Turk Neurosurg 36(1):89-98, 2026
DOI: 10.5137/1019-5149.JTN.47941-24.4

Original Investigation
Spine and Peripheral Nerves

Received: 23.10.2024
Accepted: 17.05.2025
Published Online: 16.01.2026

Distal Junctional Failure in Posterior Thoracolumbar Surgery: An Analysis of Spinopelvic Alignment and Surgical Outcomes

Numan KARAARSLAN[1], Hidayet Safak CINE[1], Ece UYSAL[2], Mehmet Ali KAHRAMAN[1], Emre HERDAN[1], Mohammed ALADDAM[1], Abdullah Talha SIMSEK[1], Mahmut DEMIRKOL[1], Burak BAYRAKTAR[1], Yunus Emre OZBILGI[1]

[1]Istanbul Medeniyet University, Prof. Dr. Suleyman Yalcin City Hospital, Department of Neurosurgery, Istanbul, Türkiye
[2]University of Health Sciences, Prof. Dr. Cemil Tascioglu City Hospital, Department of Neurosurgery, Istanbul, Türkiye

Corresponding author: Numan KARAARSLAN ✉ numankaraarslan@yahoo.com

ABSTRACT

AIM: To evaluate the incidence, risk factors, and spinopelvic alignment parameters associated with distal junctional failure (DJF) following posterior thoracolumbar stabilization surgery.

MATERIAL and METHODS: This retrospective cohort study included 40 patients who underwent thoracolumbar stabilization between 2018 and 2024. Patients were divided into two groups: those who developed DJF (n=20) and those who did not (n=20, control group). Radiographic evaluations, including pre- and postoperative lateral radiographs, were used to assess spinopelvic parameters such as lumbar lordosis (LL), pelvic incidence (PI), and PI–LL mismatch. Statistical analyses were conducted to examine the correlation between these parameters and DJF occurrence.

RESULTS: The DJF group exhibited a significant postoperative reduction in LL and an increase in PI–LL mismatch compared to the control group, which maintained better sagittal alignment postoperatively ($p < 0.05$). Patients with higher preoperative PI–LL mismatch were more likely to develop DJF, highlighting the importance of preoperative planning and correction to prevent this complication.

CONCLUSION: Optimizing spinopelvic alignment, particularly LL and PI–LL mismatch, is crucial for reducing the risk of DJF after thoracolumbar stabilization surgery. Future studies should aim to refine surgical techniques and strategies to enhance postoperative outcomes and minimize complications.

KEYWORDS: Distal junctional failure, Thoracolumbar stabilization surgery, Spinopelvic parameters, Lumbar lordosis, PI-LL mismatch

ABBREVIATIONS: CT: Computed tomography, **DEXA:** Dual-energy x-ray absorptiometry, **DJF:** Distal junctional failure, **DJK:** Distal junctional kyphosis, **ESV:** End segment vertebra, **IQR:** Interquartile range, **LIV:** Lower instrumented vertebra, **LL:** Lumbar lordosis, **MRI:** Magnetic resonance imaging, **NPV:** Negative predictive value, **PI:** Pelvic incidence, **PI–LL Mismatch:** Pelvic incidence and lumbar lordosis mismatch, **PPV:** Positive predictive value, **PT:** Pelvic tilt, **SD:** Standard deviation, **SS:** Sacral slope, **SVA:** Sagittal vertical axis

Numan KARAARSLAN : 0000-0001-5590-0637
Hidayet Safak CINE : 0000-0002-0808-5921
Ece UYSAL : 0000-0002-2355-8395
Mehmet Ali KAHRAMAN : 0009-0005-3719-654X
Emre HERDAN : 0000-0003-2046-2133
Mohammed ALADDAM : 0009-0004-2289-2975
Abdullah Talha SIMSEK : 0000-0002-8668-3935
Mahmut DEMIRKOL : 0009-0009-4286-6690
Burak BAYRAKTAR : 0009-0006-4317-5961
Yunus Emre OZBILGI : 0009-0004-8394-402X

INTRODUCTION

Posterior transpedicular fixation is the most commonly used and widely accepted method for treating adult spinal deformities, thoracolumbar fractures, and scoliosis (5). The primary goal of this stabilization technique is to achieve a balanced spine in both the coronal and sagittal planes while preserving as much functional movement as possible and preventing future complications (21). However, despite successful stabilization, motion persists in the unfused segments, leading to increased stress and movement in the adjacent upper and lower segments. This biomechanical shift may result in adjacent segment disease.

While much of the existing literature has focused on the proximal junction-where insufficiencies are most commonly observed-distal junctional failure (DJF) is also a significant complication that warrants attention (19). Distal junctional kyphosis (DJK) refers to the development of kyphosis at the caudal end of the instrumentation, typically defined by a sagittal Cobb angle greater than 10 degrees between the vertebrae in the caudal region (13). DJF, in contrast, refers to failure at the most caudal end of the instrumented segments, which may occur even in the absence of kyphosis. It is characterized by clinical and radiological changes at the distal segment (20).

Clinically, DJF may present with lower back and hip pain, loss of function, neurological symptoms, and postural deformity. Radiologic findings include progressive loss of lumbar lordosis, degeneration of the adjacent disc at the lower end of the instrumentation, loss of vertebral height, wedging, fractures of the distal instrumented or adjacent vertebrae, and implant-related issues such as screw breakage, loosening, stenosis, and instability at the segment adjacent to the distal instrumented vertebra (2).

The incidence of DJF following adult spinal deformity surgery ranges from 1.8% to 15.6%, significantly impacting patients' quality of life, leading to increased deformities, repeated surgeries, and reduced productivity (6). Prevention of DJF requires a comprehensive assessment of various spinal parameters. The sagittal vertical axis (SVA) is a widely used measure of sagittal alignment, but it can be influenced by compensatory mechanisms such as pelvic retroversion, knee flexion, and patient posture (12). Among the most critical parameters to evaluate during stabilization surgery are the pelvic parameters, including lumbar lordosis (LL), pelvic tilt (PT), pelvic incidence (PI), sacral slope (SS), and PI–LL mismatch. These should be carefully evaluated preoperatively, as they play a vital role in maintaining sagittal balance (16).

Despite the recognized importance of these parameters, few studies have specifically investigated their role in patients who develop DJF following thoracolumbar stabilization. This study aims to investigate the causes of DJF in patients who have undergone thoracolumbar posterior stabilization, focusing on the surgical levels involved, identification of the last instrumented vertebra, and relevant sagittal pelvic parameters. Furthermore, the study seeks to explore the relationship between the timing of DJF onset and these parameters, with the ultimate goal of informing strategies to prevent this complication.

MATERIAL and METHODS

Study Design

This study protocol received approval from the Usak University Ethics Board (approval no. 448-448-13/2024). Due to the retrospective design and institutional regulations for research, specific informed consent from patients was not required.

This retrospective study includes patients treated for spinal stenosis, deformity, or trauma who underwent posterior transpedicular stabilization at our institution between 2018 and 2024. All procedures were performed by different surgeons within the same clinic. The surgical approach involved a posterior midline incision followed by posterolateral transpedicular screw fixation, including both cases with and without decompression and fusion.

Out of 237 patients who underwent lumbar rigid stabilization and were initially reviewed, 116 were excluded based on the inclusion criteria. Of the remaining 121 patients, 20 were identified as having developed DJF. These patients were categorized into two groups. The first group consisted of patients who had undergone revision surgery due to DJF following their initial posterior stabilization surgery. For the control group, patients without DJF were randomized at a ratio of 5:1 (100 patients) to ensure the reliability of the study. Hence, the failure group included only cases that required revision within six years post-surgery. Medical histories, surgical reports, follow-up reports, and diagnostic imaging (radiographs, CT, and MRI) of all patients stored in the hospital's digital archive were reviewed.

A patient was assigned to the DJF group if a failure occurred at the last instrumented fused level or the immediately adjacent caudal vertebra and met one or more of the following criteria:

- Pullout or loosening of the pedicle screws,
- mechanical breakage of rods or screws,
- adjacent segment pathology (e.g., stenosis/disc/listhesis).

Inclusion Criteria

The inclusion criteria included patients who underwent posterior transpedicular fixation with rigid rods in the thoracolumbar region. There were no age restrictions. Patients who presented with pain, neurological deficits, or other clinical symptoms confirmed through imaging (e.g., CT, X-ray, or MRI) during follow-up were included as part of the DJF group. Patients who did not exhibit any clinical pain or neurological symptoms and showed no evidence of DJF on radiological imaging were included in the control group. Patients with a coronal balance <5 degrees were included in the study.

Exclusion Criteria

Patients who underwent anterior or anterolateral fixation as well as those who had fixation methods other than transpedicular screw fixation were not included in the study. Patients stabilized with dynamic or semi-dynamic systems were also excluded. Patients were monitored for osteoporosis using DEXA scans either preoperatively or postoperatively.

Those with advanced osteoporosis were excluded from the study to avoid conflicts, as were patients who underwent interbody fusion. Patients with a coronal balance >5 degrees were excluded from the study.

Radiological Evaluation

Spinopelvic parameters were assessed in both groups using available lateral standing radiographs that included the entire spine or at least the C2 to femoral heads. For radiological evaluation, pelvic parameters were assessed at three key time points: preoperatively, within three months postoperatively, and immediately prior to revision surgery (for the DJF group). Spinopelvic parameters were analyzed using Surgimap software (Nemaris Inc, New York, NY, www.surgimap.com), a validated, freely available tool designed for surgical planning and spinal measurement. Following prior studies, the following spinopelvic parameters were measured for each patient.

Spinopelvic Parameters: Sagittal and pelvic parameters included LL, PT, PI, SS, and PI–LL mismatch.

Timing of Failure: For the failure group, the time between the first and second surgeries was calculated to determine the timing of DJF onset.

Surgical Details: The number of levels stabilized, whether the lumbar and/or thoracic regions were involved, and the lowest instrumented vertebra (LIV) were recorded for all patients.

Statistical Analyses

Statistical analyses were conducted using the Shapiro–Wilk test to assess normality of the data distribution. For comparisons between groups, either the Student's t-test or Mann–Whitney U test was applied to continuous variables, depending on whether the data were normally distributed. Categorical variables were analyzed using the Chi-square test or Fisher's exact test as appropriate. Parametric variables are presented as mean ± standard deviation (SD) along with minimum–maximum (min–max) values, while categorical variables are reported as percentages (%).

Correlations were assessed using either Pearson or Spearman correlation coefficients, based on data distribution. Statistical significance was set at $p<0.05$. All analyses were performed using SPSS (Statistical Package for the Social Sciences), version 26.0.

RESULTS

A total of 40 patients were included in the study, equally divided between the control group (n=20) and the DJF group (n=20). The overall mean age was 59.62 ± 12.85 years, with an interquartile range (IQR) of 55.0–68.0 years. The control group had a mean age of 58.90 ± 13.02 years (range: 23–80 years; IQR 54.5–66.5 years), while the DJF group had a mean age of 60.35 ± 12.97 years (range: 25–80 years; IQR 57.25–68.25 years).

In terms of gender distribution, 67.5% of all patients were female and 32.5% were male. The control group consisted of 65.0% females and 35.0% males, while the DJF group consisted of 70.0% females and 30.0% males. Regarding surgical location, 92.5% of patients underwent procedures in the lumbar region, 5.0% in the thoracolumbar region, and 2.5% in the thoracic region. Specifically, in the control group, 95.0% of patients underwent lumbar surgery and 5.0% thoracolumbar surgery. In the DJF group, 90.0% had lumbar procedures, 5.0% thoracolumbar, and 5.0% thoracic.

The distribution of LIV varied. Across all patients, LIV was at L5 in 65.0% of cases, S1 in 25.0%, L3 in 5.0%, L1 in 2.5%, and T7 in 2.5%. In the control group, LIV was at L5 in 55.0% of cases, S1 in 40.0%, and L2 in 5.0%. In the DJF Group, LIV was at L5 in 75.0% of cases, L3 in 10.0%, S1 in 10.0%, and T7 in 5.0%.

The mean number of instrumented fused levels was 3.27 ± 1.20 (range: 2.00–7.00 levels; IQR: 2.75–4.00) for all patients. The control group had a mean of 3.10 ± 0.91 fused levels (range: 2.00–6.00), while the DJF group had a mean of 3.45 ± 1.43 fused levels (range 2.00–7.00). In the DJF Group, the mean interval between the first and second surgeries was 39.40 ± 29.21 months (range: 5.0–108.0 months; IQR: 18.75–57.5 months) (Table I, Figure 1).

The preoperative LL for all patients was 47.33 ± 14.37 degrees (range: 18.3–73.9 degrees). The control group had a mean preoperative LL of 43.97 ± 15.08 degrees, while the DJF group had a mean of 50.68 ± 13.14 degrees. The difference between the groups was not statistically significant (p=0.14). Postoperatively, overall LL was 45.63 ± 13.65 degrees. The control group had a significantly higher mean LL (50.14 ± 8.91 degrees) than the DJF group (41.11 ± 16.13 degrees; p=0.03).

Preoperative PT averaged 21.30 ± 11.97 degrees. The control group had a mean of 19.06 ± 12.93 degrees, while the DJF Group had a mean of 23.53 ± 10.78 degrees (p=0.24). Postoperatively, PT decreased to 19.10 ± 11.08 degrees overall, with the control group at 15.83 ± 10.92 degrees and the DJF group at 22.37 ± 10.49 degrees. This difference did not reach statistical significance (p=0.06).

PI averaged 54.45 ± 11.27 degrees preoperatively, with no significant difference between the control group (51.65 ± 9.40 degrees) and the DJF group (57.24 ± 12.49 degrees; p=0.12). PI remained stable postoperatively (p=0.24).

Preoperative SS was 33.43 ± 11.74 degrees overall, with no statistically significant difference between groups (control: 32.65 ± 11.18 degrees; DJF: 34.21 ± 12.51 degrees; p=0.68). Postoperative SS increased slightly to 35.90 ± 9.87 degrees for all patients, without significant between-group differences (p=0.43).

The preoperative PI–LL mismatch was 12.60 ± 10.07 degrees overall, with no statistically significant difference between the control group (15.11 ± 10.15 degrees) and the DJF group (10.09 ± 9.58 degrees; p=0.12). Postoperatively, the PI–LL mismatch increased slightly to 13.56 ± 11.89 degrees for all patients. The DJF group had a significantly higher mismatch (17.98 ± 14.13 degrees) than the control group (9.13 ± 7.02 degrees; p=0.02) (Table II). Among patients with L5 as the LIV, no statistically significant difference was observed in either

Table I: Demographic and Clinical Characteristics of Patients in the Control and DJF Groups

Data	All Patients (n=40)	Control Group (n=20)	DJF Group (n=20)
	n (%) / M ± SD (min - max) [Q1 Q3]		
Age	59.62 ± 12.85 [55.0-68.0]	58.90 ± 13.02 (23-80) [54.5-66.5]	60.35 ± 12.97 (25-80) [57.25-68.25]
Gender	Female (67.5%) Male (32.5%)	Female (65.0%) Male (35.0%)	Female (70.0%) Male (30.0%)
Region	Lumbar (92.5%) Thoracolumbar (5.0%) Thoracic (2.5%)	Lumbar (95.0%) Thoracolumbar (5.0%)	Lumbar (90.0%) Thoracolumbar (5.0%) Thoracic (5.0%)
Lower Instrumented vertebra (LIV)	L5 (65.0%) S1 (25.0%) L3 (5.0%) L1 (2.5%) T7 (2.5%)	L1 (55.0%) S1 (40.0%) L2 (5.0%)	L5 (75.0%) L3 (10.0%) S1 (10.0%) T7 (5.0%)
Instrumental fused levels	3.27 ± 1.20 [2.00 - 7.00] [2.75-4.0]	3.10 ± 0.91 [2.00 - 6.00]	3.45 ± 1.43 [2.00 - 7.00]
Duration between first and second surgery (month)	39.40 ± 29.21 (5.0-108.0) [18.75-57.5]		39.40 ± 29.21 (5.0-108.0) [18.75-57.5]

***DJF:** Distal junctional failure, **LIV:** Lower Instrumented Vertebra, **M:** Mean, **SD:** Standard Deviation, **min:** Minimum, **max:** Maximum, **Q1:** First Quartile, **Q3:** Third Quartile.*

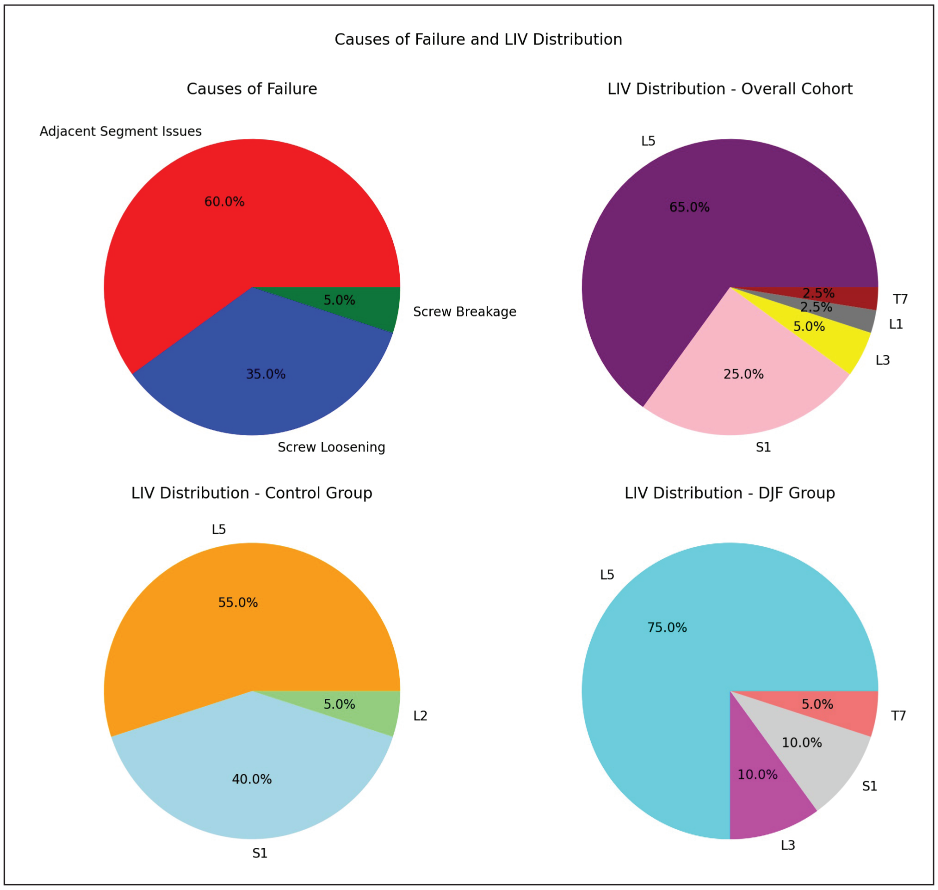

Figure 1: Causes of Failure and Distribution of Lower Instrumented Vertebra (LIV) in the Overall Cohort, Control Group, and DJF Group. This figure illustrates the distribution of failure causes, including screw breakage, screw loosening, and adjacent segment issues, alongside the distribution of the LIV in the overall cohort, control group, and DJF group. The pie charts provide a visual breakdown of the distribution of L5, S1, L3, L1, and T7 as the lower instrumented vertebrae in each group.

Table II: Preoperative and Postoperative Spinopelvic Parameters of Patients in the Control and DJF Groups

Parameter	All Patients (n=40)	Control Group (n=20)	DJF Group (n=20)	p-value
	n (%) / M ± SD (min - max) [Q1 Q3]			
Preoperative LL	47.33 ± 14.37 (18.3-73.9) [35.63-57.38]	43.97 ± 15.08 (18.3-67.9) [30.88-56.73]	50.68 ± 13.14 (27.8-73.9) [43.05-62.57]	0.14
Postoperative LL	45.63 ± 13.65 (6.9-87.7) [38.9-50.3]	50.14 ± 8.91 (37.6-75.0) [45.25-53.65]	41.11 ± 16.13 (6.9-87.7) [34.7-46.6]	**0.03***
Preoperative PT	21.30 ± 11.97 (0.2-50.9) [13.15-29.58]	19.06 ± 12.93 (0.2-43.6) [9.1-25.35]	23.53 ± 10.78 (6.5-50.9) [14.9-30.53]	0.24
Postoperative PT	19.10 ± 11.08 (3.0-50.9) [12.45-25.83]	15.83 ± 10.92 (3.0-40.1) [6.88-19.92]	22.37 ± 10.49 (4.4-50.9) [14.73-27.28]	0.06
Preoperative PI	54.45 ± 11.27 (34.9-80.2) [47.48-62.22]	51.65 ± 9.40 (34.9-68.2) [45.75-57.55]	57.24 ± 12.49 (36.8-80.2) [47.65-66.38]	0.12
Postoperative PI	54.68 ± 12.18 (35.3-83.3) [45.73-61.13]	52.38 ± 11.74 (35.3-83.3) [44.28-57.2]	56.99 ± 12.46 (36.5-80.3) [48.0-65.98]	0.24
Preoperative SS	33.43 ± 11.74 (4.4-56.3) [27.08-41.0]	32.65 ± 11.18 (8.3-48.4) [25.23-40.8]	34.21 ± 12.51 (4.4-56.3) [27.83-41.0]	0.68
Postoperative SS	35.90 ± 9.87 (5.2-60.8) [30.65-40.88]	37.16 ± 6.42 (26.6-50.2) [32.2-40.63]	34.63 ± 12.47 (5.2-60.8) [26.8-42.3]	0.43
Preoperative PI-LL mismatch	12.60 ± 10.07 (1.2-45.3) [5.48-18.10]	15.11 ± 10.15 (1.2-45.3) [8.05-19.0]	10.09 ± 9.58 (1.4-34.0) [2.65-12.65]	0.12
Postoperative PI-LL mismatch	13.56 ± 11.89 (1.6-68.4) [7.8-16.55]	9.13 ± 7.02 (1.6-29.5) [3.475-12.08]	17.98 ± 14.13 (1.72-68.4) [9.48-20.03]	**0.02***
Preoperative LL (LIV L5)		43.89 ± 12.51 (22.7 - 59.5) [35.05-53.85]	52.84 ± 14.16 (27.8 - 73.9) [43.75-64.70]	0.11
Postoperative LL (LIV L5)		47.95 ± 4.73 (38.9 - 55.0) [45.95-50.40]	42.38 ± 18.48 (6.9 - 87.7) [34.20-50.25]	0.34

***LL:** Lumbar lordosis, **PT:** Pelvic tilt, **PI:** Pelvic incidence, **SS:** Sacral slope, **PI-LL mismatch:** Pelvic incidence - Lumbar Lordosis mismatch, **M:** Mean, **SD:** Standard Deviation, **min:** Minimum, **max:** Maximum, **Q1:** First Quartile, **Q3:** Third Quartile, ***:** p<0.05.*

preoperative or postoperative LL values (p=0.011, p=0.34, respectively).

A comparison between preoperative and postoperative spinopelvic parameters revealed significant changes in both groups. Both groups showed significant improvement in LL after surgery (control: p=0.03; DJF: p=0.01). PT, PI, and SS did not show statistically significant preoperative to postoperative changes in either group (PT: control p=0.22, DJF p=0.25; PI: control p=0.51, DJF p=0.07; SS: control p=0.06, DJF p=0.68). Postoperatively, the PI–LL mismatch significantly improved in both the control group (p=0.01) and the DJF group (p=0.01) (Table III).

The change in LL differed significantly between groups (p=0.01). The DJF group showed a mean decrease in LL of –9.58 degrees, while the control group had a mean increase of 6.18 degrees. Postoperatively, the PI–LL mismatch increased in the DJF group by 7.9 degrees and decreased by 5.98 degrees in the control group, a statistically significant difference (p=0.01). Changes in PT, PI, and SS did not significantly differ between groups (p=0.45, p=0.37, p=0.11, respectively) (Table IV, Figure 2).

The PI–LL mismatch and the change in PI–LL mismatch were evaluated in terms of sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). For postoperative PI–LL mismatch, sensitivity was 0.65, specificity was 0.75, PPV was 0.722, and NPV was 0.682. When analyzing the change in PI–LL mismatch, sensitivity was 0.8, specificity was 0.9, PPV was 0.889, and NPV was 0.818 (Table V, Figures 3 and 4).

DISCUSSION

The incidence of DJF has been reported to range between 1.8% and 15.6% (15). DJF refers to mechanical failure occurring at the distal end of the instrumented spine. Some patients may remain asymptomatic, with DJF identified only through radiographic findings, while others may experience

Table III: Comparison of Preoperative and Postoperative Spinopelvic Parameters in Control and DJF Groups

Parameter	Control Group p-value	DJF Group p-value
Preoperative LL vs Postoperative LL	**0.03***	**0.01***
Preoperative PT vs Postoperative PT	0.22	0.25
Preoperative PI vs Postoperative PI	0.51	0.07
Preoperative SS vs Postoperative SS	0.06	0.68
Preoperative PI-LL mismatch vs Postoperative PI-LL mismatch	**0.01***	**0.01***

LL: *Lumbar lordosis,* ***PT:*** *Pelvic tilt,* ***PI:*** *Pelvic incidence,* ***SS:*** *Sacral slope,* ***PI-LL mismatch:*** *Pelvic incidence - Lumbar Lordosis mismatch,* ***:*** *p<0.05.*

Table IV: Postoperative Changes in Spinopelvic Parameters for DJF and Control Groups

Parameter	DJF Group Change	DJF Group Description	Control Group Change	Control Group Description	p-value
LL change after surgery	-9.58	Decreased	6.18	Increased	**0.01**
PT change after surgery	-1.17	Decreased	-3.23	Decreased	0.45
PI change after surgery	-0.26	Decreased	0.73	Increased	0.37
SS change after surgery	0.42	Increased	4.51	Increased	0.11
PI-LL mismatch change after surgery	7.9	Increased	-5.98	Decreased	**0.01**

LL: *Lumbar lordosis,* ***PT:*** *Pelvic tilt,* ***PI:*** *Pelvic incidence,* ***SS:*** *Sacral slope,* ***PI-LL mismatch:*** *Pelvic incidence - Lumbar Lordosis mismatch,* ***:*** *p<0.05.*

Table V: Sensitivity, Specificity, and Predictive Values for Postoperative and Change in PI-LL Mismatch

Metric	Postoperative PI-LL Mismatch	Change in PI-LL Mismatch
Sensitivity	0.65	0.8
Specificity	0.75	0.9
PPV	0.722	0.889
NPV	0.682	0.818

PI-LL mismatch: *Pelvic incidence - lumbar lordosis mismatch,* ***PPV:*** *Positive predictive value,* ***NPV:*** *Negative predictive value.*

more acute symptoms, often describing an audible sound or a sensation linked to hardware failure, such as a rod or screw fracture (15). In other cases, DJF presents more gradually, with persistent postoperative pain, leading to the discovery of pseudarthrosis or adjacent segment disease on advanced imaging (14).

In our study, the primary causes of failure in patients undergoing thoracolumbar posterior stabilization were adjacent segment disease (60%), screw loosening (35%), and screw breakage (5%). This distribution aligns with findings in the literature, although variations exist depending on patient demographics, surgical techniques, and follow-up durations. Adjacent segment disease was the most frequent cause of failure in our cohort, accounting for 60% of all failures (7). Screw loosening was responsible for 35% of failures, while screw breakage accounted for 5%. Screw loosening is often attributed to poor bone quality, incorrect screw positioning, or excessive stress at the instrumented junctional segment. Screw-related issues, including loosening and breakage, are particularly common in patients with osteoporosis or those undergoing long instrumented fusions (3,20). Hardware complications such as screw breakage are frequently preceded by loosening, as increased micromotion weakens the screw–bone interface over time. Additionally, variability in surgical technique (e.g., using stronger, larger diameter screws or dual–rod systems) may also influence these outcomes.

In our study, most patients had LIV at L5, which is consistent with literature emphasizing the importance of selecting the distal-most instrumented vertebra, often referred to as the end segment vertebra (ESV). The use of L5 as the LIV has been a subject of ongoing debate due to its anatomical position and the biomechanical stresses placed on the L5–S1. Studies suggest that fusions ending at L5 may predispose patients to degeneration, sagittal imbalance, and ultimately DJF (8). Thus, while L5 may be appropriate for certain patients—particularly those with a healthy L5–S1 disc and short fusions—surgeons must carefully consider individual anatomical and alignment factors.

LL is a crucial parameter in maintaining spinal sagittal balance. Normal LL values typically range from 40 to 60 degrees,

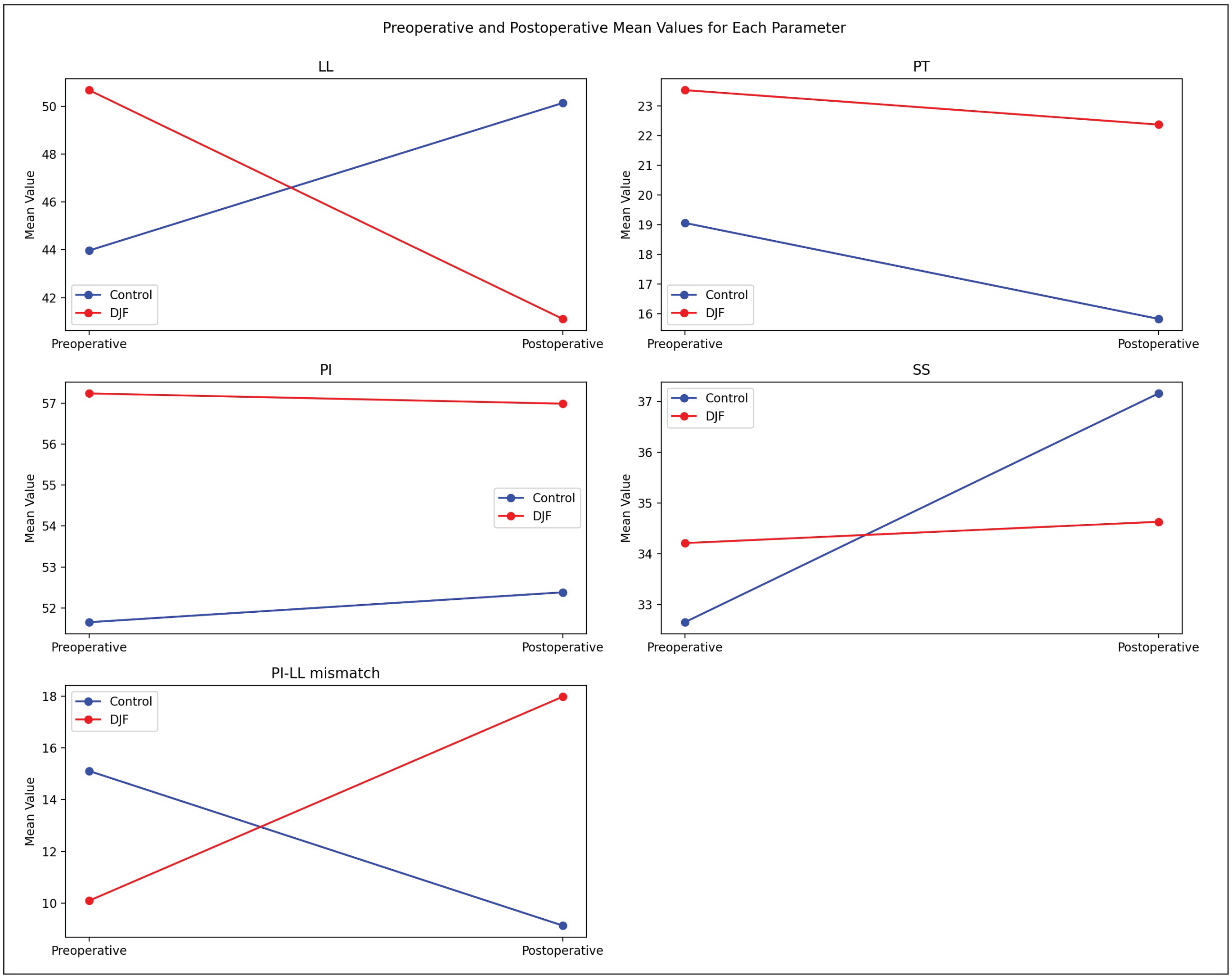

Figure 2: Preoperative and Postoperative Mean Values for Lumbar Lordosis (LL), Pelvic Tilt (PT), Pelvic Incidence (PI), Sacral Slope (SS), and PI–LL Mismatch in the Control and DJF Groups. This figure illustrates the comparison of mean preoperative and postoperative values for LL, PT, PI, SS, and PI–LL mismatch between the control and DJF groups. The graphs depict the trends and differences in each parameter after surgical intervention.

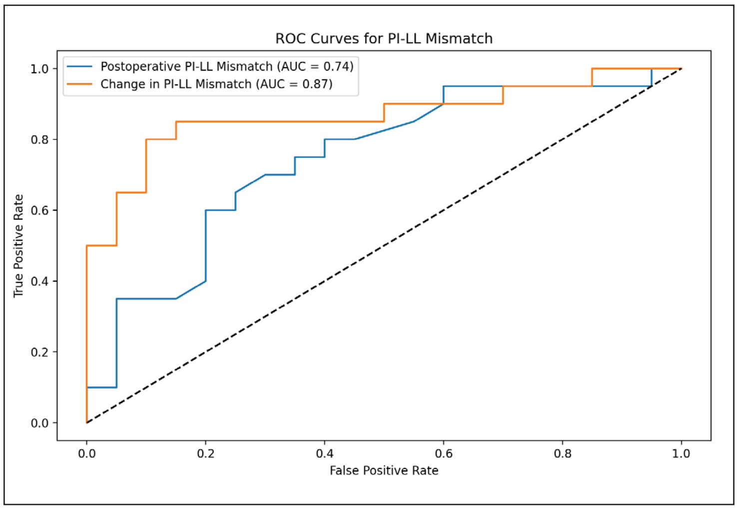

Figure 3: ROC Curves for Postoperative PI–LL Mismatch and Change in PI–LL Mismatch. This figure displays the receiver operating characteristic (ROC) curves comparing the postoperative PI–LL mismatch (AUC = 0.74) and the change in PI–LL mismatch (AUC = 0.87), illustrating the diagnostic performance of these metrics in predicting outcomes.

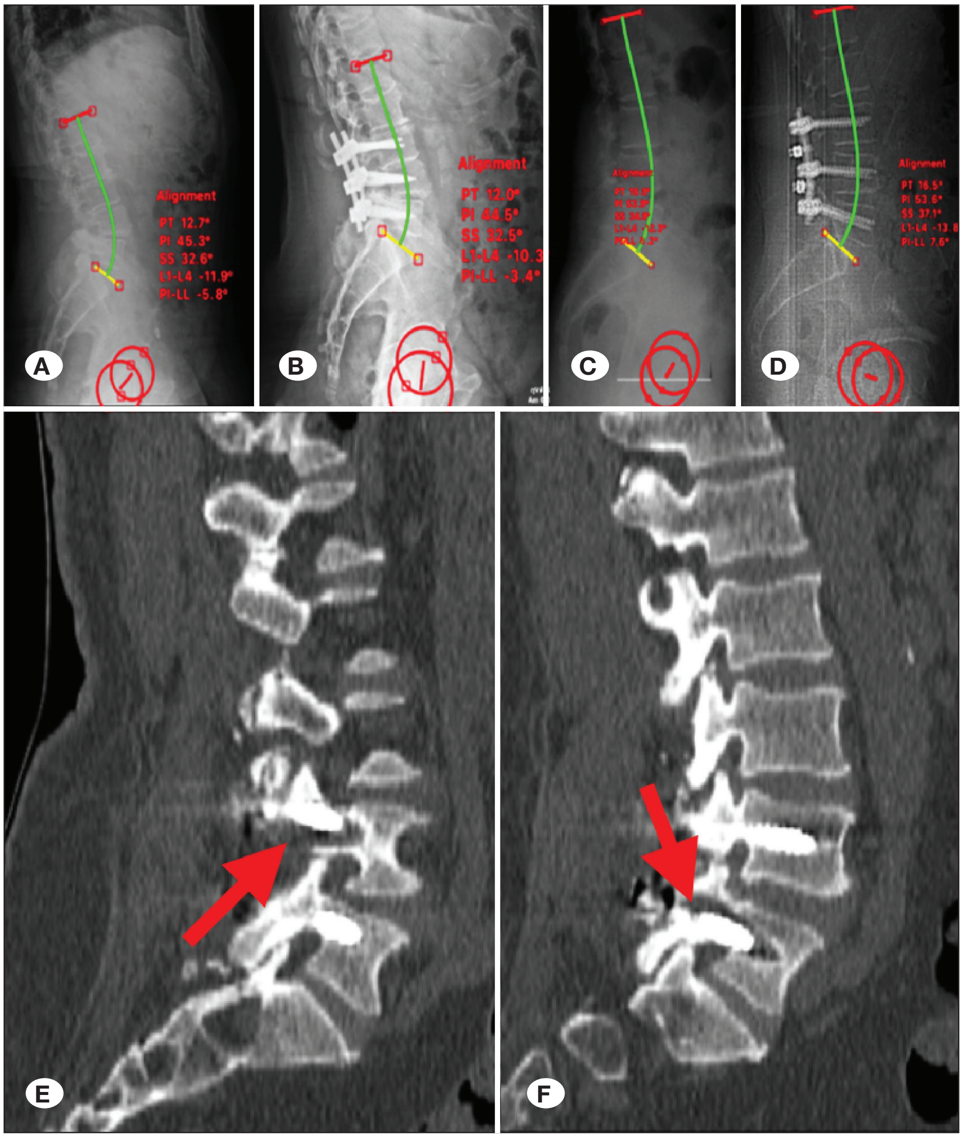

Figure 4: A, C) depict preoperative images showing the measurement of pelvic parameters in patient case examples,
B, D) show the postoperative measurements of the same pelvic parameters in these cases,
E, F) are sagittal CT images from the cases, highlighting screw loosening, indicated by the red arrows.

depending on pelvic morphology (9). This curvature facilitates appropriate force distribution along the spine and plays a critical role in overall posture and mobility (4). Achieving or restoring optimal LL is essential, as inadequate correction is associated with postoperative complications, including DJF. In our study, the DJF group exhibited a postoperative reduction in LL of –9.58 degrees, whereas the control group showed a mean increase of 6.18 degrees. Several studies have suggested that overcorrecting LL, particularly when L5 is selected as the LIV, may elevate the risk of DJF (10). However, we found no statistically significant difference in DJF rates between patients whose fusions ended at L5 and those whose fusions did not, despite similar LIV selection across groups.

The PI–LL mismatch is widely considered a critical indicator of sagittal balance. PI is a constant anatomical parameter that determines the optimal degree of lordosis for an individual (18). A PI–LL mismatch greater than 10 degrees is considered pathologic and has been strongly linked to poor surgical outcomes, including DJF (17). In our analysis, patients who developed DJF exhibited an increased postoperative PI–LL mismatch, whereas those without DJF maintained a more balanced alignment. These findings support previous reports suggesting that both insufficient correction and overcorrection of the PI–LL mismatch may contribute to the development of DJF. Maintaining this mismatch within a physiologic range is critical for minimizing the mechanical burden at both the proximal and distal junctions. Ailon et al. similarly observed a significantly increased DJF risk in patients with a postoperative mismatch exceeding 15 degrees (1), reinforcing our conclusions.

Limitations

This study has several limitations. First, its retrospective design may introduce selection bias, as data were collected from existing medical records, and not all relevant variables could be consistently controlled. Second, the relatively small sample size—40 patients divided into two groups—may limit the generalizability of our findings. Nevertheless, given the rarity of DJF, this number remains acceptable for initial analysis. Another limitation is the variable follow-up period. Although some patients were followed for up to six years, longer-term data would offer deeper insight into the durability of surgical corrections and the development of DJF over time.

Additionally, while the study focused on spinopelvic parameters such as LL and PI–LL mismatch, other potentially influential factors—such as bone quality, comorbidities, and specific surgical techniques—were not comprehensively analyzed. Our reliance on radiographic evidence to identify DJF may have also overlooked subtler or purely clinical manifestations, as some patients remain asymptomatic despite radiologic evidence of failure. Future research should incorporate advanced imaging modalities and detailed functional assessments to better capture the full spectrum of DJF.

We excluded patients with advanced osteoporosis to better isolate other contributing factors to DJF. However, we recommend future subgroup analyses focusing on osteoporotic patients, as preoperative osteoporosis is a known risk factor for postoperative DJF. The American National Osteoporosis Foundation advises preoperative vitamin D and calcium supplementation for surgical cases, and a study by Liu et al. found a lower incidence of adjacent segment pathology in patients receiving osteoporosis treatment (11). Furthermore, the use of expandable or cement-augmented cannulated screws has been suggested to reduce DJF risk in osteoporotic individuals (14).

CONCLUSION

To minimize the risk of DJF in posterior thoracolumbar fusion surgery, it is essential to achieve an optimal LL. Both overcorrection and undercorrection can disrupt sagittal balance and increase mechanical stress on distal segments, leading to DJF. Maintaining an appropriate PI–LL mismatch is equally critical in reducing the biomechanical burden on junctional regions and improving long-term surgical outcomes.

Declarations

Funding: The authors did not receive support from any organization for the submitted work. The authors have no relevant financial or non-financial interests to disclose.

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: HSC, NK, EU

Data collection: HSC, EU, YEO

Analysis and interpretation of results: MD, ATS, BB

Draft manuscript preparation: HSC, EU, YEO

Critical revision of the article: NK

Other (study supervision, fundings, materials, etc...): MAK, EH, MA

All authors (NK, HSC, EU, MAK, EH, MA, ATS, MD, BB, YEO) reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Ailon T, Smith JS, Shaffrey CI, Lenke LG, Brodke D, Harrop JS, Fehlings M, Ames CP: Degenerative spinal deformity. Neurosurgery 77 Suppl 4:S75-91, 2015. https://doi.org/10.1227/NEU.0000000000000938.
2. Arlet V, Aebi M: Junctional spinal disorders in operated adult spinal deformities: Present understanding and future perspectives. Eur Spine J 22 Suppl 2:95, 2013. https://doi.org/10.1007/s00586-013-2676-x.
3. Berjano P, Damilano M, Pejrona M, Langella F, Lamartina C: Revision surgery in distal junctional kyphosis. Eur Spine J 29 Suppl 1:86-102, 2020. https://doi.org/10.1007/s00586-020-06304-y.
4. Cho KJ, Suk SI, Park SR, Kim JH, Kang SB, Kim HS, Oh SJ: Risk factors of sagittal decompensation after long posterior instrumentation and fusion for degenerative lumbar scoliosis. Spine 35:1595-1601, 2010. https://doi.org/10.1097/BRS.0b013e3181bdad89.
5. Deville R, Khalifé M, Rollet ME, Chatelain L, Guigui P, de Loubresse CG, Ferrero E: Readmission rate after adult scoliosis surgery on primary cases over 45 years-old with long-term follow-up. Eur Spine J 33:3880-3886, 2024 https://doi.org/10.1007/s00586-024-08429-w.
6. Faulks CR, Biddau DT, Munday NR, McKenzie DP, Malham GM: Patient-specific spinal rods in adult spinal deformity surgery reduce proximal junctional failure: A review of patient outcomes and surgical technique in a prospective observational cohort. J Spine Surg 9:409-421, 2023. https://doi.org/10.21037/jss-23-85.
7. Hosthota A, Govindasamy R, Rudrappa S: Distal junctional failure secondary to nontraumatic fracture of lower instrumented vertebra: Our experience and review of literature. Int J Spine Surg 15:1031-1038, 2021. https://doi.org/10.14444/8131.
8. Kuhns CA, Bridwell KH, Lenke LG, Amor C, Lehman RA, Buchowski JM, Edwards C 2nd, Christine B: Thoracolumbar deformity arthrodesis stopping at L5: Fate of the L5-S1 disc, minimum 5-year follow-up. Spine 32:2771-2776, 2007. https://doi.org/10.1097/BRS.0b013e31815a7ece.
9. Legaye J: The femoro-sacral posterior angle: An anatomical sagittal pelvic parameter usable with dome-shaped sacrum. Eur Spine J 16:219-225, 2007. https://doi.org/10.1007/s00586-006-0090-3.

10. Lee NJ, Marciano G, Puvanesarajah V, Park PJ, Clifton WE, Kwan K, Morrissette CR, Williams JL, Fields M, Hassan FM, Angevine PD, Mandigo CE, Lombardi JM, Sardar ZM, Lehman RA, Lenke LG: Incidence, mechanism, and protective strategies for 2-year pelvic fixation failure after adult spinal deformity surgery with a minimum six-level fusion. J Neurosurg Spine 38:208-216, 2022. https://doi.org/10.3171/2022.8.SPINE22755.
11. Liu D, Hu Z, Tang Z, Li P, Yuan W, Li F, Chen Q, Min W, Zhao C: Early risk assessment and prediction model for osteoporosis based on traditional Chinese medicine syndromes. Heliyon. 9:e21501, 2023. https://doi.org/10.1016/j.heliyon.2023.e21501.
12. Liu Y, Yuan L, Zeng Y, Li W: Risk factors for distal junctional problems following long instrumented fusion for degenerative lumbar scoliosis: Are they related to the paraspinal muscles. Orthop Surg 15:3055-3064, 2023. https://doi.org/10.1111/os.13878.
13. Lowe TG, Lenke L, Betz R, Newton P, Clements D, Haher T, Crawford A, Letko L, Wilson LA: Distal junctional kyphosis of adolescent idiopathic thoracic curves following anterior or posterior instrumented fusion: Incidence, risk factors, and prevention. Spine 31:299-302, 2006. https://doi.org/10.1097/01.brs.0000197221.23109.fc.
14. Marciano GF, Simhon ME, Lehman RA, Lenke LG: Strategies to avoid distal junctional pathology. Neurosurg Clin N Am 34:585-597, 2023. https://doi.org/10.1016/j.nec.2023.06.006.
15. McDonnell JM, Ahern DP, Wagner SC, Morrissey PB, Kaye ID, Sebastian AS, Butler JS: A systematic review of risk factors associated with distal junctional failure in adult spinal deformity surgery. Clin Spine Surg 34:347-354, 2021. https://doi.org/10.1097/BSD.0000000000001224.
16. Montanari S, Griffoni C, Cristofolini L, Girolami M, Gasbarrini A, Barbanti Bròdano G: Correlation between sagittal balance and mechanical distal junctional failure in degenerative pathology of the spine: A retrospective analysis. Global Spine J 10:21925682231195954, 2023. https://doi.org/10.1177/21925682231195954.
17. Schwab FJ, Blondel B, Bess S, Hostin R, Shaffrey CI, Smith JS, Boachie-Adjei O, Burton DC, Akbarnia BA, Mundis GM, Ames CP, Kebaish K, Hart RA, Farcy JP, Lafage V; International Spine Study Group (ISSG): Radiographical spinopelvic parameters and disability in the setting of adult spinal deformity: A prospective multicenter analysis. Spine 38: E803-12, 2013. https://doi.org/10.1097/BRS.0b013e318292b7b9.
18. Tartara F, Garbossa D, Armocida D, Di Perna G, Ajello M, Marengo N, Bozzaro M, Petrone S, Giorgi PD, Schirò GR, Legrenzi S, Boeris D, Piazzolla A, Passarelli AC, Longo A, Ducati A, Penner F, Tancioni F, Bona A, Paternò G, Tassorelli C, De Icco R, Lamaida GA, Gallazzi E, Pilloni G, Colombo EV, Gaetani P, Aimar E, Zoia C, Stefini R, Rusconi A, Querenghi AM, Brembilla C, Bernucci C, Fanti A, Frati A, Manelli A, Muzii V, Sedia M, Romano A, Baram A, Figini S, Ballante E, Gioia G, Locatelli M, Pluderi M, Morselli C, Bassani R, Costa F, Cofano F: Relationship between lumbar lordosis, pelvic parameters, PI–LL mismatch and outcome after short fusion surgery for lumbar degenerative disease. Literature review, rational and presentation of public study protocol: RELApSE study (registry for evaluation of lumbar artrodesis sagittal alignEment). World Neurosurg X 18:100162, 2023. https://doi.org/10.1016/j.wnsx.2023.100162.
19. Wang Y, Li J, Xi Y, Zeng Y, Yu M, Sun Z, Ma Y, Liu Z, Chen Z, Li W: Distal junctional failures in degenerative thoracolumbar hyperkyphosis. Orthop Surg 16:830-841, 2024. https://doi.org/10.1111/os.13973.
20. Wang Y, Zhu W, Sun K, Kong C, Wang W, Lu S: Selecting proper distal fusion level in severe thoracolumbar kyphosis secondary to late osteoporotic vertebral compression fracture to limit distal complications. J Orthop Sci 27:1177-1184, 2022. https://doi.org/10.1016/j.jos.2021.07.025.
21. Wilk B, Karol LA, Johnston CE 2nd, Colby S, Haideri N: The effect of scoliosis fusion on spinal motion: A comparison of fused and nonfused patients with idiopathic scoliosis. Spine (Phila Pa 1976) 31:309-314, 2006. https://doi.org/10.1097/01.brs.0000197168.11815.ec.