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Patterns of Pedicle Wall Violations Following Thoracolumbar Stabilization in Osteoporotic and Non-Osteoporotic Patients

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ABSTRACT

AIM: To investigate which pedicle level and wall were most affected by screw malposition in osteoporotic and non-osteoporotic patients undergoing thoracolumbar stabilization, and to determine whether significant differences existed between the groups.

MATERIAL and METHODS: This retrospective study analyzed pedicle screw malpositions and the specific walls involved in thoracolumbar stabilization procedures performed between 2014 and 2025 using the freehand technique with fluoroscopic guidance by the same surgical team. A total of 972 patients were included: those with a T-score ≤–2.5 (osteoporotic group) and those with a T-score > –2.5 (non-osteoporotic group). Indications for surgery included traumatic vertebral fracture, spinal stenosis, recurrent disc herniation, spinal tumor, or spondylolisthesis. All patients underwent preoperative MRI, CT, bone mineral densitometry, and X-rays, as well as postoperative CT and X-rays. Patients with acute decompression without preoperative densitometry and those treated with vertebroplasty/kyphoplasty were excluded. In cases of malposition, postoperative CT scans were used to evaluate superior, inferior, lateral, medial, and anterior cortical breaches, and comparisons were made between groups.

RESULTS: Screw malposition rates were significantly higher in osteoporotic patients across all levels, particularly in thoracic vertebrae. The medial pedicle wall was most frequently affected in this group.

CONCLUSION: In osteoporotic patients, transpedicular screw fixation using the freehand technique with fluoroscopic guidance was associated with higher malposition rates, especially involving the medial pedicle wall. These complications may be reduced through greater surgical experience and careful intraoperative technique.

KEYWORDS: Osteoporosis, spinal fusion, vertebral anatomy

INTRODUCTION

In 1948, King introduced the use of transpedicular screws for internal fixation in lumbosacral fusion (18). Intraoperative evaluation of pedicle screw placement is typically performed with fluoroscopy in posteroanterior (PA) and lateral projections, while postoperative computed tomography (CT) provides precise visualization of cortical breaches. Historically, malposition rates with freehand techniques using fluoroscopic guidance have ranged from 30% to 40% (3,8). In contrast, intraoperative CT-guided navigation systems have recently improved accuracy to more than 95.5% (24).

Postoperative CT remains the gold standard for assessing pedicle screw malposition, and several classification systems have been proposed. The Gertzbein and Robbins classification assesses the extent of pedicle breach in millimeters but accounts only for spinal canal violations and not lateral breaches (9). The Youkilis classification, although numeric, is limited to thoracic vertebrae (32). Heary's classification incorporates lateral, medial, superior, inferior, and anterior breaches but lacks quantitative measurement and is also restricted to thoracic vertebrae (12). The Wiesner classification, which was used in our study, evaluates breach distances in lumbar

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vertebrae and considers all pedicle walls, defining them as minor (0-3 mm), moderate (3-6 mm), or severe (>6 mm) (31).

In this study, we aimed to determine the incidence of pedicle screw malposition and related complications in 5,552 screws placed in the thoracic and lumbosacral regions using the conventional freehand technique with fluoroscopic guidance in osteoporotic and non-osteoporotic patients. We further compared the levels of breach and the specific pedicle walls affected between the two groups.

MATERIAL and METHODS

This retrospective study was approved by the Institutional Review Board of Ankara Training and Research Hospital (protocol number E-25-619). The requirement for informed consent was waived due to the retrospective and observational design. All patient data were anonymized during collection and analysis to ensure confidentiality.

Study Design and Patient Selection

Patients who underwent transpedicular screw fixation in our spine surgery unit between 2014 and 2025 were included. Indications for surgery were spinal stenosis, spondylolisthesis, traumatic fracture, recurrent disc herniation, or spinal tumor. Only patients who underwent stabilizing procedures for spinal tumors were considered. Emergency cases without preoperative bone densitometry were excluded.

Data Collection

Demographic data, clinical diagnoses, number of screws inserted, malposition rates, and revision procedures were collected retrospectively. Osteoporosis was defined as a T-score ≤−2.5 measured by dual-energy X-ray absorptiometry (DEXA); patients with T-scores >−2.5 were classified as the non-osteoporotic group.

Imaging and Evaluation

All patients underwent preoperative magnetic resonance imaging (MRI), CT, DEXA, and radiographs, as well as postoperative CT and radiographs. Screw placement was assessed on axial and coronal CT scans. Screw length and diameter were determined according to pedicle diameter and vertebral body length. Malpositions were categorized as anterior, medial, or lateral. Medial and lateral breaches were further graded as Grade 1 (0-3 mm), Grade 2 (3-6 mm), and Grade 3 (>6 mm) (Figure 1A-D).

Surgical Technique and Evaluation Criteria

All procedures were performed using an open surgical technique with intraoperative fluoroscopy by experienced spine surgeons following consistent surgical principles. In the lumbar spine, entry points were defined at the junction of the transverse and superior articular processes, while in the thoracic spine, they were defined by the bony triangle formed by the superior articular facet, transverse process, and pars interarticularis (5,7). Patients were positioned prone, and C-arm fluoroscopy was used in PA and lateral views. Entry holes were prepared with an awl and probed before screw insertion. Titanium screws were used to minimize imaging artifacts. Data collected included patient age, sex, pre- and postoperative neurological deficits, number of screws per level, malposition sites, and revision procedures. Postoperative complications evaluated were wound infections, dural tears, cerebrospinal fluid (CSF) leaks, and delayed wound healing.

Postoperative CT scans with 1-mm slices were obtained within 12 h after surgery, or earlier if new neurological deficits occurred, and were reviewed in axial, coronal, and sagittal planes. Screw placement was assessed independently by both the operating surgeons and radiologists. Cortical breaches in medial, lateral, superior, inferior, or anterior directions were measured in millimeters and classified as mild, moderate, or severe according to Wiesner's criteria. Screws that caused neurological symptoms or mechanical instability were revised.

The study addressed the following questions:

1. Does the breach rate increase as T-score decreases?
2. Are malposition rates higher in thoracic or lumbosacral regions?
3. Which pedicle wall is most frequently violated at each level?

Statistical Analysis

Malposition and revision rates, breach patterns, and the prevalence of osteoporosis across pathologies were compared using the chi-squared (χ^2) test. Binary logistic regression was performed to identify risk factors for malposition, with the outcome variable defined as the presence of malposition (1, yes; 0, no). Predictors included osteoporosis (T-score ≤ −2.5), anatomical region (thoracic vs. lumbosacral), sex, and diagnosis. Odds ratios (OR) and 95% confidence intervals (CI) were calculated. A p-value <0.05 was considered statistically significant. All analyses and figures were generated using Python version 13.3.

RESULTS

A total of 972 patients were included, comprising 612 women (62.96%) and 360 men (37.03%). The osteoporotic group (T-score ≤ −2.5) consisted of 202 patients (20.78%) with a mean T-score of −2.9, while the non-osteoporotic group (T-score > −2.5) included 770 patients (79.22%) with a mean T-score of −1.3.

Of 475 patients with spinal stenosis, 102 (21.47%) were osteoporotic. Among 142 patients with spondylolisthesis, 45 (31.69%) were osteoporotic. Of 285 patients with fractures, 26 (9.12%) were osteoporotic. In 47 patients with recurrent disc herniation, 7 (14.89%) were osteoporotic. Among 23 patients with tumors, 2 (8.69%) were osteoporotic (Table I).

Of 4,538 screws placed in non-osteoporotic patients, 257 (5.66%) were malpositioned, of which 32 (12.45%) required revision. In osteoporotic patients, 92 of 1,014 screws (9.07%) were malpositioned, with 28 (30.43%) revised ($p < 0.001$) (Table II).

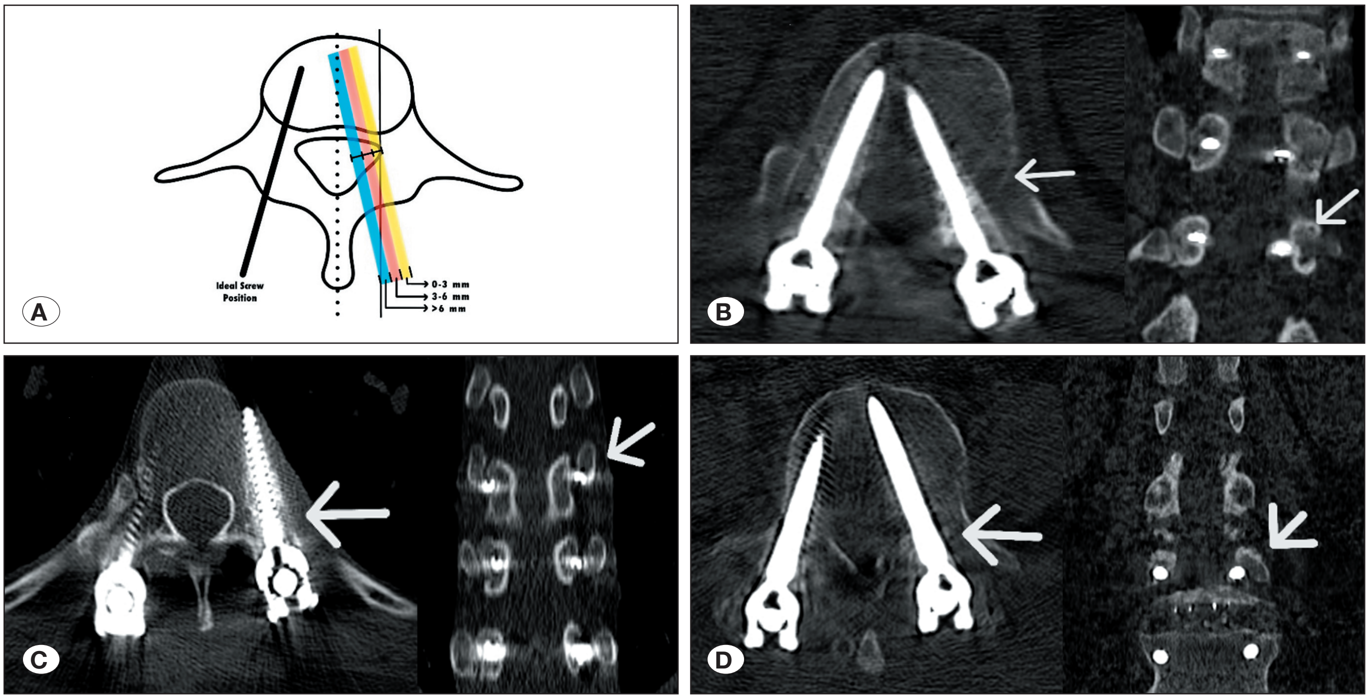

Figure 1: Examples of malpositioned pedicle screws. **A)** Schematic representation of Wiesner's classification of pedicle screw malposition: minor (0-3 mm, yellow line), moderate (3-6 mm, red line), and severe (>6 mm, blue line) (31). **B)** Computed tomography (CT) scan example of a medial malposition. **C)** Example of a lateral malposition. **D)** Example of an inferomedial malposition.

Table I: Distribution of Patients According to Diagnoses and Osteoporosis Status

Diagnosis	Patients n (%)	Non-osteoporotic Group n (%)	Osteoporotic Group n (%)	p-value
Spinal Stenosis	475 (48.8)	373 (47.2)	102 (56.0)	**0.039**
Spondylolisthesis	142 (14.6)	97 (12.2)	45 (24.7)	**<0.001**
Traumatic Fracture*	285 (29.3)	259 (31.7)	26 (14.2)	**<0.001**
Recurrent Disc Herniation	47 (4.8)	40 (5.0)	7 (3.8)	0.618
Spinal Tumour**	23 (2.3)	21 (2.6)	2 (1.0)	0.328
Total	972 (100.0)	790 (100.0)	182 (100.0)	

**A total of 94 trauma patients requiring emergency decompression who could not undergo bone mineral densitometry were excluded from the study.*
***Only patients with spinal tumours requiring stabilisation were included in the study.*

Table II. Malposition and Revision Rates in Osteoporotic and Non-Osteoporotic Patients

	Screw Counts n (%)	Malposition n (%)	Revision n (%)*
Non-osteoporotic group	4538 (81.7)	257 (5.6)	32 (12.4)
Osteoporotic group	1014 (18.3)	92 (9.0)	28 (30.4)
Total	5552 (100.0)	349 (6.2)	60 (17.1)
p-value		**<0.001**	**<0.001**

**Cases with grade 3 malposition were revised due to the potential risk of future instability. In addition, all patients with grade 1, 2, or 3 malposition who developed postoperative sciatica or neurological deficits underwent screw revision.*

Table III: Perforation Sites and Grading in Axial CT Imaging

		n (%)	Review (n=22)	n (%)	Review (n=28)	p-value
Anterior perforation*	Grade 1 (0-3 mm)	28 (10.8)	0	9 (9.7)	0	0.92
Medial perforation	Grade 1 (0-3 mm)	64 (24.9)	4	28 (30.4)	2	0.37
	Grade 2 (3-6 mm)	18 (7.0)	0	15 (16.3)	8	**0.02**
	Grade 3 (> 6 mm)	10 (3.8)	10	10 (10.8)	10	**0.03**
Lateral Perforation	Grade 1 (0-3 mm)	92 (35.7)	0	14 (15.2)	0	**<0.001**
	Grade 2 (3-6 mm)	37 (14.3)	0	8 (8.6)	0	0.22
	Grade 3 (> 6 mm)	8 (3.1)	8	8 (8.6)	8	0.06

**In 37 patients with anterior perforation, the amount of perforation ranged from 0 to 3 mm and there was no contact with any vital organs. Therefore, none of them required revisions.*

On axial CT imaging, the 257 malpositions in the non-osteoporotic group included 42 anterior (16.34%), 92 medial (35.79%), and 137 lateral (53.30%) breaches. In the osteoporotic group, the 92 malpositions included 9 anterior (9.78%), 53 medial (57.60%), and 30 lateral (32.60%) breaches. Anterior breaches (0-3 mm) did not involve critical structures and were not revised.

Grade 3 lateral breaches (8 cases) and Grade 1-3 medial breaches (26 cases) were revised due to nerve root irritation. Similar revision patterns were observed in the osteoporotic group. While lateral breaches predominated in non-osteoporotic patients, medial breaches were most common in osteoporotic patients.

At the thoracic level, 36 of 728 screws (4.94%) in non-osteoporotic patients and 24 of 164 screws (14.64%) in osteoporotic patients were malpositioned. At the lumbar level, 221 of 3,810 screws (5.80%) in non-osteoporotic patients and 68 of 850 screws (8.00%) in osteoporotic patients were malpositioned. Malposition rates were consistently higher in osteoporotic patients at both levels, particularly in the thoracic spine (Table III).

Coronal CT revealed distinct breach patterns. In non-osteoporotic patients, breaches included 78 medial, 6 medial-cranial, 8 medial-caudal, 122 lateral, 9 lateral-cranial, 6 lateral-caudal, 4 cranial, and 1 caudal. In osteoporotic patients, breaches included 43 medial, 4 medial-cranial, 6 medial-caudal, 24 lateral, 4 lateral-cranial, 2 lateral-caudal, and 1 caudal breaches (Table IV).

Postoperative complications included wound infection in nine non-osteoporotic and six osteoporotic patients, all treated successfully with antibiotics. CSF-related complications occurred in 29 and 26 patients, respectively ($p < 0.001$).

The most frequent malposition levels in non-osteoporotic patients were L5 > L4 > L3 > L2 > L1 > S1 > T12 > T11 > T10 > T9 > T7 > T8 > T6 > T5. In osteoporotic patients, the distribution was L5 > L1 > L3 > L4 > S1 > T11 > T10 > T8 > T7, with no malpositions noted at T5, T6, or T9.

Table IV: Perforation Sites and Grading in Coronal CT Imaging

	Non-osteoporıtic n=234 n (%)	Osteoporotic n=84 n (%)
Medial	78 (33.3)	43 (51.1)
Medial-cranial	6 (2.5)	4 (4.7)
Medial-caudal	8 (3.4)	6 (7.1)
Lateral	122 (52.1)	24 (28.5)
Lateral-cranial	9 (3.8)	4 (4.7)
Lateral-caudal	6 (2.5)	2 (2.3)
Cranial	4 (1.7)*	0 (0.0)
Caudal	1 (0.4)*	1 (1.1)*

**Patients with anterior perforation on axial CT*

Malposition rates in the lumbosacral region were 8% in osteoporotic versus 5.8% in non-osteoporotic patients ($p = 0.02$). Thoracic malposition rates were also significantly higher in osteoporotic patients ($p < 0.001$) (Table V).

Logistic regression analysis identified osteoporosis as a significant risk factor for screw malposition (OR, 1.6; 95% CI, 1.23-2.07; $p = 0.0004$). Thoracic region, male sex, and fracture diagnosis were not statistically significant predictors.

Overall, 257 of 4,538 screws (5.66%) in non-osteoporotic patients and 92 of 1,014 screws (9.07%) in osteoporotic patients were malpositioned. By anatomical region, malposition rates in the thoracic spine were 4.94% in non-osteoporotic versus 14.63% in osteoporotic patients, and in the lumbosacral spine were 5.80% versus 8.00%, respectively. These findings indicate that lower T-scores are associated with higher malposition risk, particularly in thoracic vertebrae.

Table V: Distribution of Malposition Ratios by Thoracic and Lumbosacral Regions and Vertebral Levels

Thoracal			Lumbosacral		
Total screws applied (n=892)	**Non-osteoporotic (n=728)**	**Osteoporosis (n=164)**	**Total screws applied (n=4660)**	**Non-osteoporotic (n=3810)**	**Osteoporosis (n=850)**
Levels	**Malposed screws**		**Levels**	**Malposed screws**	
T5	1	0	L1	12	10
T6	2	0	L2	28	15
T7	4	1	L3	44	9
T8	3	1	L4	52	7
T9	5	0	L5	76	21
T10	6	2	S1	9	6
T11	7	3	Total	221	68
T12	8	17			
Total	36	24			

DISCUSSION

Freehand transpedicular screw insertion under fluoroscopic guidance is essentially a blind technique and carries inherent risks of neurological or vascular complications (2,7,19). Reported rates of nerve root irritation reach up to 11% in cases of malposition, and revisions are frequently required (1). Anatomical factors such as canal shape may influence the direction of breaches, with round canals predisposing to medial violations and narrow canals to lateral misplacements (15).

Malposition rates as high as 40% have been reported with conventional methods (3,8). Variations in surgical technique and surgeon experience contribute substantially to these outcomes; greater experience is associated with lower malposition rates, regardless of whether conventional or navigation-assisted techniques are used (6,25).

Although intraoperative navigation systems improve screw placement accuracy (22,26), they do not appear to significantly reduce neurological complications (29). Furthermore, most existing classification systems inadequately reflect the clinical impact of breaches (9,12,31,32). For example, even a Grade 1 medial violation—considered “minor” by definition—can still cause sciatica and necessitate revision.

In this study, we applied the Wiesner classification for grading pedicle screw breaches but based revision decisions on a combination of postoperative neurological findings, mechanical instability, and sagittal balance considerations. More recently, El-Meshtawy et al. proposed a scoring system that integrates both radiological breach severity and clinical neurological deficits to better guide revision decisions (5).

Our findings align with the existing literature underscoring the clinical significance of medial wall violations, particularly given their proximity to neural structures (23,27). Medial breaches exceeding 2 mm have been shown to strongly correlate with symptomatic complications (23). Although lateral breaches are generally less likely to produce neurological symptoms, they may still warrant revision surgery due to their potential impact on patient function and pain scores, even in cases where fusion integrity is not compromised (20).

The higher revision rates observed in osteoporotic patients are likely attributable to impaired bone quality and diminished tactile feedback during screw insertion, which increase the risk of cortical wall violations and hinder intraoperative detection (11,21). Surgical experience also plays a crucial role in minimizing malpositions and subsequent revisions, as more experienced surgeons can better adjust their techniques to the challenges of osteoporotic bone (30).

Variability in revision rates across centers may reflect differences in intervention thresholds. The scoring system proposed by El-Meshtawy et al. (5), which integrates radiological breach severity with clinical symptoms, offers a more standardized and comprehensive framework for guiding revision decisions.

To our knowledge, no prior study has specifically investigated which spinal levels or pedicle walls are more susceptible to violation in osteoporotic patients. However, biomechanical evidence suggests that lateral wall violation in osteoporotic thoracic vertebrae reduces pullout strength by approximately 14.1%, with outcomes influenced by screw thread design (16).

Pedicle wall violation often results from incorrect insertion angles or intraoperative deviation, comprising screw stability. Careful preoperative planning, thorough anatomical knowledge, surgical experience, and osteoporosis management are essential to reduce the risk of malposition (13).

In osteoporotic patients, higher rates of pedicle wall violations—particularly at thoracic levels and along the medial walls—can be attributed to reduced bone mineral density and altered microarchitecture (28), which render the pedicle cortex thinner and more fragile. These changes increase the likelihood of wall breaches during screw insertion (10). Moreover, the diminished tactile feedback encountered in osteoporotic bone makes it difficult for surgeons to detect subtle cortical violations (17). Unlike healthy bone, osteoporotic bone provides softer resistance during probing and screw placement, thereby increasing the risk of unintended breaches, especially medially (14). Because surgeons rely heavily on this "sense of touch" for guidance, surgical experience and meticulous technique remain critical. To further reduce malposition rates in this vulnerable population, the importance of comprehensive preoperative imaging, careful intraoperative technique, and—where available—the use of advanced navigation or guidance technologies should be emphasized (4,10).

CONCLUSION

The conventional freehand technique with fluoroscopy remains a practical, safe, and effective option for lumbosacral fixation. Postoperative CT imaging provides reliable assessment of screw positioning. However, in osteoporotic patients, the higher incidence of pedicle wall violations—particularly at thoracic levels and along the medial walls—underscores the need for heightened vigilance. Greater surgical experience, meticulous technique, and careful intraoperative planning are essential to minimize complications in this high-risk population.

Declarations

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Availability of data and materials: The datasets generated and/or analyzed during the current study are available from the corresponding author by reasonable request.

Disclosure: The authors declare no competing interests.

AUTHORSHIP CONTRIBUTION

Study conception and design: BA, MEY
Data collection: BA, MEY
Analysis and interpretation of results: BA, MEY
Draft manuscript preparation: BA, MEY
Critical revision of the article: BA, MEY
Other (study supervision, fundings, materials, etc...): -
All authors (BA, MEY) reviewed the results and approved the final version of the manuscript.

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