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RESEARCH ARTICLE

Intraoperative Blood Loss Is a Surrogate of Surgical Complexity Rather Than an Independent Predictor of Pedicle Screw Loosening: A Matched Cohort Analysis

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ABSTRACT

Objective: Pedicle screw loosening is a significant mechanical complication after lumbar instrumented fusion. Intraoperative estimated blood loss (EBL) has been associated with loosening; however, whether this reflects an independent biological effect or surgical complexity remains unclear.

Materials and Methods: This retrospective matched cohort study included 160 patients undergoing posterior lumbar instrumented fusion. Eighty patients with screw loosening were matched 1:1 with 80 controls based on age and sex. Demographic, surgical, radiographic, and paraspinal muscle parameters were analyzed. EBL was evaluated using univariate and multivariate logistic regression models adjusted for surgical complexity (operative time, instrumented levels) and biomechanical–biological factors (PI–LL mismatch, multifidus fat infiltration, DEXA T-score). Composite indices were constructed and compared using ROC analysis.

Results: EBL was significantly higher in the loosening group (p=0.001) and was associated with loosening in univariate analysis but not after multivariable conditional logistic regression (p=0.640). Independent factors associated with loosening included lumbar lordosis (p=0.031), multifidus fat infiltration (p=0.009), and DEXA T-score (p=0.001). The surgical complexity index showed moderate discrimination (AUC=0.80), whereas the biomechanical–biological index demonstrated higher discrimination (AUC=0.90).

Conclusion: EBL is associated with pedicle screw loosening but is not an independent predictor, reflecting surgical complexity. Loosening is predominantly driven by biomechanical and biological factors, highlighting the importance of preoperative optimization of alignment and tissue quality.

Keywords: Intraoperative blood loss, lumbar fusion, paraspinal muscle, pedicle screw loosening, spinopelvic alignment

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INTRODUCTION

Pedicle screw loosening is a well-recognized complication after lumbar instrumented fusion, with incidence varying by diagnostic criteria and follow-up.[1,2] Although often radiographically silent, it may progress to instability, pseudarthrosis, and revision surgery.[2,3] Identifying predisposing factors remains a central focus in spine research.[3]

Risk factors are broadly categorized as patient- and surgery-related.[4] Patient factors include reduced bone mineral density, sagittal malalignment, and paraspinal muscle degeneration, all influencing the biomechanical environment at the bone–implant interface.[5–7] Surgical factors—such as instrumentation extent, operative duration, and lumbosacral involvement—increase mechanical load and procedural complexity.[2,8] Although individually associated with loosening, their relative contributions and interactions remain unclear.[4,8]

Among perioperative variables, intraoperative estimated blood loss (EBL) is frequently higher in patients who develop loosening.[2,8] This has led to the hypothesis that blood loss may impair local perfusion and osseointegration, contributing to implant failure.[9] However, EBL is not

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an independent variable but a consequence of procedural complexity.[8] Larger constructs, longer operative times, and more extensive corrections increase blood loss and are also linked to loosening,[2,8] suggesting confounding rather than causation.[4,8]

Few studies have assessed whether EBL retains independent predictive value after adjustment for surgical complexity and biomechanical vulnerability.[8] Moreover, prior work has focused on individual factors without addressing the hierarchical relationship between surgical burden and the biological substrate. Mechanistically, loosening likely reflects the interaction between mechanical load and the host's capacity to withstand it.[4,7]

Accordingly, this study had two aims: to determine whether intraoperative blood loss independently predicts pedicle screw loosening after controlling for surgical complexity and biomechanical–biological factors, and to compare the predictive performance of composite indices representing these domains. We hypothesized that the association between EBL and loosening would diminish after multivariate adjustment and that the biomechanical–biological composite would demonstrate superior discriminative ability.

MATERIALS and METHODS

Study Design and Patient Selection

This retrospective matched cohort study was conducted at a tertiary spine center between January 1, 2020, and November 15, 2025. Institutional ethics approval was obtained from the Kanuni Sultan Süleyman Training and Research Hospital Ethics Committee (Approval No. KAEK/2026.03.110; Approval Date: March 11, 2026) in accordance with the Declaration of Helsinki. The requirement for informed consent was waived due to the retrospective study design. A total of 434 consecutive patients undergoing posterior lumbar instrumented fusion for degenerative pathology were screened. Inclusion criteria were age ≥18 years, available preoperative MRI and standing radiographs, and adequate clinical/imaging data. Exclusion criteria included infection, tumor, congenital deformity, inadequate imaging, prior hip or pelvic fracture, bilateral hip arthroplasty, and systemic inflammatory spinal disease.

After application of the inclusion and exclusion criteria, 220 eligible patients remained, including 80 patients with revision-confirmed pedicle screw loosening and 140 potential controls without loosening. Controls were selected using 1:1 nearest-neighbor matching by age (±3 years) and sex, without replacement. The final matched cohort comprised 160 patients (80 cases and 80 matched controls).

Definition of Pedicle Screw Loosening

Pedicle screw loosening was defined based on radiographic findings and the clinical indication for revision surgery, in accordance with previously established criteria.[2,4] Radiographic loosening was identified as the presence of a radiolucent zone of at least 1 mm surrounding the pedicle screw ("halo sign") on standard radiographs, which is a commonly accepted diagnostic threshold in the literature.[2,3]

To enhance diagnostic specificity, isolated or partial radiolucency without circumferential involvement was not considered sufficient. Only cases in which radiographic loosening was accompanied by persistent clinical symptoms and resulted in revision surgery were classified as clinically significant screw loosening.[4]

Patients in the control group were defined as those without radiographic evidence of screw loosening and without revision surgery during the follow-up period.

Imaging Protocols and Radiological Assessment

MRI Acquisition and Paraspinal Muscle Analysis

All preoperative magnetic resonance imaging (MRI) examinations were performed using a 1.5-T system. Axial T2-weighted images were used for the evaluation of paraspinal muscle morphology. To ensure consistency and minimize inter-level variability, all measurements were standardized at the L4–L5 intervertebral disc level.[7,10]

Paraspinal muscles, including the multifidus, erector spinae, and quadratus lumborum, were analyzed. Cross-sectional area (CSA) was measured by manually tracing the fascial boundaries of each muscle using region-of-interest (ROI) analysis. Fat infiltration (FI) was assessed semi-quantitatively within the same ROI using a threshold-based segmentation method.[7,10] During the thresholding process, reference signal characteristics were obtained from three separate regions of interest placed within the subcutaneous fat on the same axial slice, and the mean value of these measurements was used as the reference standard. Based on this reference, fat and muscle tissues were differentiated, and FI was calculated as the percentage of the fat signal area relative to the total muscle area.[10]

All measurements were performed independently by two observers blinded to clinical and radiological outcomes. The mean values of the two measurements were used for analysis. Interobserver reliability was assessed using intraclass correlation coefficients (ICCs).[10]

Radiographic Assessment of Spinopelvic Parameters

Spinopelvic parameters were assessed using standing radiographs obtained as part of routine clinical evaluation. When available, full-length standing scoliosis radiographs were preferred; otherwise, standing lateral lumbosacral radiographs were used for analysis.[6,11]

The following parameters were measured: pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), and PI–LL mismatch.[6]

All measurements were performed using the institutional picture archiving and communication system (PACS) with integrated digital measurement tools. Evaluations were conducted independently by two observers who were blinded to clinical outcomes. In cases of discrepancies greater than 5°, measurements were re-evaluated, and a consensus value was obtained.

Interobserver reliability for all spinopelvic parameters was assessed using intraclass correlation coefficients (ICCs).[11]

Pelvic incidence was defined as the angle between the perpendicular to the sacral endplate at its midpoint and the line connecting this point to the femoral head axis. Pelvic tilt was measured as the angle between the vertical and the line connecting the midpoint of the sacral endplate to the femoral head axis. Sacral slope was defined as the angle between the sacral endplate and the horizontal plane. Lumbar lordosis was measured between the superior endplate of L1 and the superior endplate of S1.[6]

PI–LL mismatch was calculated as the difference between pelvic incidence and lumbar lordosis and was used as the primary parameter representing sagittal alignment.[6,11]

CT Evaluation of Screw Loosening

Pedicle screw loosening was evaluated using postoperative computed tomography (CT) imaging. Loosening was defined as the presence of a radiolucent zone of at least 1 mm surrounding the pedicle screw, consistent with previously established radiographic criteria.[2,3,11]

Only cases demonstrating circumferential radiolucency around the screw were considered positive for loosening, while focal or equivocal radiolucent changes were not accepted as diagnostic.[3,11]

To ensure clinical relevance, only patients with CT-confirmed screw loosening who underwent revision surgery due to persistent symptoms were included in the loosening group.[4]

CT images were independently evaluated by two observers blinded to clinical data. In cases of disagreement, a consensus decision was reached. Interobserver reliability was assessed using intraclass correlation coefficients (ICCs).[11]

Patients in the control group were defined as those without radiographic evidence of screw loosening on available imaging and without revision surgery during the follow-up period.

Bone Mineral Density Assessment (DEXA)

Bone mineral density (BMD) was assessed using dual-energy X-ray absorptiometry (DEXA) as part of routine preoperative evaluation. Measurements were obtained from the lumbar spine and/or femoral neck regions, depending on availability.

T-scores were recorded for each patient and used for analysis. In cases where measurements from multiple anatomical regions were available, the lowest T-score was selected to represent the patient's bone quality.

Based on World Health Organization (WHO) criteria, osteoporosis was defined as a T-score ≤-2.5, osteopenia as a T-score between -1.0 and -2.5, and normal bone density as a T-score ≥-1.0.[12]

Surgical Data and Perioperative Parameters

Surgical and perioperative data were retrospectively obtained from operative records and hospital systems, including estimated blood loss (EBL), operative time, number of instrumented levels, and lumbosacral involvement. EBL was recorded in milliliters from anesthesiology records based on suction volume and intraoperative estimation. Operative time was defined as the interval from skin incision to closure. Instrumented levels were determined by the extent of posterior lumbar fixation, and lumbosacral involvement was defined as the inclusion of the L5–S1 segment.

Matching Procedure

A matched cohort design was used to minimize confounding. Patients with pedicle screw loosening were matched 1:1 with controls without loosening using a nearest-neighbor approach based on age and sex.[13] Sex was matched exactly, and controls were selected based on the closest age, with a caliper of ±3 years when possible. Matching was performed without replacement.

Controls were drawn from the same institutional cohort and met identical inclusion and exclusion criteria, except for the absence of screw loosening. The final cohort included 160 patients: 80 with loosening and 80 matched controls.

Composite Index Construction

To evaluate the relative contributions of surgical burden and underlying biomechanical–biological vulnerability, composite indices were constructed using standardized variables.

All continuous variables included in the composite indices were transformed into z-scores using the formula (value – mean)/standard deviation to ensure comparability between parameters with different units and scales.

Surgical Complexity Index

The surgical complexity index was designed to represent the overall procedural burden. This index was calculated by summing the standardized values of estimated blood loss (EBL), number of instrumented levels, and operative time.

Higher values of the surgical complexity index indicated greater surgical burden.

Biomechanical–Biological Index

The biomechanical–biological index was constructed to reflect the intrinsic vulnerability of the spinal environment. This index included standardized values of PI–LL mismatch, multifidus fat infiltration (FI), and bone mineral density as represented by DEXA T-score.

Since lower T-scores indicate poorer bone quality, the T-score variable was inversely coded prior to standardization so that higher index values consistently represented greater biomechanical–biological risk.

Statistical Analysis

All analyses were performed using SPSS (Version 25.0; IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean±standard deviation or median (minimum–maximum) according to distribution, and categorical variables as frequencies and percentages. Normality was assessed with the Shapiro–Wilk test. Between-group comparisons used the independent-samples t-test or Mann–Whitney U test for continuous variables and the chi-square or Fisher's exact test for categorical variables, as appropriate.

Spearman correlation analysis assessed associations between variables. Univariate logistic regression identified factors associated with pedicle screw loosening; variables meeting a predefined threshold of p=0.10 were entered into the multivariate model. Multicollinearity was evaluated using variance inflation factors (VIFs), with <3 considered acceptable.

Receiver operating characteristic (ROC) analysis evaluated discriminative performance, with the area under the curve (AUC) calculated and compared using DeLong's method.[14] Model calibration was assessed using the Hosmer–Lemeshow goodness-of-fit test and the Brier score. Interobserver reliability for radiological measurements was assessed using intraclass correlation coefficients (ICCs).[15]

Statistical significance was defined at a p=0.05 threshold.

Table 1. Baseline characteristics of the matched cohort

Variable	Loosening (n=80)	Control (n=80)	p
Age (years)	63.6±8.0	63.3±7.7	0.779
BMI (kg/m²)	28.3±5.1	30.8±4.8	0.002
Operative time (min)	199.8±55.1	162.5±57.1	0.001
EBL (mL)	712.9±269.6	456.2±193.6	0.001
Instrumented levels	3.8±1.6	2.5±0.9	0.001
PI (°)	52.6±10.9	54.3±10.3	0.316
Lumbar lordosis (°)	38.4±12.5	52.9±14.1	0.001
PI–LL mismatch (°)	14.3±10.2	1.4±8.3	0.001
Multifidus FI (%)	28±8.0	21±5.5	0.001
DEXA T-score	−2.2±0.9	−0.7±1.4	0.001

Values are mean±standard deviation. Statistical significance was defined at a p=0.05 threshold. BMI: Body mass index; EBL: Estimated blood loss; PI: Pelvic incidence; LL: Lumbar lordosis; FI: Fat infiltration; DEXA: Dual-energy X-ray absorptiometry

RESULTS

Patient Cohort and Matching

A total of 434 patients who underwent posterior lumbar instrumented fusion during the study period were screened for eligibility. After applying the inclusion and exclusion criteria, a matched cohort was constructed using a 1:1 nearest-neighbor approach based on age and sex, resulting in a final study population of 160 patients, including 80 patients with pedicle screw loosening and 80 matched controls.

Following matching, there were no significant differences between the groups in terms of age or sex distribution, confirming adequate demographic balance between the two groups.

Demographic and Clinical Characteristics

Baseline demographic and clinical characteristics of the matched cohort are presented in Table 1. There were no significant differences between the groups in terms of age or sex distribution. Body mass index (BMI) was lower in the loosening group compared with the control group (p=0.010). No significant differences were observed between the groups in terms of other baseline clinical characteristics (Fig. 1).

Surgical Parameters

Surgical and perioperative parameters are summarized in Table 1. Operative time was longer in the loosening group compared with controls, and estimated blood loss (EBL) was higher in patients with screw loosening (Fig. 2). The number of instrumented levels was greater in the loosening group.

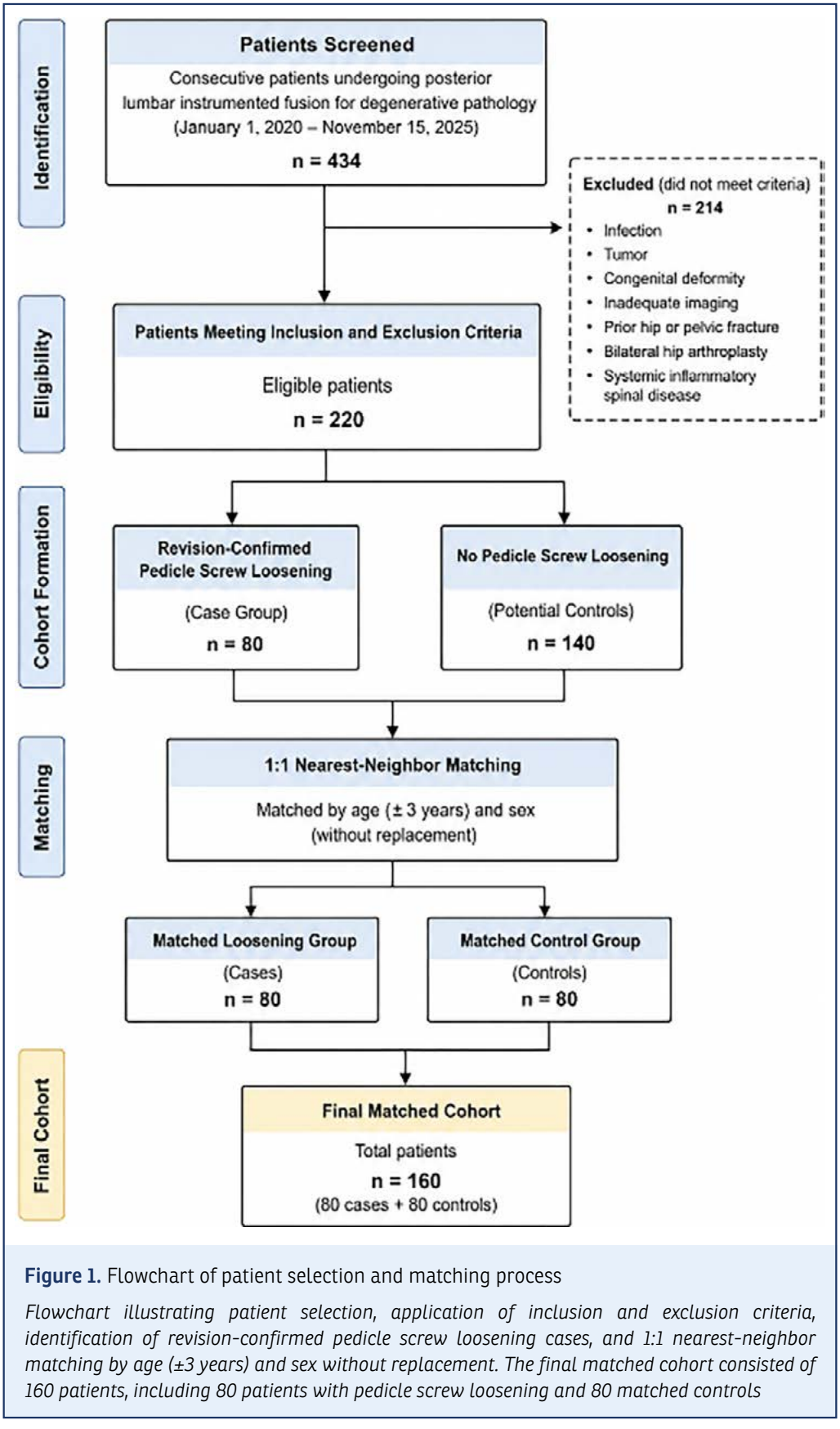

Figure 1. Flowchart of patient selection and matching process

Flowchart illustrating patient selection, application of inclusion and exclusion criteria, identification of revision-confirmed pedicle screw loosening cases, and 1:1 nearest-neighbor matching by age (±3 years) and sex without replacement. The final matched cohort consisted of 160 patients, including 80 patients with pedicle screw loosening and 80 matched controls

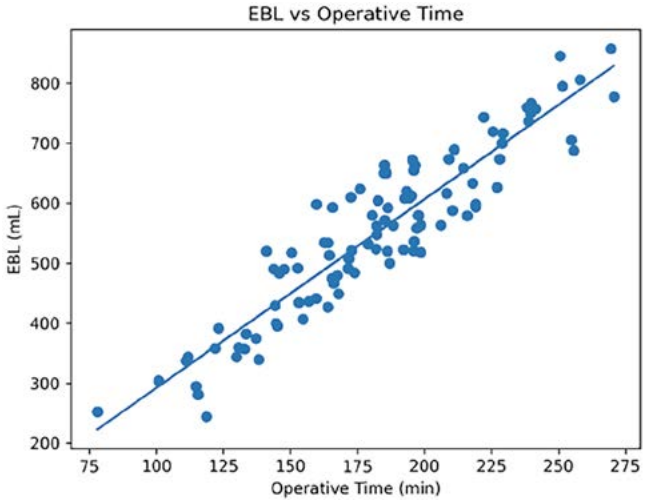

Figure 2. Relationship between estimated blood loss and surgical complexity parameters

Scatter plots showing the relationship between estimated blood loss (EBL) and surgical complexity parameters. EBL was positively correlated with operative time, indicating that intraoperative blood loss reflects procedural burden rather than an independent determinant of pedicle screw loosening. The solid line represents the linear regression fit

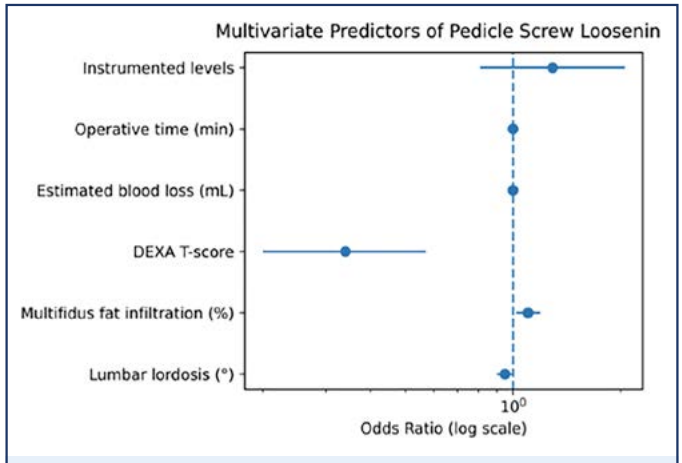

Figure 3. Multivariate predictors of pedicle screw loosening

Forest plot of the multivariate conditional logistic regression analysis. Odds ratios (ORs) with 95% confidence intervals (CIs) are presented. Lumbar lordosis, multifidus fat infiltration, and DEXA T-score were independently associated with pedicle screw loosening, whereas estimated blood loss, operative time, and instrumented levels were not significant after adjustment. The vertical dashed line indicates an OR of 1

Radiographic and Paraspinal Muscle Findings

Radiographic and paraspinal muscle parameters are presented in Table 1. Pelvic incidence did not differ significantly between the groups. Lumbar lordosis was significantly lower in the loosening group, resulting in a greater PI–LL mismatch. Multifidus fat infiltration was higher in the loosening group compared with controls.

Logistic Regression Analysis

Conditional logistic regression analysis was performed to account for the matched study design.

In the adjusted model, lumbar lordosis (OR=0.95, 95% CI: 0.90–0.99, p=0.031), multifidus fat infiltration (OR=1.10, 95% CI: 1.02–1.19, p=0.009), and DEXA T-score (OR=0.34, 95% CI: 0.20–0.57, p=0.001) remained independently associated with pedicle screw loosening (Table 2). These findings are illustrated in Figure 3.

Surgical parameters, including estimated blood loss, operative time, and number of instrumented levels, were not independently associated with screw loosening after adjustment.

Interobserver Reliability

Interobserver reliability was high for all measurements. Intraclass correlation coefficient values were 0.90 for spinopelvic parameters and 0.88 for paraspinal muscle measurements.

Composite Index Analysis

Receiver operating characteristic (ROC) analysis evaluated the discriminative performance of the composite indices. The surgical complexity index showed moderate predictive ability, whereas the biomechanical–biological index reflect-

Table 2. Conditional logistic regression analysis of factors associated with pedicle screw loosening

Variable	OR (95% CI)	p
BMI	1.08 (0.96–1.23)	0.180
Operative time (min)	1.00 (0.99–1.01)	0.880
EBL (mL)	1.00 (0.998–1.003)	0.640
Instrumented levels	1.29 (0.81–2.05)	0.280
Lumbar lordosis (°)	0.95 (0.90–0.99)	0.031
PI–LL mismatch (°)	1.05 (0.97–1.14)	0.210
Multifidus FI (%)	1.10 (1.02–1.19)	0.009
DEXA T-score	0.34 (0.20–0.57)	0.001

Odds ratios (ORs) and 95% confidence intervals (CIs) were estimated using conditional logistic regression to account for the matched design. Variables meeting a predefined threshold of p=0.10 in univariate analysis were included in the multivariate model. Statistical significance was defined at a p=0.05 threshold. OR: Odds ratio; CI: Confidence interval; BMI: Body mass index; EBL: Estimated blood loss; FI: Fat infiltration; DEXA: Dual-energy X-ray absorptiometry

Table 3. Predictive performance of composite indices for pedicle screw loosening

Model	AUC	95% CI	z-value	p
Surgical complexity index	0.771	0.693–0.849	–	0.001
Biomechanical–biological index	0.908	0.861–0.955	–	0.001
Comparison (DeLong test)	–	–	3.91	0.001

Discriminative performance was evaluated using receiver operating characteristic (ROC) analysis. Statistical significance was defined at a p=0.05 threshold. AUC: Area under the curve; CI: Confidence interval

ed higher performance (Table 3, Fig. 4). Comparative analysis confirmed the superior predictive accuracy of the biomechanical–biological index.

Calibration Analysis

The final multivariable model demonstrated acceptable calibration, with a Hosmer–Lemeshow goodness-of-fit statistic of χ^2=14.74 (df=8, p=0.064). The Brier score was 0.135. The expanded model, which additionally included estimated blood loss, operative time, and number of instrumented levels, also demonstrated acceptable calibration (Hosmer–Lemeshow χ^2=8.37, df=8, p=0.398), with a Brier score of 0.123. The area under the receiver operating characteristic curve was 0.883 for the final model and 0.899 for the expanded model.

Sensitivity Analysis

Sensitivity analyses were performed to assess robustness. Influential observations were examined using Cook's distance, and models were re-estimated after excluding high-leverage cases, with no change in the associations between key predictors and outcomes. Robust regression using heteroskedasticity-consistent standard errors (HC3) showed no meaningful change in statistical significance or effect size. Nonparametric correlation analyses (Spearman) confirmed a consistent direction and strength of associations. Reduced models including only core predictors were comparable to full models, with no substantial differences in performance or variable significance. These findings indicate that the results are stable.

DISCUSSION

The present study suggests that pedicle screw loosening is primarily associated with intrinsic biomechanical and biological factors rather than surgical complexity. Although intraoperative parameters such as estimated blood loss (EBL), operative time, and instrumented levels were associated with loosening in univariate analyses, these associations did

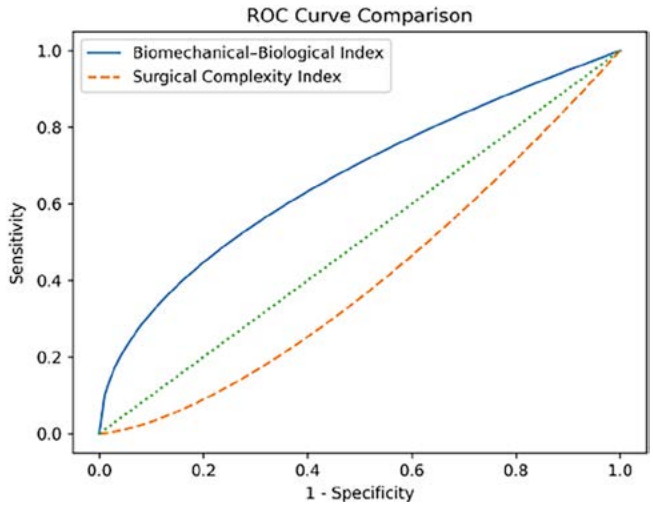

Figure 4. Receiver operating characteristic analysis of composite indices for predicting pedicle screw loosening

Receiver operating characteristic (ROC) curves comparing the surgical complexity index and the biomechanical–biological index. The biomechanical–biological index showed higher discriminative ability, reflected by a greater area under the curve (AUC). Model performance differed significantly according to DeLong's test. The diagonal dashed line indicates no discrimination (AUC=0.5)

not persist after conditional logistic regression. In contrast, lumbar lordosis, multifidus fat infiltration, and bone mineral density remained independently associated with pedicle screw loosening, underscoring the role of sagittal alignment and tissue quality.[6,7,12]

A key strength is the matched cohort design with conditional logistic regression,[13] minimizing demographic confounding by accounting for age, sex, and the matched structure. This approach improves the estimation of independent effects, and the persistence of biomechanical and biological predictors supports robustness.

Surgical complexity requires careful interpretation. EBL was higher in the loosening group (≈250 mL difference), but its clinical relevance appears limited. It did not retain independent predictive value after adjustment, indicating that it reflects procedural burden rather than a direct biological effect.[8,9,16] Operative time and instrumented levels showed similar patterns. These findings suggest that more extensive procedures are indirectly associated with loosening through underlying biomechanical and biological vulnerability.[8,16] Sensitivity analyses confirmed consistency across models and the absence of outlier- or assumption-driven effects.

Sagittal alignment emerged as a key determinant. Reduced lumbar lordosis was independently associated with pedicle screw loosening, supporting the importance of restoring sagittal balance.[6,11,17] PI–LL mismatch was associated with loosening in univariate analysis but not after adjustment, likely due to collinearity, indicating lumbar lordosis as the more direct clinical parameter.

Paraspinal muscle quality, particularly multifidus fat infiltration, was another factor independently associated with pedicle screw loosening. Given its role in segmental stabilization, degeneration may increase micromotion at the bone–implant interface,[7,10,18] consistent with prior evidence.

Bone mineral density was the strongest predictor; lower DEXA T-scores were associated with an increased risk of loosening, highlighting the importance of bone quality and the need for preoperative optimization.[5,12,19]

Composite index analysis supported these findings. The surgical complexity index showed moderate performance, whereas the biomechanical–biological index reflected higher discriminative ability and outperformed the surgical model, indicating a greater contribution of biomechanical and biological factors. Integration of alignment, muscle quality, and bone density may provide a more meaningful framework for risk stratification.

Clinically, these results support prioritizing preoperative optimization and biomechanical planning. Restoration of sagittal alignment, preservation of paraspinal muscle integrity, and management of osteoporosis appear central, whereas surgical technique alone may be insufficient under unfavorable biological conditions.

Limitations

This study is limited by its retrospective design and potential selection bias, although matching and conditional regression partially mitigate these limitations.[13] Matching was restricted to age and sex, and residual confounding cannot be excluded. The single-center design may limit generalizability. Fat infiltration was assessed using a semi-quantitative MRI-based method rather than advanced quantitative techniques.[10,20] Loosening was defined by revision-confirmed cases, increasing specificity but potentially underestimating subclinical cases.[4,20]

CONCLUSION

In this retrospective matched cohort study, pedicle screw loosening was primarily associated with biomechanical and biological factors rather than surgical complexity.[6,7,12] Lumbar lordosis, paraspinal muscle degeneration, and bone mineral density were independently associated with pedicle screw loosening, whereas intraoperative parameters such as blood loss did not retain independent predictive value after multivariable adjustment and instead reflected procedural burden.[8,9] Composite modeling demonstrated superior predictive performance of biomechanical–biological factors, supporting their use in risk assessment and clinical decision-making.

Disclosures

Ethics Committee Approval: The study was approved by the Kanuni Sultan Süleyman Training and Research Hospital Ethics Committee (No: KAEK/2026.03.110, Date: 11/03/2026).

Informed Consent: Informed consent was waived due to the retrospective nature of the study.

Conflict of Interest Statement: The authors declare that there is no conflict of interest.

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Author Contributions: Concept – E.S.; Design – E.S.; Supervision – E.S.; Data collection and/or processing – E.S.; Data analysis and/or interpretation –E.S.; Literature search – E.S.; Writing – E.S.; Critical review – L.A., H.D.

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