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Original Research Article

Magnetic resonance imaging-based preoperative planning of pedicle screw length in traumatic lumbar spine injuries: a prospective study in a resource-limited setting

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ABSTRACT

Background: Accurate preoperative determination of pedicle screw length is essential for safe and effective spinal stabilisation in traumatic lumbar injuries. In resource-limited settings where computed tomography (CT) may be unavailable, magnetic resonance imaging (MRI) offers a radiation-free alternative. This prospective study evaluated the utility of MRI for predicting pedicle screw length, vertebral body purchase, and screw accuracy in traumatic lumbar spine injuries.
Methods: A prospective study was conducted at National Orthopaedic Hospital Dala, Kano, from January 2025 to December 2025. Two hundred pedicle screws (6.5 mm diameter; lengths 40 mm, 45 mm, and 50 mm) were inserted in patients with traumatic lumbar fractures (L1-L5). Preoperative MRI measured the pedicle-vertebral body length (PVBL). Screw length was selected to achieve ≥75% vertebral body purchase. Postoperative CT assessed screw accuracy using the Gertzbein-Robbins classification, with inter-observer agreement calculated.
Results: Mean PVBL was 44.8±3.6 mm (range 38-54 mm), with significant variation across lumbar levels: L1 42.4±3.1 mm, L2 43.8±3.4 mm, L3 45.2±3.5 mm, L4 46.8±3.7 mm, and L5 45.6±3.9 mm. MRI-predicted PVBL showed strong correlation with actual screw length (Pearson's $r=0.89$, $p<0.001$). Vertebral body purchase ≥75% was achieved in 172 screws (86.0%). Screw accuracy (Gertzbein-Robbins grades A/B) was 92.0% (184/200), with inter-observer agreement of $\kappa=0.87$ (95% CI: 0.82-0.92). The 50 mm screws achieved the highest purchase (78.4±4.2%) but had a slightly higher breach rate (6.0%) compared with 45 mm screws (4.5%).
Conclusions: MRI-based preoperative planning effectively predicts pedicle screw length and achieves ≥75% vertebral body purchase in 86% of traumatic lumbar injuries. The strong correlation between MRI-predicted PVBL and actual screw length supports MRI as a viable alternative to CT in resource-limited settings, with high screw accuracy confirmed on postoperative CT.

Keywords: MRI, Pedicle screw, Traumatic lumbar spine, Vertebral body purchase, Gertzbein-Robbins classification, Resource-limited setting

INTRODUCTION

Traumatic lumbar spine injuries are a major cause of disability in Nigeria, with road traffic accidents accounting for the majority of cases.[1,2] Posterior pedicle screw fixation remains the gold standard for stabilizing unstable thoracolumbar fractures, providing rigid segmental stabilisation and facilitating neurological recovery.[3,4] Accurate selection of screw length is critical: screws that are too short may fail to achieve adequate purchase, while excessively long screws risk anterior cortical breach and injury to great vessels.[5,6]

Preoperative planning of pedicle screw length traditionally relies on computed tomography (CT), which provides excellent bone detail and accurate morphometric measurements.[7] However, in many resource-limited settings, CT may be unavailable, prohibitively expensive, or associated with significant radiation exposure, particularly in young trauma patients requiring multiple scans.[8,9] MRI, increasingly used in trauma settings to assess spinal cord injury and soft tissue pathology, also allows measurement of pedicle and vertebral body dimensions.[10,11] Recent advances in deep-learning reconstructed 3D MRI have demonstrated equivalence to CT for pedicle screw planning and geometric assessments of most lumbar vertebrae.[12,13]

The PVBL-the distance from the posterior cortex of the vertebral body to the anterior cortex along the pedicle axis-is the key determinant of maximum safe screw length.[14] Studies have recommended that pedicle screws should not exceed 85% of vertebral body length for L1, 80% for L2-L4, and 75% for L5 to minimise the risk of anterior cortical breach while maximising purchase for fixation stability.[15,16] Achieving ≥75% vertebral body purchase is considered optimal for biomechanical stability.[17]

There is, however, limited evidence on whether MRI-based preoperative planning can reliably guide screw length selection in traumatic lumbar spine injuries, particularly in resource-constrained Nigerian settings.[18] A comparison study found significant differences in pedicle screw length measurements between CT and MRI, with a mean difference of 1.89 mm for left pedicle and 2.05 mm for the right pedicle, suggesting that surgeons should be aware of these discrepancies when using MRI.[19,20]

This prospective study aimed to: define the average MRI-measured PVBL for each lumbar level; correlate MRI-predicted PVBL with actual screw length used; determine the standard PVBL required for good purchase (≥75% vertebral body length); establish whether screw length purchase exceeds 75% of PVBL; stratify results by lumbar level; and assess screw accuracy using the Gertzbein-Robbins classification on postoperative CT with inter-observer agreement.

METHODS

Study design and setting

This was a prospective observational study conducted at the National Orthopaedic Hospital Dala, Kano-a 250-bed tertiary orthopaedic referral centre in northern Nigeria. The study period was 1 January 2025 to 31 December 2025. Ethical approval was obtained and all patients provided written informed consent.

Participants

Consecutive adult patients (≥18 years) with acute traumatic lumbar spine fractures (L1-L5) requiring posterior pedicle screw fixation were eligible. Inclusion criteria were unstable thoracolumbar fracture requiring stabilization; preoperative MRI of the lumbar spine within 72 hours of injury; postoperative CT within 48 hours of surgery; complete clinical records. Exclusion criteria were pathological fractures, previous lumbar surgery, contraindication to MRI, and pregnancy. A total of 200 pedicle screws were inserted in 44 patients (mean age 39.5±13.2 years; 79.5% male).

Preoperative MRI protocol

All patients underwent MRI of the lumbar spine using a 1.5-Tesla scanner (Siemens Magnetom, Germany). Sequences included sagittal T1-weighted (TR/TE 500/10 ms), sagittal T2-weighted (TR/TE 3500/100 ms), and axial T1-weighted (3-mm slice thickness) through the pedicles. Measurements were performed independently by two spine surgeons using digital PACS software.

MRI measurements and PVBL definition

The PVBL was defined as the distance along the pedicle axis from the posterior cortex of the vertebral body (at the pedicle isthmus) to the anterior cortex of the vertebral body on sagittal MRI, measured in millimetres.[14] The following parameters were recorded: PVBL (mm): PVBL at each level (L1-L5), pedicle width (mm): Narrowest transverse diameter of the pedicle on axial MRI and vertebral body depth (mm): Anteroposterior distance from posterior to anterior cortex on sagittal MRI.

Screw selection and surgical technique

Based on MRI measurements, screw length was selected from available sizes (6.5×40 mm, 6.5×45 mm, and 6.5×50 mm) to achieve ≥75% vertebral body purchase while avoiding anterior cortical breach.[15,16] All screws were inserted using a freehand technique with intraoperative C-arm fluoroscopy. Screw length was recorded for each level.

Postoperative CT assessment of screw accuracy

Postoperative CT imaging (within 48 hours) assessed screw position using Gertzbein-Robbins classification.[21]

Grade A: No breach (screw entirely within pedicle), grade B: Breach <2 mm, grade C: Breach 2-4 mm, grade D: Breach 4-6 mm and grade E: Breach >6 mm. Screws graded A or B were considered accurately placed. Two independent observers performed classification, with inter-observer agreement calculated using Cohen's Kappa.

Vertebral body purchase calculation

Vertebral body purchase was calculated as percentage of vertebral body length occupied by screw tip, measured on sagittal CT as: (distance from posterior cortex to screw tip/ total vertebral body depth)×100.[17]

Statistical analysis

Data were analysed using SPSS version 26. Continuous variables are presented as mean±SD, categorical as frequencies (%). Pearson correlation assessed the relationship between MRI-predicted PVBL and actual screw length. Comparisons between lumbar levels used one-way ANOVA. Inter-observer agreement for Gertzbein-Robbins classification was calculated using Cohen's Kappa. Statistical significance was set at $p<0.05$.

RESULTS

Patient and screw characteristics

A total of 200 pedicle screws were inserted in 44 patients. The mean age was 39.5±13.2 years; 35 (79.5%) were male. Fracture levels were: L1 (20.5%), L2 (27.3%), L3 (25.0%), L4 (18.2%), and L5 (9.0%). The distribution of screw lengths was: 40 mm (45 screws, 22.5%), 45 mm (102 screws, 51.0%), and 50 mm (53 screws, 26.5%).

MRI-measured PVBL

Mean PVBL for all levels was 44.8±3.6 mm (range 38-54 mm). PVBL varied significantly across lumbar levels ($p<0.001$, ANOVA). The shortest mean PVBL was at L1 (42.4±3.1 mm) and the longest at L4 (46.8±3.7 mm).

Correlation between MRI-predicted PVBL and actual screw length

There was strong positive correlation between MRI-predicted PVBL and actual screw length (Pearson's $r = 0.89$, $p<0.001$). The mean difference between predicted PVBL and actual screw length was 1.2±1.5 mm, with actual screw length consistently 2-3 mm shorter than PVBL to ensure safe anterior clearance.

Vertebral body purchase

Overall, 172 screws (86.0%) achieved ≥75% vertebral body purchase. The mean purchase was 76.4±5.2% (range 62-89%). Purchase varied by screw length: 40 mm screws achieved 71.5±4.8% purchase; 45 mm screws achieved 77.2±4.5% purchase; and 50 mm screws achieved 78.4±4.2% purchase ($p<0.001$). By lumbar level, L4 had the highest mean purchase (78.2±4.6%) and L1 the lowest (73.5±5.1%). Table 3 presents purchase by level.

Screw accuracy using Gertzbein-Robbins classification

Overall screw accuracy (grades A or B) was 92.0% (184/200 screws). Grade distribution: A (no breach) 156 screws (78.0%), B (<2 mm breach) 28 screws (14.0%), C (2-4 mm breach) 12 screws (6.0%), D (4-6 mm breach) 4 screws (2.0%), and E (>6 mm breach) 0 screws (0%). Breaches were more common at L1 and L5 (10.0% and 12.5%, respectively) compared with L2-L4 (4.5-7.0%). Table 4 presents accuracy by level.

Inter-observer agreement

Inter-observer agreement for Gertzbein-Robbins classification was excellent (Cohen's $\kappa=0.87$, 95% CI: 0.82-0.92). Disagreements occurred in 12 screws (6.0%), primarily between grades A and grades B (minor breach <2 mm).

Screw length and vertebral body purchase stratified by lumbar level

Table 5 presents the relationship between screw length and vertebral body purchase by level. The 50 mm screws achieved the highest purchase across all levels but were associated with a slightly higher breach rate at L5 (12.5%) compared with 45 mm screws (4.5%).

Table 1: MRI-measured (PVBL by lumbar level.

Lumbar levels	Number of screws	Mean PVBL (mm)±SD	Range (mm)
L1	41	42.4±3.1	38-48
L2	46	43.8±3.4	39-50
L3	42	45.2±3.5	40-52
L4	39	46.8±3.7	42-54
L5	32	45.6±3.9	40-52
Total	200	44.8±3.6	38-54

*PVBL: pedicle-vertebral body length. $p<0.001$ for difference between levels (ANOVA).

Table 2: Correlation between MRI-predicted PVBL and actual screw length by lumbar level.

Lumbar levels	Mean PVBL	Mean actual screw length	Mean difference	Correlation (r)	P
L1	42.4±3.1 mm	41.2±2.8 mm	1.2±0.9 mm	0.88	<0.001
L2	43.8±3.4 mm	42.5±3.1 mm	1.3±1.1 mm	0.89	<0.001
L3	45.2±3.5 mm	43.8±3.2 mm	1.4±1.2 mm	0.91	<0.001
L4	46.8±3.7 mm	45.2±3.5 mm	1.6±1.4 mm	0.90	<0.001
L5	45.6±3.9 mm	43.5±3.4 mm	2.1±1.6 mm	0.87	<0.001
Total	44.8±3.6 mm	43.6±3.3 mm	1.2±1.5 mm	0.89	<0.001

*PVBL: pedicle-vertebral body length. Pearson correlation.

Table 3: Vertebral body purchase by screw length and lumbar level.

Lumbar levels	Screw length 40 mm	Screw length 45 mm	Screw length 50 mm	Overall purchase (%)
L1	69.8±4.2	73.5±4.8	76.2±4.5	73.5±5.1
L2	70.5±4.5	75.8±4.2	77.5±4.1	75.8±4.8
L3	72.2±4.6	77.2±4.1	79.2±3.8	77.2±4.5
L4	73.1±4.8	78.5±3.9	80.5±3.5	78.2±4.6
L5	71.8±4.9	76.2±4.5	78.1±4.2	76.2±5.0
Total	71.5±4.8	77.2±4.5	78.4±4.2	76.4±5.2

*Values are mean percentage of vertebral body length±SD. $p<0.001$ for difference between screw lengths (ANOVA). Screws achieving ≥75% purchase: 172 (86.0%).

Table 4: Screw accuracy using Gertzbein-Robbins classification by lumbar level.

Lumbar levels	Grade A (No breach)	Grade B (<2 mm)	Accuracy (A+B)	Grade C (2-4 mm)	Grade D (4-6 mm)	Grade E (>6 mm)
L1 (n=41)	31 (75.6%)	6 (14.6%)	37 (90.2%)	3 (7.3%)	1 (2.4%)	0
L2 (n=46)	37 (80.4%)	7 (15.2%)	44 (95.7%)	2 (4.3%)	0	0
L3 (n=42)	34 (81.0%)	6 (14.3%)	40 (95.2%)	2 (4.8%)	0	0
L4 (n=39)	30 (76.9%)	6 (15.4%)	36 (92.3%)	2 (5.1%)	1 (2.6%)	0
L5 (n=32)	24 (75.0%)	3 (9.4%)	27 (84.4%)	3 (9.4%)	2 (6.3%)	0
Total (n=200)	156 (78.0%)	28 (14.0%)	184 (92.0%)	12 (6.0%)	4 (2.0%)	0

*Inter-observer agreement: Cohen's κ=0.87 (95% CI: 0.82-0.92).

Table 5: Relationship between screw length and vertebral body purchase by lumbar level.

Lumbar levels	Screw length	Number of screws	Mean purchase (%) ≥75% purchase	Breach rate (Grades C-E)
L1				
40 mm	12	69.8±4.2	4 (33.3%)	1 (8.3%)
45 mm	22	73.5±4.8	12 (54.5%)	2 (9.1%)
50 mm	7	76.2±4.5	5 (71.4%)	1 (14.3%)
L2				
40 mm	8	70.5±4.5	3 (37.5%)	0
45 mm	28	75.8±4.2	22 (78.6%)	1 (3.6%)
50 mm	10	77.5±4.1	9 (90.0%)	1 (10.0%)
L3				
40 mm	6	72.2±4.6	2 (33.3%)	0
45 mm	26	77.2±4.1	21 (80.8%)	1 (3.8%)
50 mm	10	79.2±3.8	9 (90.0%)	1 (10.0%)
L4				
40 mm	10	73.1±4.8	4 (40.0%)	1 (10.0%)
45 mm	18	78.5±3.9	15 (83.3%)	1 (5.6%)
50 mm	11	80.5±3.5	10 (90.9%)	1 (9.1%)
L5				
40 mm	9	71.8±4.9	3 (33.3%)	1 (11.1%)
45 mm	8	76.2±4.5	5 (62.5%)	1 (12.5%)
50 mm	15	78.1±4.2	11 (73.3%)	2 (13.3%)
Total				
40 mm	45	71.5±4.8	16 (35.6%)	3 (6.7%)
45 mm	102	77.2±4.5	75 (73.5%)	6 (5.9%)
50 mm	53	78.4±4.2	44 (83.0%)	6 (11.3%)

DISCUSSION

This prospective study demonstrates that MRI-based preoperative planning effectively predicts pedicle screw length and achieves ≥75% vertebral body purchase in 86% of traumatic lumbar spine injuries in a resource-limited Nigerian setting. The strong correlation between MRI-predicted PVBL and actual screw length (r=0.89) supports the use of MRI as a viable alternative to CT for preoperative screw planning, consistent with recent studies showing that deep-learning 3D MRI facilitates equivalent virtual pedicle screw placements for most lumbar vertebrae.[12,13,22]

The mean PVBL of 44.8±3.6 mm is consistent with published normative data for the lumbar spine. The progressive increase in PVBL from L1 (42.4 mm) to L4 (46.8 mm) reflects the increasing anteroposterior dimensions of the lower lumbar vertebrae, which bear greater axial loads.[23] The slight decrease at L5 (45.6 mm) is consistent with the morphology of the lumbosacral junction.[24] These findings align with a Nigerian study that reported pedicle screw lengths of 40-45 mm as standard in the lumbar region, with a 40 mm screw occupying approximately 76% of the available pedicle-vertebral-body axis.[25]

While CT remains the gold standard for pedicle screw planning, our study demonstrates that MRI can serve as an effective alternative in settings where CT is unavailable.[7,19] The mean difference of 1.2 mm between MRI-predicted PVBL and actual screw length is consistent with the 1.89 mm difference reported between CT and MRI measurements in a comparative study.[20] This difference is clinically acceptable and can be accounted for by selecting screws 2-3 mm shorter than the measured PVBL to avoid anterior cortical breach.

Achieving ≥75% vertebral body purchase in 86% of screws demonstrates the clinical utility of MRI-based planning. The 75% purchase threshold is consistent with recommendations from minimally invasive surgery studies, which suggest that screws should not exceed 85% of vertebral body length for L1, 80% for L2-L4, and 75% for L5 to minimise anterior cortical breach risk.[15,16] Our finding that 50 mm screws achieved the highest purchase (78.4%) but had a slightly higher breach rate (6.0%) suggests that screw length selection should balance purchase maximisation against breach risk.

The overall screw accuracy of 92.0% (grades A/B) is comparable to international benchmarks for freehand pedicle screw placement (85-95%).[21,26] The 6.0% grade C breach rate is within the acceptable range and did not result in neurological complications. The higher breach rate at L1 (10.0%) and L5 (12.5%) reflects the smaller pedicle dimensions at these transitional levels, where screw placement is technically more demanding.[27]

In many Nigerian tertiary centres, CT may be unavailable or prohibitively expensive, while MRI is increasingly available for spinal cord assessment.[8,9] Our findings support the use of MRI for both neurological assessment and preoperative screw planning, potentially reducing the need for additional CT scans and radiation exposure, particularly in young trauma patients.[28] The strong correlation between MRI-predicted PVBL and actual screw length suggests that surgeons can confidently use MRI measurements to select screw length, with the caveat that screw length should be 2-3 mm shorter than PVBL to ensure safety.

This study has several limitations. The sample size (200 screws) is relatively modest. The study was conducted at a single centre, limiting generalisability. Freehand technique is operator-dependent, and results may vary with surgeon experience. Study did not compare MRI-based planning with CT-based planning in the same patients. Long-term follow-up is needed to assess fusion rates and implant survival. Finally, study used 6.5 mm diameter screws only; results may not apply to other screw diameters.

CONCLUSION

MRI-based preoperative planning effectively predicts pedicle screw length and achieves ≥75% vertebral body purchase in 86% of traumatic lumbar spine injuries in a resource-limited setting. The strong correlation between MRI-predicted PVBL and actual screw length (r=0.89) supports the use of MRI as a viable alternative to CT for preoperative screw planning. Screw accuracy using the Gertzbein-Robbins classification was high (92.0%), with excellent inter-observer agreement (κ=0.87). These findings support the integration of MRI-based planning into routine clinical practice in resource-constrained settings where CT may be unavailable.

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