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Ball Tip Feeler *vs*. Depth Gauge: Detection of Bony Pedicle Defects Before Pedicle Screw Insertion

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Abstract

Background/Aim: The objective of this study was to investigate whether the detection rates of pedicle breaches depended on the surgeon's experience level and whether different instruments resulted in varied palpation quality.
Materials and Methods: Experienced surgeons (ES) (n=8) and inexperienced surgeons (IS) (n=10) were compared. The study was performed using a sawbone model of the spine. Pedicle defects were created at various positions and levels. Participants detected and located the bony defects using a depth gauge and a straight ball tip feeler. After the first measurement, the IS group underwent training focused on identifying bone defects. The experiment was repeated after three weeks under identical conditions.
Results: A significant difference was found between ES and IS in the time required to palpate pedicles and bony defects using the ball tip feeler during the first measurement (297.2±114.4 s *vs.* 202.1±77.9 s; $p=0.05$). However, after training and during the second measurement three weeks later, these differences were no longer observed (223.7±65.1 s *vs.* 212.2±73.6 s; $p=0.73$). Notably, no significant differences were found in the accuracy in detecting bony pedicle defects between the two groups, regardless of the device used. Furthermore, no improvement was found in the IS group after training, regardless of the device used.
Conclusion: ES and IS accurately detected pedicle breaches without significant differences. Training did not affect detection rates between the groups, and the choice of device did not affect the accuracy of pedicle breach detection.

Keywords: Pedicle screw placement, pedicle defect, ball tip feeler, pedicle screw misplacement, depth gauge.

Introduction

Pedicle screws (PS) play an essential role in different spinal surgeries. Pedicle screw placement (PSP) is often challenging, with the quality of free-hand screw placement heavily dependent on the surgeons' experience (1-3). Misplaced PS pose significant risks, including severe complications such as neurological damage or potentially fatal hemorrhage from

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injury to major blood vessels (4-7). Moreover, misplaced PS can compromise biomechanical implant stability (8). Therefore, to mitigate these risks, intraoperative palpation of the pedicle and vertebra is routinely performed following probing, serving as a key method to confirm a correct and fully intraosseous screw canal (9).

Numerous studies have evaluated the accuracy of PSP in different spinal regions using the freehand technique. These studies focused on patients with conditions such as vertebral fractures, spinal stenosis, kyphosis, tumors, infections, and pelvic fractures. The reported rates of screw misplacement, including perforations of the pedicle wall or the anterior cortex of the vertebral bodies, varied by spinal region. Misplacement rates were observed to be 5.4%-11.1% in the cervical spine, 9.0%-16.1% in the thoracic spine, and 0.9%-9.1% in the lumbar spine (3, 10-13).

Consequently, various techniques and technologies have been developed to enhance the safety of PSP. In addition to palpation, intraoperative 3D navigation, robotics, and impedance-measuring devices are available to ensure the accuracy of this procedure. In particular, robotics and navigation have demonstrated significant potential in improving precision during PSP (14-17).

Several studies have evaluated surgeons' ability to assess screw tracts for violations prior to screw insertion, utilizing ball tip feelers and different wires (2, 18).

In the thoracic spine, Lehman *et al.* demonstrated that the accuracy of detecting pedicle tract violations and pinpointing their precise location largely depends on the surgeon's level of training. This suggests that such detection is a skill that improves with practice and experience. The study reported a sensitivity range of 50% to 81% in identifying pedicle breaches (2).

Based on published data and our clinical experience, we aimed to further investigate whether the detection rates of pedicle breaches depend on the surgeon's experience level. Moreover, we aimed to explore whether short, intensive training could enhance the ability to identify pedicle defects and whether different instruments yield variations in palpation quality.

Table I. *Location of pedicle defects in the thoracic and lumbar spine.*

Segments	Left pedicle	Right pedicle
T7	Medial	None
T8	Medial	None
T9	None	None
T10	None	None
T11	None	Caudal
T12	Anterior	Medial
L1	Caudal	None
L2	None	None
L3	None	Anterior
L4	Caudal	None
L5	Medial	None
S1	Medial	Anterior

Materials and Methods

The study was performed in accordance with the guidelines set by the local ethics committee. No formal approval was required, as all participants voluntarily joined and only a plastic spine model was used.

Spine model and defects. A high-resolution plastic spine model (full spine, C1 to sacrum; item #1323-41; Sawbones, Vashon, WA, USA) was mounted and secured in a prone position using a spine holder (full length; item #1526; Sawbones). To simulate a more realistic impression for the participants, the model was covered with foam.

Defects were introduced with a drilling machine and a K-wire, while PS trajectories were prepared using a pedicle probe. The bony defects or penetrations were randomly distributed across the thoracic and lumbar spine in medial, lateral, and caudal directions, reflecting typical patterns of malposition (Table I). A total of eleven defects were created, including five medial defects, three anterior defects, and three caudal defects, with no defects introduced in the cranial or lateral directions. Moreover, 13 correct intraosseous trajectories were prepared.

Study design. The study involved experienced surgeons (ES) (n=8), who had previously inserted more than 1000

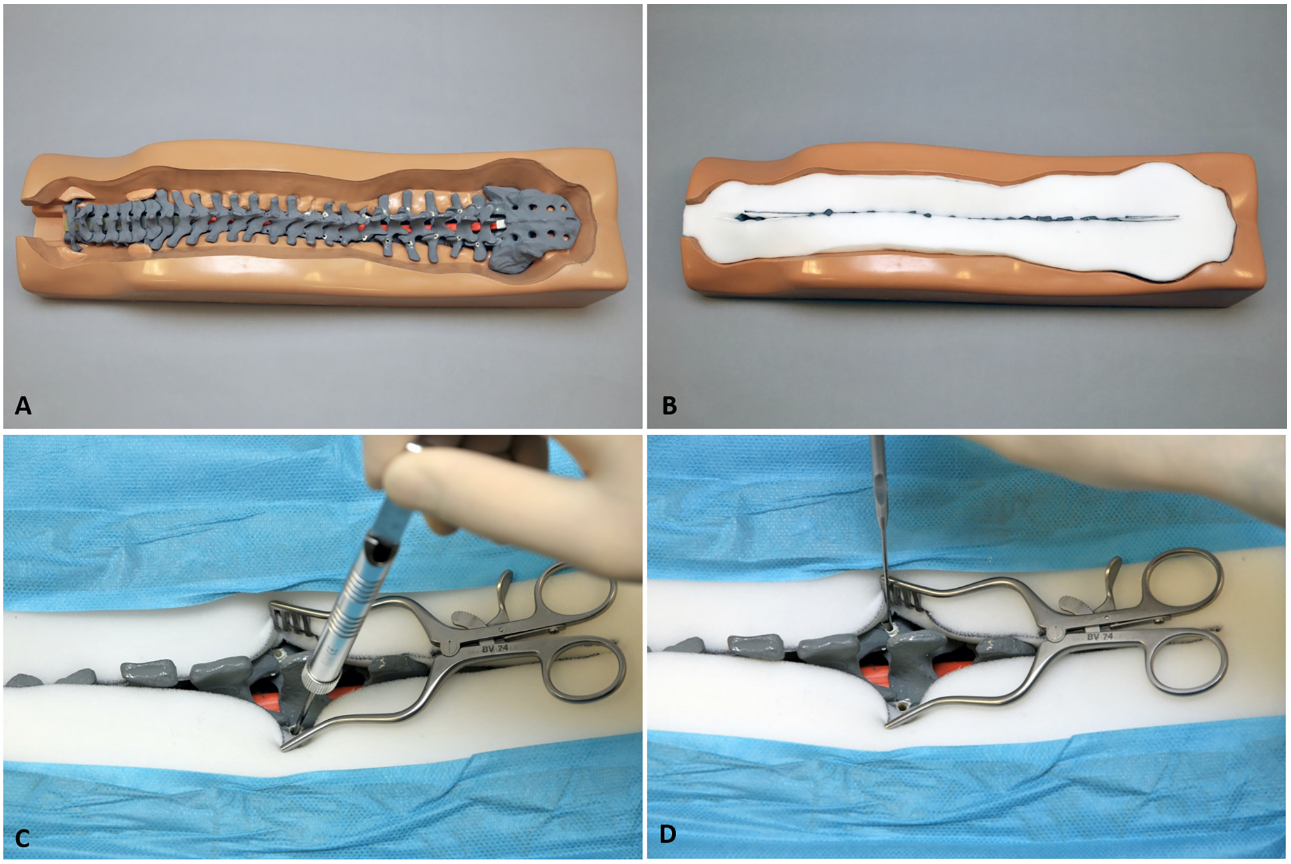

Figure 1. *Experimental setup. Pedicle defects were created in the full spine model, which was placed in a spine holder (A). The model was covered with foam (B). Participants were instructed to palpate the pedicles using a depth gauge (C) or a straight ball tip feeler (D). During palpation, only the specific part of the spine being analyzed was exposed. This ensured that participants focused solely on palpation, avoiding reliance on anatomical orientation by visualizing adjacent vertebrae.*

PS, and inexperienced surgeons (IS) (n=10), who had inserted less than 10 PS during their careers.

All participants were instructed to palpate the pedicles demonstrated in Table I using two devices: a depth gauge (item #2750-10-100; Depuy Synthes, Umkirch, Baden-Würtemberg, Germany) and a straight ball tip feeler (item #2750-10-140; Depuy Synthes). The experimental setup is shown in Figure 1.

Study participants assessed whether pedicles were intact or exhibited bony defects. These assessments were performed under supervision. Neither the time required, nor the number of trials were restricted. The analysis included the following parameters: time required (s), number of trials per pedicle, and assessment outcome (presence or absence of pedicle defects).

Subsequently, IS underwent training to identify bone defects using a different saw bone model that was similar to the initial model. This training was conducted for seven days. After an interval of three weeks, the experiment was repeated as previously described.

Statistical analysis. Statistical analysis was performed using SPSS 21 (IBM, Armonk, NY, USA), with significance set at $p<0.05$. The Student's t-test, after confirming the normality assumption, was used to compare the means of the continuous variables between study groups defined by the categorical variables.

Results

ES (n=8) had an average of 16.9±5.7 years of surgical experience. By contrast, IS (n=10) had been practicing for an average of 3.0±6.7 years at the time of the study ($p<0.01$). The mean ages of ES and IS were 43.9±4.9 years and 30.1±2.5 years, respectively ($p<0.01$). Details about the study participants are presented in Table II.

When comparing the overall time required for palpating the pedicles using the depth gauge during the first measurement, no significant difference was found between the ES and IS groups (305.9±177.1 s *vs.* 215.5±67.0 s; $p=0.15$). Similarly, the second measurement, conducted after 7 days of training, also showed no significant difference in the time needed for this task between the two groups (235.1±105.9 s *vs.* 206.8±73.8 s; $p=0.51$).

However, a significant difference was found when using the straight ball tip feeler to palpate the pedicles. During the first measurement, ES were significantly slower than IS (297.2±114.4 s *vs.* 202.1±77.9 s; $p=0.05$). This difference was no longer evident during the second measurement. These results are summarized in Table III.

Furthermore, the accuracy of the pedicle palpations performed by each surgeon was analyzed, focusing on the identification of correctly placed intraosseous trajectories (n=13) and the detection of pedicle breaches (n=11) using either the depth gauge or the straight ball tip feeler. No significant differences in accuracy were found between ES and IS during the first measurement (depth gauge: 72.6% *vs.* 64.8%, $p=0.21$; straight ball tip feeler: 64.9% *vs.* 63.3%, $p=0.85$). These results remained consistent after seven days of training in the second measurement.

Moreover, no significant improvement in the detection of the correct screw channel was found after the training of IS, regardless of the device used (Table IV).

For lesion-free sites, the specificity of detection was 0.72 for ES and 0.70 for IS when using a depth gauge. With the straight ball tip feeler, specificity was 0.87 for ES and 0.85 for IS in identifying lesion-free sites. For sites with lesions, sensitivity was 0.98 for ES and one for IS when using a depth gauge. When the ball tip feeler was used, sensitivity values were 0.74 and 0.88 for ES and IS, respectively, in detecting lesions.

Table II. *Characteristics of study participants.*

	Experienced surgeons	Inexperienced surgeons
Number	8	10
Inserted pedicle screws	>1,000	<10
Age [years] (mean±SD)	43.9±4.9	30.1±2.5
Sex [male:female]	7:3	7:1
Surgical experience [years] (mean±SD)	16.9±5.7	3.0±6.7

Discussion

A significant difference was found between ES and IS in the time required for palpating the intraosseous trajectory and bony defects during the first measurement using the ball tip feeler ($p=0.05$). Interestingly, ES required more time to palpate the intraosseous trajectory, which may seem counterintuitive. This result could be attributed to that ES, given their experience, are more cautious due to awareness of the severe consequences of pedicle breaches or screw mispositioning. This caution may lead them to palpate the pedicles more meticulously. In addition, ES have a well-developed expectation of how an intact pedicle or a breach should feel. However, the tactile experience of pedicle palpation on sawbones differs from that of a human spine, which could further influence their approach. By contrast, IS may lack such referential experiences, resulting in a more expedient but potentially less thorough palpation process.

During the second measurement using the ball tip feeler, no significant difference was observed between ES and IS regarding the time required for pedicle palpation. Compared with the first measurement, ES demonstrated a reduction in time during the second measurement, although this decrease was not statistically significant.

Table III. *Time required for palpating the prepared pedicles using both instruments.*

	Experienced surgeons	Inexperienced surgeons	*p*-Value
Depth gauge			
First measurement [s±SD]	305.9±177.1	215.5±67.0	0.15
Second measurement [s±SD]	235.1±105.9	206.8±73.8	0.51
p-Value	p=0.35	p=0.69	
Straight ball tip feeler			
First measurement [s±SD]	297.2±114.4	202.1±77.9	0.05
Second measurement [s±SD]	223.7±65.1	212.2±73.6	0.73
p-Value	p=0.14	p=0.77	

Table IV. *Accurately reported results after pedicle palpation using both devices.*

	Experienced surgeons	Inexperienced surgeons	*p*-Value
Depth gauge			
Detection rate first measurement (%)	15.3 (72.6)	13.6 (64.8)	0.21
Detection rate second measurement (%)	14.9 (70.9)	13.9 (66.1)	0.39
p-Value	p=0.83	p=0.66	
Straight ball tip feeler			
Detection rate first measurement (%)	13.6 (64.9)	13.3 (63.3)	0.85
Detection rate second measurement (%)	15.1 (72.0)	13.1 (62.4)	0.19
p-Value	p=0.47	p=0.86	

Conversely, the time needed by IS did not show a significant improvement after training. This indicates that the results during the second measurements were due to the faster pedicle palpation by the ES. However, speed alone should not be considered a quality criterion; the most important aspect is the accurate detection of breaches.

For the depth gauge, no significant difference in pedicle palpation time was found between the first and second measurements, regardless of whether the user was an IS or ES. This result seems somewhat inconsistent with the previously explained findings. A possible explanation is that ES generally do not rely on the depth gauge for palpation and therefore may not possess greater expertise with this instrument compared with IS.

The lack of significant improvement in IS performance during the second measurement, observed for both the depth gauge and the ball tip feeler, suggests that training did not have a significant effect on the time required for pedicle palpation. This could be due to the three-week interval between training and the second measurement. Either the training was insufficient to produce a significant improvement, or the time gap diminished the training's effectiveness.

Interestingly, no significant differences were found in the accuracy of detecting pedicle breaches between ES and IS. Training did not significantly affect the accuracy of results reported by IS. Overall, our findings suggest that training level did not play a substantial role in a surgeon's ability to accurately identify pedicle breaches.

Numerous studies have evaluated the accuracy of pedicle screw placement, reporting breach rates ranging from 3.7% to 15.6% across different spinal segments (3, 10, 11, 13). Misplacement of pedicle screws can lead to severe consequences, such as neurological damage and vascular injuries (4, 5). As a result, accurately identifying pedicle tract violations before pedicle screw placement remains a crucial component of spinal instrumentation procedures.

Accurate detection of bony defects helps in reducing the rate of screw misplacements. Several factors contribute to the correct placement of pedicle screws, including the placement technique, the surgeon's experience, spinal pathology, and the use of intraoperative imaging (2). Therefore, the combined use of intraoperative imaging and pedicle palpation remains an important part in spine surgery.

Probing alone may be insufficient to detect pedicle breaches. A study by Sedory *et al.* demonstrated that the standard ball tip feeler was less reliable than expected. While the tool proved effective in confirming intact pedicles, with surgeons accurately identifying 81% of them, it showed a high false-positive rate for breach detection. The positive predictive value for breaches varied from 12% to 20% depending on the location, indicating that pedicle palpation could lead to either misidentification of breach locations or incorrect diagnoses of violations when none exist (19).

A prospective study by Donohue *et al.* also assessed the accuracy of manual palpation with a ball tip feeler during thoracic spine surgery. Surgeons accurately identified 98% of pedicles without breaches (20). However, only 19% of medial and 13% of lateral breaches measuring ≥2 mm were correctly identified. These findings corroborated the results of the study conducted by Sedory *et al.* (19).

Few studies have explored the factors affecting a surgeon's ability to detect pedicle tract violations. Lehmann *et al.* found that this ability largely depends on the surgeon's level of training. The study suggested that breach detection is a skill honed through practice and experience (2).

Numerous studies have evaluated the effect of a surgeon's training level on the accuracy of screw placement. Baird *et al.*, using a human cadaveric model, reported that the frequency of facet violations during placement of percutaneous pedicle screws is significantly higher among surgical trainees compared with attending surgeons (21). However, no significant difference was found among trainees themselves. In another cadaveric study, Bergeson *et al.* assessed the effects of training sessions on screw placement accuracy in inexperienced orthopedic residents. Each resident surgeon instrumented five thoracic spines, placing a total of 297 screws. The findings revealed a decrease in the incidence of pedicle breaches starting from the third cadaver, with accuracy improving by the fourth cadaver. By this point, all surgeons achieved levels of accuracy comparable to those reported in the literature for experienced spine surgeons operating on intact spine specimens or live patients (22).

Similar training effects have been demonstrated using 3D-printed spine models. For instance, Park *et al.* conducted a study in which two surgical residents with no prior experience in free-hand pedicle screw instrumentation were guided by an experienced surgeon. Each resident inserted 10 pedicle screws for each lumbar spine model. Initially, 18.5% of the screws perforated the pedicle cortex; however, total violations significantly decreased over time. The latter half of the models exhibited significantly fewer pedicle violations than the former half (10/100 *vs.* 27/100, $p<0.001$). Moreover, as residents continued practicing on the 3D-printed models, the time required for screw instrumentation decreased significantly (23). The latter 10 spine models required significantly less time to complete than the former 10 models (42.8±5.3 min *vs.* 35.6±2.9 min; $p<0.01$) (23). A strong negative relationship was observed between the number of repetitions and the length of the procedure. Based on these findings, whether the reduced time resulted from faster palpation of the pedicle or quicker screw insertion is unclear. In our study, no improvement was found in the time required for pedicle palpation after training, and no significant difference was observed between the performance of IS and ES during the second measurement. These findings suggest that while training may not influence the duration of pedicle palpation, the critical factor affecting operation time may lie in the pedicle screw insertion process rather than pedicle palpation itself.

A retrospective study by Samdani *et al.* examined the pedicle breach rate in patients with adolescent idiopathic scoliosis using postoperative computed tomography (CT) scans. The results were stratified based on surgeon experience (<2 years in practice or <20 surgical cases, 2–5 years or 20–50 cases, and >5 years or >50 cases). The results showed no correlation between surgeon experience and the overall pedicle breach rate; however, surgeon experience significantly influenced the number of medial pedicle breaches (24).

Contrary to other studies, we could not show an effect of training on the accuracy of palpating bony defects or identifying breaches in the pedicle screw channel.

To address pedicle perforations, new devices, such as impedance-measuring probes, have been developed. These devices assess electrical conductivity at the tip to distinguish between bone and soft tissue to reduce the occurrence of pedicle breaches (25).

This study has some limitations. First, surgeons were not able to view a CT scan before pedicle palpation, leaving them unaware of the specific anatomical features they might encounter. Second, the tactile properties of sawbone differ from those of human bone. Third, participants did not perform pedicle drilling themselves, depriving them of another regular tactile reference. This approach was necessary to ensure consistency across experimental conditions. Finally, fluoroscopic imaging was not used to evaluate the pedicle tract, focusing the study solely on the surgeon's ability to palpate pedicles without supplementary aids.

Conclusion

Significant differences were not observed between ES and IS in detecting pedicle breaches. The comparison of ES and IS did not show an effect of training on the detection rate of bony pedicle defects. Our data may be used for surgical education as they demonstrate that skills are more important than devices during pedicle palpation, however, also highlight that experience is not always equated with better results.

Conflicts of Interest

The Authors have no conflicts of interest to declare in relation to this study.

Authors' Contributions

U.B.: study idea, study execution, statistical analysis, interpretation of data; S.R.: manuscript preparation, statistical analysis; C.W.M.: manuscript preparation, interpretation of data; T.H.: Study idea; S.D.: manuscript preparation, statistical analysis, interpretation of data.

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