placement. We did not identify any medial or lateral breach greater than 25% in these patients. There were no complications during the perioperative or postoperative periods related to the pedicle screws. None of the pedicle screws had to be revised.

5. Discussion

The use of pedicle screws has become an important practice in spinal surgery. The most important factor increasing the adoption of the pedicle screw is the powerful three-dimensional corrective force (of deformities) during spinal surgery [23–26]. The other advantages of pedicle screws are increased stability and a low rate of pseudoarthrosis [4–10]. Pedicle screw placement has become a widely used technique for spinal instrumentation in the treatment of various spinal disorders, including spinal deformities, spinal fractures, tumors, and degenerative diseases of the spine. Use of this technique in many diseases brings with it great responsibility. While pedicle screw placement does have advantages, there are several disadvantages if is not performed by an experienced operator. Mispositioned screws may have catastrophic complications, including neurological, vascular, and visceral organ injuries. There have been a number of reports regarding complications of inappropriate pedicle screw placement, including pedicle fracture, pulmonary complications, dural tears, nerve root irritation, neural injury, epidural hematoma causing neurological deficits, and vascular injury, including aortic abutment [8,9,27]. Therefore, accurate and safe pedicle screw placement is critical.

To prevent such complications, a number of pedicle screw placement techniques have been described in the literature, such as the free-hand technique, Penfield outside-in technique, computer-assisted navigational surgery, fluoroscopy-guided methods, and stereotactic surgery [28]. The free-hand technique differs from other techniques due to the absence of intraoperative fluoroscopy, radiography, or imaging guidance [29,30], which reduces the operation time. Radiation exposure poses a risk to both the patient and the treatment team. Usually, surgeons and their teams can protect themselves from exposure to radiation, but the fact that the free-hand technique also protects the patient from exposure to radiation constitutes an important advantage. Preoperative CT is required in stereotactic image-guided systems that results in higher levels of radiation and higher costs [17,31–35]. Despite the advantages of reduced operation time and radiation exposure with the free-hand technique, it requires surgical experience, including mastery in recognizing anatomical landmarks.

In the free-hand technique, landmarks, especially facet joints, clearly show the medial orientation angle. However, sagittal orientation can be more difficult with the free-hand technique, according to the severity of the deformity. Various thoracic pedicle screw starting points have been described in the literature. Two methods have been discussed for thoracic pedicle screw placement [36]: the straight-forward technique and the anatomical trajectory technique. The pedicle screw is

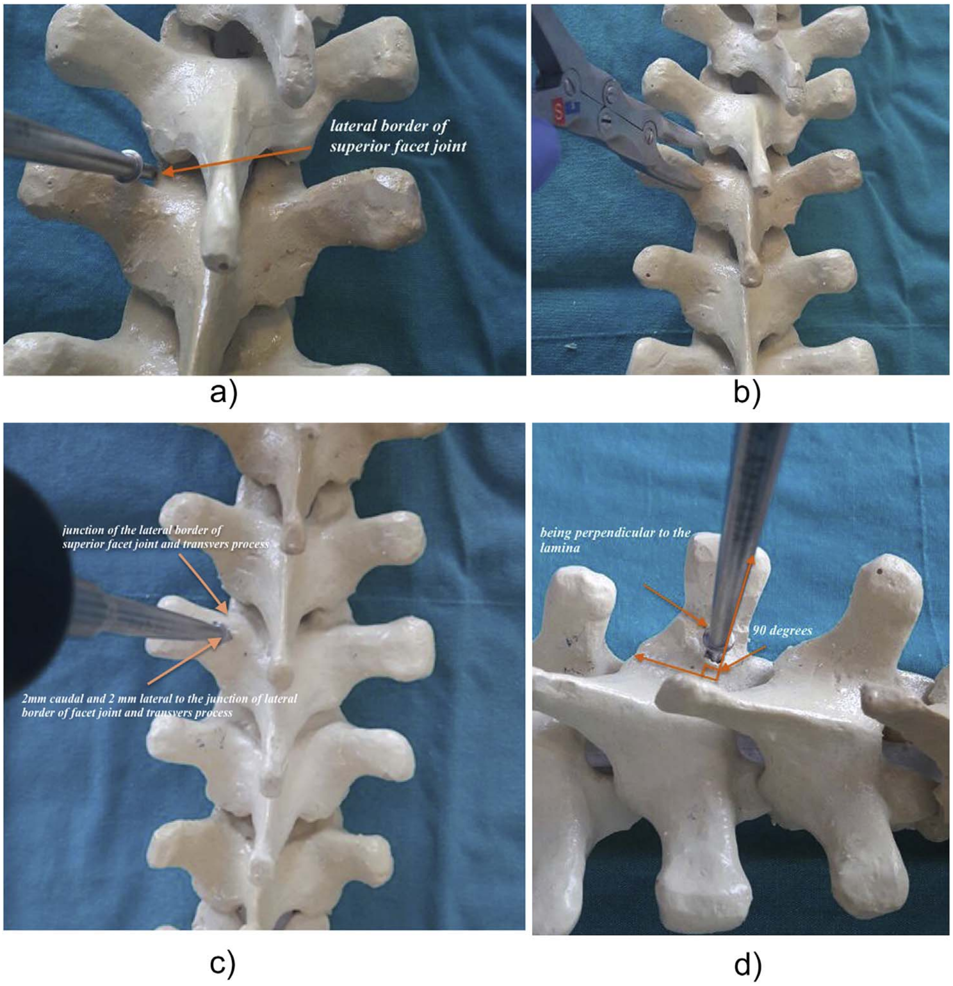

Fig. 3. a–d: Description of the sagittal orientation technique. a. Palpating the lateral border of the superior facet to assess medial angulation. b. Preparing the entry point with a rongeur to visualize the cancellous bone. c. The entry point is 2 mm caudal and 2 mm lateral to the junction of the lateral border of the superior facet joint and transverse process. d. Adjusting the sagittal orientation by holding the pathfinder perpendicular to the lamina of the pedicle.

Table 2
Comparison of two measurements made by three different observers with a 1-month interval (intraobserver).

	First measurement Average ± standard deviation Med (min – max)	Second measurement Average ± standard deviation Med (min – max)	*p*
1. Observer Right	2.78 ± 0.59 3 (2–4)	2.79 ± 0.59 3 (2–4)	0.180
1. Observer Left	2.91 ± 0.59 3 (2–4)	2.9 ± 0.59 3 (2–4)	0.366
2. Observer Right	2.77 ± 0.59 3 (2–4)	2.76 ± 0.59 3 (2–4)	0.058
2. Observer Left	2.89 ± 0.58 3 (2–4)	2.88 ± 0.59 3 (2–4)	0.102
3. Observer Right	2.78 ± 0.59 3 (2–4)	2.77 ± 0.58 3 (2–4)	0.248
3. Observer Left	2.91 ± 0.59 3 (2–4)	2.91 ± 0.59 3 (2–4)	1.00

Note. There were no significant differences between the first and second measurements (Wilcoxon's signed rank test, $p > 0.05$).

parallel to the superior end plate in the straight-forward technique, whereas it is angled 22° caudally in the sagittal plane in the anatomical trajectory technique. The entry points are different between these two methods, varying by the level of the vertebra. Although the free-hand technique is not complicated for an experienced surgeon, standardization of the entry points for all levels may increase the effectiveness of free-hand pedicle screw placement and decrease the misplacement rate.

A practical method that can be used during surgery allows the free-hand technique to be simplified and standardized. Therefore, we attempted to standardize and improve the free-hand thoracic pedicle screw placement technique by combining it with our own technique, which requires no radiation exposure and allows for a shorter screw insertion time. Fennel et al. defined a uniform entry point in the thoracic spine, but their technique uses intraoperative fluoroscopy for initial localization [37]; this conflicts with the reduced radiation exposure associated with the free-hand technique.

In our technique, the entry point of the pedicle screw is 2 mm caudal and 2 mm lateral to the junction of the lateral border of the superior facet joint and transverse process. Meticulous exposure of posterior elements is an important first step in successfully determining proper alignment. In our technique, we determined the sagittal orientation as perpendicular to the lamina and the medial orientation as parallel to the lateral border of the upper facet joint of the pedicle. Regardless of the rotation and angle of the vertebral column, keeping the screw perpendicular to the lamina is the key to proper sagittal alignment. We used fluoroscopy once at the end of screw placement to evaluate the positions of the screws.

Previous studies on the free-hand pedicle screw insertion technique have shown lower rates of pedicle wall perforation when performed by experienced surgeons [14,28,38]. In our study, all pedicle screws were placed by one surgeon with over 10 years of experience in spinal surgery. We used neuromonitoring in all cases. Glassman et al. evaluated the sensitivity and specificity of intraoperative electromyographic monitoring with CT after surgery for documenting screw locations, and concluded that it was a valuable and efficacious method [39]. The efficacy of intraoperative electromyographic monitoring of pedicle screw placement has been reported previously [40–43]. In this study, we did

Table 3
Comparison of measurements made by three different observers (interobserver).

	Observer 1 Average ± standard deviation Med (min – max)	Observer 2 Average ± standard deviation Med (min – max)	Observer 3 Average ± standard deviation Med (min – max)	*p*
1. Measurement Right	2.78 ± 0.59 3 (2–4)	2.77 ± 0.59 3 (2–4)	2.78 ± 0.59 3 (2–4)	0.987
1. Measurement Left	2.91 ± 0.59 3 (2–4)	2.89 ± 0.58 3 (2–4)	2.91 ± 0.59 3 (2–4)	0.982
2. Measurement Right	2.79 ± 0.59 3 (2–4)	2.76 ± 0.59 3 (2–4)	2.77 ± 0.58 3 (2–4)	0.963
2. Measurement Left	2.9 ± 0.59 3 (2–4)	2.88 ± 0.59 3 (2–4)	2.91 ± 0.59 3 (2–4)	0.967

There was good concordance among the observers (Cronbach's alpha, > 0.90).

not observe any neurological complications during surgery.

The primary limitation of the present study may have been the exclusion of patients with severe scoliosis. Although we have used this technique in patients with scoliosis (Cobb angle range: 45°–69°), postoperative rotation of the vertebrae in patients with severe scoliosis (Cobb angle > 80° and patients with neuromuscular scoliosis) at some levels may affect the results. We evaluated postoperative lateral X-rays of patients with severe scoliosis, and determined that rotation may lead to inaccurate evaluation of the pedicle screw tip. Therefore, we excluded patients with severe scoliosis from the present study.

Here, we divided the vertebral corpus into five areas. Areas 1 and 5 corresponded to inappropriate placement of the pedicle screw. We propose that Areas 2, 3, and 4 are appropriate locations for pedicle screw placement. There has been one previous report evaluating proper screw placement; Lehman et al. [44] compared two methods, the anatomical and straight-forward technique, in biomechanical terms. In the present study, we evaluated 382 pedicle screws; apart from the T2 level, most pedicle screws were in Area 3. Moreover, recognition of pedicle screw placement in Area 3, as defined in our study, may aid future researchers attempting to biomechanically define accurate placement of pedicle screws in the sagittal plane.

6. Conclusion

Our technique shows practical differences in terms of entry site and sagittal orientation compared to other methods. This technique allows for accurate and safe craniocaudal orientation of pedicle screws in the thoracic area with a simple operation and no radiation exposure.

Ethical approval

Because of its retrospective design, no ethical approval was mandatory.

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Author contribution

Study concept and design: H.Bahadir Gokcen.

Interpretation of data: Sinan Erdogan, Sidar Ozturk, Gurkan Gumussuyu.

Drafting of the manuscript: H.Bahadir Gokcen, Sinan Erdogan, Irem Bayram, Cagatay ozturk.

Statistical analysis: H.Bahadir Gokcen, Irem Bayram.

Study supervision: Cagatay Ozturk.

Conflicts of interest

None.

Trial registry number

Researchregistry2707.

Guarantor

H.Bahadir GOKCEN, Cagatay OZTURK.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ijsu.2018.01.006.

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