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Accuracy of Freehand Versus Modified Funnel Technique for Pedicle Screw Insertion in the Thoracic Spine

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ABSTRACT

AIM: To describe a new pedicle screw insertion technique, a modification of the funnel technique, and to compare this technique with conventional freehand screw insertion regarding their accuracy and complications in the thoracic spine.

MATERIAL and METHODS: Three hundred forty-three patients who underwent a posterior spinal fusion with different etiologies were retrospectively analyzed. In 84 patients, pedicle screws were placed using the freehand technique, and in 259 patients, the modified funnel technique was used. Screw malposition was evaluated in the immediate and final follow-up in anteroposterior and lateral spinal radiographs by two independent observers. The rates of incorrect pedicle screws and complications, surgical duration, and estimated blood loss were compared between the groups.

RESULTS: A total of 6141 pedicle screws (1468 in the freehand group, 4673 in the modified funnel group) were evaluated. The rate of incorrect pedicle screws was higher in the freehand group (12.0% vs. 4.6%, p=0.001). The surgical time was shorter in the modified funnel group (190.9 ± 57.0 vs. 174.1 ± 47.6 min; p=0.017). The estimated blood loss was similar between the groups (1391.50 ± 570.01 vs. 1264.13 ± 602.29 mL; p=0.053). There were 82 intraoperative pedicle fractures but no neurologic complications in either group.

CONCLUSION: The modified funnel technique provides more accurate pedicle screw insertion in the thoracic spine in the presence of dysplastic pedicles in conjunction with axial rotation compared with the freehand technique. Furthermore, surgical time may be reduced without increasing blood loss.

KEYWORDS: Thoracic pedicle screw, Scoliosis, Freehand technique, Modified funnel technique, Ultrasonic bone curette

ABBREVIATIONS: EBL: Estimated blood loss, **PACS:** Picture archiving and communication system, **CT:** Computed tomography

INTRODUCTION

Thoracic spine pedicles are challenging locations for screw insertion due to the lack of standardized anatomic landmarks and narrow pedicle diameter (13). In the presence of a dysplastic pedicle accompanied by severe vertebral rotation, screw insertion becomes more difficult. Various techniques have been described to ease the insertion of pedicle screws in the thoracic spine,

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such as freehand, fluoroscopy-assisted, and stereotactic navigation technology-assisted techniques (1-3,20). Among these, the freehand technique is the most commonly used pedicle screw insertion method, as described by Kim et al. (10). However, the accuracy of this technique is directly related to the experience and competence of the surgeon. Malpositioned pedicle screws inserted using the freehand technique are not uncommon, and the rate has been reported up to 54.7% (10,16). Thus, several alternative techniques have been described to increase accuracy and decrease possible neurologic and vascular complications. Unfortunately, none of these techniques has been proven to be more effective than the freehand technique. Furthermore, they have many disadvantages such as prolonged surgical time, costly equipment, high radiation exposure, the need for qualified staff, and difficulties in implementation (1,2,20).

In 2000, Gaines described a novel and simple technique, known as the funnel technique, which aimed to place screws with direct visualization of the pedicle entrance by excising the posterior cortical and cancellous bone in the transverse process (24,25). However, this technique has not gained widespread use over time due to certain disadvantages. In particular, the traditional curette used in this technique is both time-consuming and cannot provide a clear field of view due to continuous bleeding from cancellous bone. We modified the funnel technique using an ultrasonic bone curette. The advantage of an ultrasound bone curette over a traditional curette is that it provides a more apparent field of view without damaging cortical bone or the requirement for continuous lavage and aspiration (7,18).

In this investigation, our hypothesis was; "the modified funnel technique would provide a clear view of the pedicle entry point for secure screw insertion in the thoracic spine", and "the rate of the malpositioned screws would be less than in the freehand technique". It was aimed to compare radiologic and clinical outcomes of the modified funnel and freehand techniques.

MATERIAL and METHODS

Patients and Study Design

The institution's Ethics Committee approved the study protocol (Date: 18.06.2020, Number: 9/36). The study was conducted according to the principles of the Declaration of Helsinki. Patients who underwent spinal surgery for various etiologies between February 2014 and March 2020 in the current institution were retrospectively reviewed. The inclusion criteria were defined as patients undergoing thoracic pedicle screw fixation (T1-T12), complete preoperative, and postoperative radiologic images, and regular follow-up. The exclusion criteria for the study were a lack of clinical or radiological data and a follow-up period of less than one year.

During 2014 and 2016, 84 patients (number of screws: 1468) underwent surgery with the freehand technique (group 1). After 2016, we started using the modified funnel technique with the help of an ultrasonic bone curette. Two hundred fifty-nine patients (number of screws: 4673 screws) underwent surgery with the modified funnel technique (group 2). Due to the retrospective nature of the study, randomization techniques were not used. The sample was investigated as two groups according to the pedicle screw insertion technique.

Surgical Technique

All of the pedicle screws were placed by the same spinal surgeons under hypotensive anesthesia with neuro-monitorization. Meticulous hemostasis was performed on all patients, and tranexamic acid was administered (100 mg/kg at the beginning of the surgery and then as an infusion of 10 mg/kg/hour during the surgery) to minimize bleeding. Subperiosteal exposure of the posterior elements, including the facet joints and transverse process, was performed to reveal the anatomic landmarks. Screw placement was initiated from the most distal neutral vertebra.

Freehand Technique

In the freehand group, the screws were implanted after identifying the anatomic entry point, as described by Kim et al. (10). Then, the entry point was penetrated with the awl and pedicle finder, respectively. Before the pedicle screw insertion, five bony borders (anterior, medial, lateral, superior, and inferior) of the trajectory were checked with a ball-tip probe. After all the screws were placed, a single anteroposterior (AP) and lateral checking fluoroscopy was performed.

Modified Funnel Technique

In the modified funnel technique group, no anatomic landmarks were used. The posterior cortex of the transverse process and lateral portion of the lamina were removed using a rongeur over the estimated pedicle entrance. The cancellous isthmus of the pedicle was removed using the ultrasonic bone curette. During this procedure, the anterior cortex of the transverse process was protected. Curettage was continued in a controlled manner until the pedicle entrance was seen. The surgical field was continuously rinsed and aspirated; thus, the bleeding cancellous bone within the pedicle and the surrounding cortical bone could be identified. During the pedicle probe placement, the anterior cortex of the transverse process and the lateral part of the pedicle were used as a guide. The rest of the procedure was the same as in the freehand technique (Figure 1A-H). A video demonstration of the technique can be found in the supplementary materials.

Data Extraction and Clinical Assessments

The patient's demographic data, clinical diagnosis, surgical duration, estimated blood loss (EBL), follow-up period, and complications were procured from the hospital records database. Nadler et al.'s formula was preferred for the calculation of the total blood volume, taking into account the sex, height, and weight of the patient (17). EBL was determined by using the formula defined by Meunier et al. (15). In cases that erythrocyte suspension was used, the relevant volume was added to the EBL. Screw complications were classified by Suk et al. as complications occurring before the screw hole preparation stage (step I), screw hole drilling and screw insertion (step II), and complications after screw insertion (step III) (22).

Radiographic Evaluations

All measurements and evaluations were performed on digital radiographs stored in the Picture Archiving and Communication System (PACS) by two independent observers. Screw malposition was assessed based on previously described methods (11,14). A screw was rated as malpositioned when one of the following criteria was fulfilled: (1) The screw should be inside the elliptical pedicle image, and the tip should not exceed either the midline of the corpus and the lateral border on the AP radiograph; (2) The tip of the screw should stay in the corpus and should not show abnormal deviation in superior or inferior direction on the AP radiograph; (3) On lateral radiographs, the screws should be within the borders of the rectangle forming the vertebral body, and there should be no inferior and superior deviations; (4) The tip of the screw should not exceed the anterior cortex of the vertebral body (Figure 2A-E).

Interobserver reliability was assessed after both observers completed their assessments. Kappa statistics revealed an almost perfect agreement on correct and incorrect screw rating and substantial agreement on the direction of incorrect screws (Table I). Afterwards, both observers discussed the contradictory ratings and reached a consensus decision. The final analysis was performed using the final joint decision.

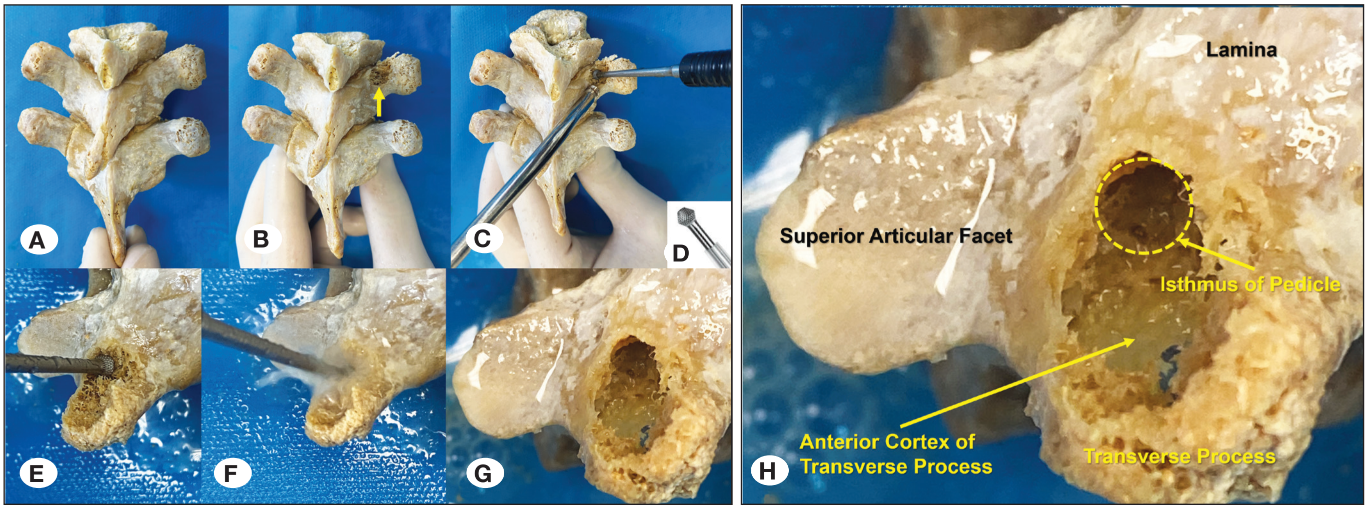

Figure 1: A) Intact cadaver spine (T6, T7, and T8). **B)** The cortex overlying the estimated entrance of the pedicle was removed (yellow arrow). **C)** Application of the ultrasonic curette and the continuous aspiration. **D)** The tip of the ultrasonic curette. **E, F)** Removal of the cancellous bone with continuous rinsing and aspiration. **G)** Final appearance after the curettage. **H)** The schematic appearance of the pedicular isthmus and surrounding anatomic structures.

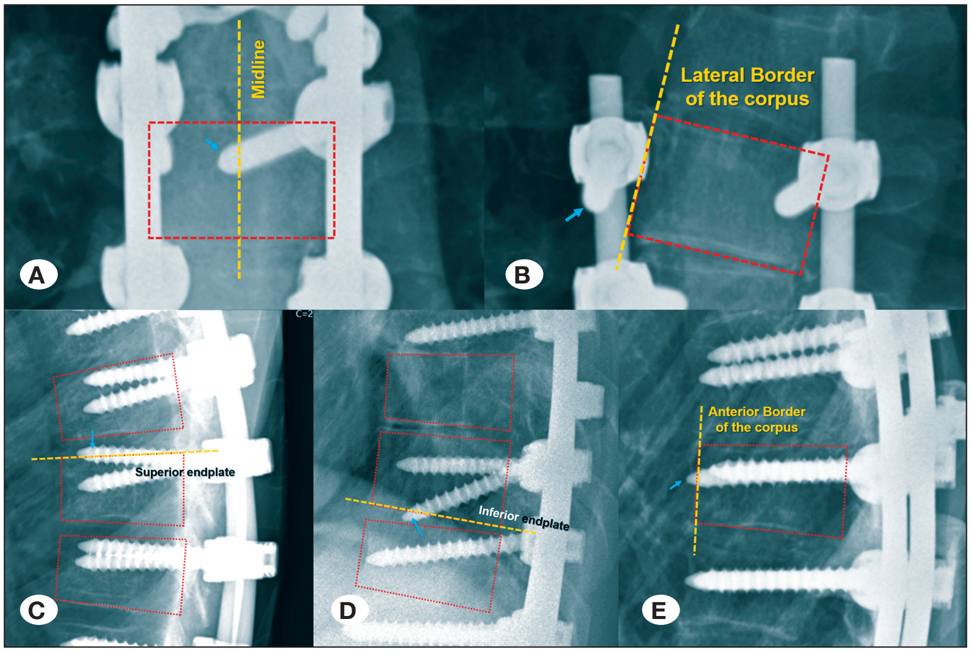

Figure 2: Radiographic examples of the criteria used to rate the position of the screws. **A)** An example of a pedicle screw (blue arrow) that exceeds the midline on the AP radiograph. **B)** An example of a pedicle screw (blue arrow) that exceeds the lateral border of the corpus on the AP radiograph. **C)** An example of a pedicle screw that penetrated the superior endplate and entered intervertebral disc space on the lateral radiograph. **D)** An example of a pedicle screw that penetrated the inferior endplate and entered to intervertebral disc space on the lateral radiograph. **E)** An example of a pedicle screw that penetrated the anterior border of the corpus on the lateral radiograph.

Table I: Inter-Observer Reliability of the Position of the Screws (Correct vs. Incorrect) and the Direction of the Incorrect Screws

		Observer B						Total	Kappa (95% CI)	Agreement (%)
		Correct	Midline	Lateral	Superior	Inferior	Anterior			
Observer A	Correct	5722	13	21	16	10	1	5783	0.861* (0.888- 0.833)	98.4%*
	Midline	16	103	1	0	0	0	120		
	Lateral	17	1	135	1	1	0	155		
	Superior	1	0	0	30	0	0	31		
	Inferior	4	0	1	0	42	0	47	0.729 ** (0.779-0.678)	80.1%**
	Anterior	3	0	0	0	0	2	5		
	Total	5763	117	158	47	53	3	6141		

**kappa for Correct/Incorrect rating, **kappa for the Direction of the Incorrect screw.*

Statistical Analysis

The IBM SPSS Statistics for Windows, Version 23.0 (IBM Corp., Armonk, NY, USA) was used for performing statistical analysis, and statistical significance was accepted as p-values <0.05. Categorical variables are presented as numbers and percentages, and continuous variables are given as mean ± standard deviation (SD). The compliance of continuous variables with parametric assumptions was evaluated using visual and analytical methods. Pearson's Chi-square test was performed for thre comparison of categorical variables, the independent samples t-test was used when the data conformed to normal distribution, otherwise the Mann-Whitney U test was preferred.

RESULTS

Comparison of Baseline Demographic and Clinical Characteristics

There were 84 patients (25 males, 59 females) with a mean age of 18.50 ± 7.93 years in the freehand group and 259 patients (100 males, 159 females) with a mean age of 19.00 ± 10.31 years in the modified funnel technique group (sex p=0.079, age p=0.737). The mean follow-up period was 32.9 ± 15.4 (range, 12 – 72) months in the freehand group and 26.0 ± 11.7 (range, 12 – 49) months in the modified funnel technique group (p<0.001). In the freehand group, a total of 1468 pedicle screws were implanted in the thoracic vertebra, and in the modified funnel technique group, a total of 4673 pedicle screws were implanted. In the modified funnel technique group, 41.4% of the patients had adolescent idiopathic scoliosis, 22.7% had Scheuermann kyphosis, and 16.4% had neuromuscular scoliosis. In the freehand technique group, 53.6% of the patients had adolescent idiopathic scoliosis, 22.6% had Scheuermann kyphosis, and 16.7% had adult scoliosis. The mean instrumented number of segments was 12.52 ± 1.22 in the freehand group and 13.10±1.53 in the modified funnel technique group (p=0.001). The mean surgical time was similar in both groups (190.95 ± 57.02 vs. 174.14 ± 47.67 min; p=0.017). The mean EBL was 1391.50 ± 570.01 mL and 1264.13 ± 602.29 mL, respectively, in the freehand and modified funnel technique groups (p=0.053). A summary of all data is presented in Table II.

Radiographic Results

The screw placement accuracy in the thoracic spine was significantly higher in the modified funnel technique group (95.4% vs. 88.0%, p=0.001) (Table III). Malpositioned screws were more common on the concave side (7.8%) compared with the convex (6.0%) and neutral sides (4.7%) (p=0.001) (Table IV). In the freehand group, the highest number of malpositioned screws were implanted in T3 (8.3%), followed by T6 (6.6%) and T4 (6.6%). In the modified funnel technique group, the highest number of malpositioned screws was implanted in T2 (23.1%), followed by T6 (17.2%), and T5 (17.0%) (Table V).

Among the total of 392 misplaced screws, lateral (41.3%) and medial (31.3%) perforations were the most common, followed by inferior (13.2%), superior (11.4%), and anterior (1.5%), respectively.

Complications

There were no neurologic, vascular, and visceral injuries in any patients associated with thoracic pedicle screws. Furthermore, no intraoperative dural tears or cerebrospinal fluid (CSF) leakage was observed in any cases. Fractures occurred at step II in 26 (0.01%) pedicles in the freehand group and 56 (0.01%) pedicles in the modified funnel technique group (p=0.099). Broken pedicles were left empty. In the final radiographs, no screw pull-out was detected.

DISCUSSION

The results of this study showed that the ultrasonic bone curette-assisted funnel technique had a better accuracy rate for screw insertion in the thoracic spine, even in the presence of severe vertebral rotation and dysplastic pedicles. Although the number of instrumented segments and the number of total screws were higher in the modified funnel technique, surgical duration was shorter than with the freehand technique. Moreover, the EBL was not higher despite curettage of the

Table II: Comparison of Baseline Demographic and Clinical Characteristics of the Patients

Variables	Free-Hand Technique (n=84)	Modified Funnel Technique (n=256)	p
Age (years±SD)	18.50 ± 7.93	19.00 ± 10.31	0.737*
Sex (M/F)	25/59	100/159	0.079**
Follow-up (months±SD)	32.9 ± 15.4	26.0 ± 11.7	**0.001***
Etiology (%)			**0.040****
AIS	45 (53.6)	106 (41.4)	
Adult Scoliosis	14 (16.7)	32 (12.5)	
Neuromuscular scoliosis	3 (3.6)	42 (16.4)	
Congenital Scoliosis	3 (3.6)	11 (4.3)	
Scheuermann Kyphosis	19 (22.6)	58 (22.7)	
Adult Spinal Deformity Other Etiologies	0	15 (5.9)	
Spinal Stenosis	0	2 (0.8)	
Thoracal screws per case (n ± SD)	17.46 ± 3.14	18.25 ± 2.14	0.220*
Total screws per case (n ± SD)	23.03 ± 3.21	24.88 ± 3.20	**0.001***
Instrumented segment per case (n ± SD)	12.52 ± 1.22	13.10 ± 1.53	**0.001***
Surgical Time (min ± SD)	190.95 ± 57.02	174.14 ± 47.67	**0.017***
Mean surgical time per segment (min ± SD)	15.21 ± 4.05	13.36 ± 3.62	**0.001***
EBL (ml ± SD)	1391.50 ± 570.01	1264.13 ± 602.29	0.053*
Mean EBL per segment (ml ± SD)	112.51 ± 49.74	97.71 ± 47.45	**0.017***

Mann-Whitney U-test, **Chi-Square Test.* ***AIS:* *Adolescent idiopathic scoliosis,* ***M:*** *Male,* ***F:*** *Female.*

Table III: Comparison of the Accuracy of the Pedicle Screw Position Between Techniques

Accuracy	Group		Total	p
	Free-Hand Technique	Modified Funnel Technique		
Correct	1292 (88.0%)	4457 (95.4%)	5749 (93.6%)	**0.001***
Incorrect	176 (12.0%)	216 (4.6%)	392 (6.4%)	
Total	1468	4673	6141	

**Chi-square test, % within Group.*

Table IV: Accuracy of the Screws according to Site of the Screw on the Curvature

		Location of the Screw			Total	p
		Neutral	Convex	Concave		
Accuracy	**Correct**	1346 (95.3%) [a]	2220 (94.0%) [a]	2183 (92.2%) [b]	5749 (93.6%)	**0.001***
	Incorrect	67 (4.7%) [a]	141 (6.0%) [a]	184 (7.8%) [b]	392 (6.4%)	
Total	**Count**	1413	2361	2367	6141	

**Chi-Square test. [b]>[a] Statistically more frequent (Bonferroni correction).*

Table V: Comparison of Accuracy according to Vertebral Levels

	Free-Hand Technique, n(%)		Modified Funnel Technique, n(%)		
	Correct	**Incorrect**	**Correct**	**Incorrect**	**p**
T1	-	-	4 (100.0)	0 (0.0)	NA
T2	10 (76.9)	3 (23.1)	31 (96.9)	1 (3.1)	0.066
T3	97 (85.8)	16 (14.2)	265 (91.7)	24 (8.3)	0.060
T4	128 (89.5)	15 (10.5)	428 (93.9)	28 (6.1)	0.062
T5	127 (83.0)	26 (17.0)	471 (95.3)	23 (4.7)	**0.001***
T6	130 (82.8)	27 (17.2)	465 (93.4)	33 (6.6)	**0.001***
T7	131 (85.1)	23 (14.9)	465 (94.7)	26 (5.3)	**0.001***
T8	119 (82.6)	25 (17.4)	468 (95.1)	24 (4.9)	**0.001***
T9	129 (90.2)	14 (9.8)	471 (96.5)	17 (3.5)	**0.004***
T10	143 (95.3)	7 (4.7)	478 (97.8)	11 (2.2)	0.103
T11	134 (90.5)	14 (9.5)	464 (96.9)	15 (3.1)	**0.003***
T12	144 (96.0)	6 (4.0)	447 (97.0)	14 (3.0)	0.364
Total	1292 (88.0)	176 (12.0)	4457 (95.4)	216 (4.6)	**0.001***

cancellous bone. This new modification might be an alternative technique for accurate pedicle screw insertion in the thoracic spine without increasing complications. To the best of our knowledge, this is the first study to evaluate the accuracy and reliability of the modified funnel technique compared with the freehand technique in the thoracic spine.

There are several approaches for pedicle screw placement in thoracic and thoracolumbar vertebrae, and the freehand technique remains the most commonly preferred method (10). In a systematic review by Gelalis et al., the rate of correct pedicle screw insertion with the freehand technique was reported as between 69% to 94%. In the case of intraoperative fluoroscopic controlled screw insertion, these rates increase slightly, and the accuracy reaches 81% to 92%. In computer-aided navigation systems, these rates are almost perfect (89% to 100%) (6). High accuracy rates were recently reported with custom-made guides manufactured through 3D computed tomography (CT) of each patient (19,21).

In the current study, screw implantation was performed using an ultrasonic bone curette-assisted funnel technique, and 4672 pedicle screws were placed with a 95.4% accuracy rate, which is quite similar to the methods using computer-aided navigation techniques and a personalized 3D-printed guide. Achieving this high accuracy without increasing radiation exposure or using expensive systems is the most crucial advantage of the described technique.

The second important issue in pedicle screw fixation is surgical time. Any system or method that is proposed to increase the accuracy should not simultaneously increase the surgical time. It is well known that several complications, particularly infection and blood loss, directly correlate with surgical time. The surgical time or time per screw was not available in all studies investigating the accuracy and safety of pedicle screw insertion. In a study comparing robot-assisted and freehand pedicle screw insertions, the skin-to-skin surgical time was statistically longer (220.1 ± 55.9 vs. 189.8 ± 45.1 min), even with less proximal facet joint violations and when better convergence orientations were followed (9). In a study on the use of intraoperative CT with or without a navigation system, the time per screw was 3.49 ± 0.73 in the presence of navigation, whereas it was 4.97 ± 1.01 under CT guidance only (5). The overall surgical time was 20 minutes shorter with the modified funnel technique group in the present study, even though more segments were instrumented. However, the time per screw could not be calculated precisely because this study was a retrospective study, and it included cases where screws were implanted into the lumbar segments. However, using a motorized device rather than a conventional surgical instrument keeps the curettage time short.

Given that the curettage procedure exposes more cancellous bone, it could theoretically increase bleeding. Therefore, the amount of bleeding was also compared to test this hypothesis. Similar blood loss and transfusion rates were detected in both methods. Unfortunately, blood loss has been reported in very few studies comparing screw insertion techniques. Laine et al. compared the freehand technique with computer-assisted pedicle screw insertion and reported similar blood loss in each technique (1270 ± 1325 vs. 1107 ± 809 mL; $p>0.05$) (12). A systematic review that investigated the accuracy of pedicle screw insertion with different techniques revealed no superiority of navigational techniques over conventional techniques regarding blood loss (23). In contrast, another meta-analysis revealed that 3D-printed drill guides significantly decreased blood loss compared with conventional techniques (26). The amount of bleeding can be affected by various factors such as patient positioning, surgical time, anesthesia methods, medications used, and factors related to the patient. Therefore, it is complicated to demonstrate the effectiveness of any technique alone in terms of the amount of bleeding.

One possible disadvantage of the funnel technique is its impaired biomechanical stability because the posterior cortex and the cancellous bone have been removed, which could reduce the grip of the threads of the pedicle screw. There is only one cadaveric study comparing the biomechanical stiffness and pull-out strength of screws in freehand and funnel techniques. Huang et al. reported that pull-out strength was significantly lower with the funnel technique, but the spinal column's overall stiffness was similar. The pull-out strength was only 11% weaker (789 vs. 887 N) (8). In the current study, we followed all patients for at least one year, and the final follow-up radiographs were reviewed to monitor any late complications related to stability. None of our patients had screw pull-out.

Finally, the important issue to discuss is the cost of this technique. A new technique should increase accuracy but not cost. In our country, the cost of this device per case is €150. Although it may seem like a disadvantage compared with the freehand technique, it is much cheaper than other alternative techniques such as computer-assisted navigation systems. Although intraoperative CT-based navigation systems allow highly accurate pedicle screw placement in challenging cases, it is far from being available for many facilities due to its high cost (4).

The study's retrospective design and the heterogeneous nature of the included patients are the main limitations of the study. Secondly, the evaluation was performed using conventional radiographs. Compared with CT, direct radiographic assessment has a high margin of error for a correctly rating screw malposition. However, CT is not a routine postoperative imaging modality due to the high radiation dose required and cost. Previously defined criteria were used to reduce the margin of error in radiographic evaluations rather than subjective decision-making. Two independent observers made the measurements, and consensus decisions were used in the analyses.

CONCLUSION

In conclusion, the modified funnel technique is a safer, faster, and more practical procedure for posterior instrumentation of all kinds of spinal disorders than the freehand technique. Our study shows that this technique can increase the control, speed, and comfort of surgeons and surgical staff.

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