

28. Is There a Cervical Alignment Threshold Warranting Cervical Inclusion in the Construct of Thoracolumbar ASD Patients?

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Hypothesis

Thoracolumbar (TL) adult spinal deformity (ASD) patients with poor preop cervical spine (CS) alignment have increased postop CS decompensation (D)

Design

Retrospective analysis of prospectively collected data

Introduction

Postop TL realignment in ASD patients may induce CS D. This study identifies CS D predictors after TL surgery and defines a BL CS alignment (C2PA) threshold for CS inclusion in the TL construct

Methods

ASD patients undergoing TL fusion to the sacrum with UIV at T2 or below and available BL and 2Y radiographs and PROMs were included. CS D was defined as CS surgery or >2SD above the mean in C2PA, cSVA, or TSCL at the studied postop timepoint. Radiographic parameters and PROMs were compared between D and non-D patients. Kaplan Meier (KM) analysis assessed BL C2PA impact on time to CS D. Cox regression identified predictors of CS D and BL C2PA thresholds, adjusting for preop CS and TL alignment (C2PA, TS-CL, PI-LL), prior CS surgery, age, sex, BMI, frailty, comorbidities, surgical invasiveness (SI), and UIV above vs below T8 (UT)

Results

Of 1,190 patients, 166 (13.9%) had CS D after TL surgery, including 24 (2.0%) requiring CS extension. CS D was identified in 81 patients (6.8%) at 6 weeks (4 (0.3%) extensions), 13 (1.2%) at 6 months (2 (0.2%)), 43 (3.9%) at 1Y (7 (0.6%)), and 29 (2.8%) at 2Y (11 (0.9%)). BL variables differed between patients with and without CS D and between those with and without CS extension (Fig1A). Patients with CS D at 6 months showed worse global and CS alignment at 6 weeks (LL: 53.6 vs 46.3; cSVA: 30.5 vs 38.5; $p < 0.05$). CS D at 1 year was associated with worse PROMs at 1 year (PCS: 39.0 vs 35.4; SRS: 3.6 vs 3.3; $p < 0.05$). CS D at 2 years was associated with worse CS alignment at 1 year (TS-CL: 20.8 vs 28.6; cSVA: 31.1 vs 37.8) and worse PROMs at 2 years (ODI, PCS, SRS; $p < 0.05$). KM analysis showed higher BL C2PA was associated with shorter time to CS D (Fig1B). Cox modeling identified BL C2PA (HR 1.05, 95% CI 1.03–1.06), TSCL (HR 1.05, 95% CI 1.03–1.06), SI (HR 0.99, 95% CI 0.98–0.99), and UT (HR 2.9, 95% CI 1.8–4.7) as predictors of CS D, with a C2PA threshold of 26.2° (Fig1C)

Conclusion

2Y after TL ASD surgery, 13.9% had CS D, with 14% requiring CS extension. After adjustment for patient factors and global alignment, BL CS alignment independently predicted CS D. Patients with preoperative C2PA >26.2° may benefit from CS inclusion in the TL construct

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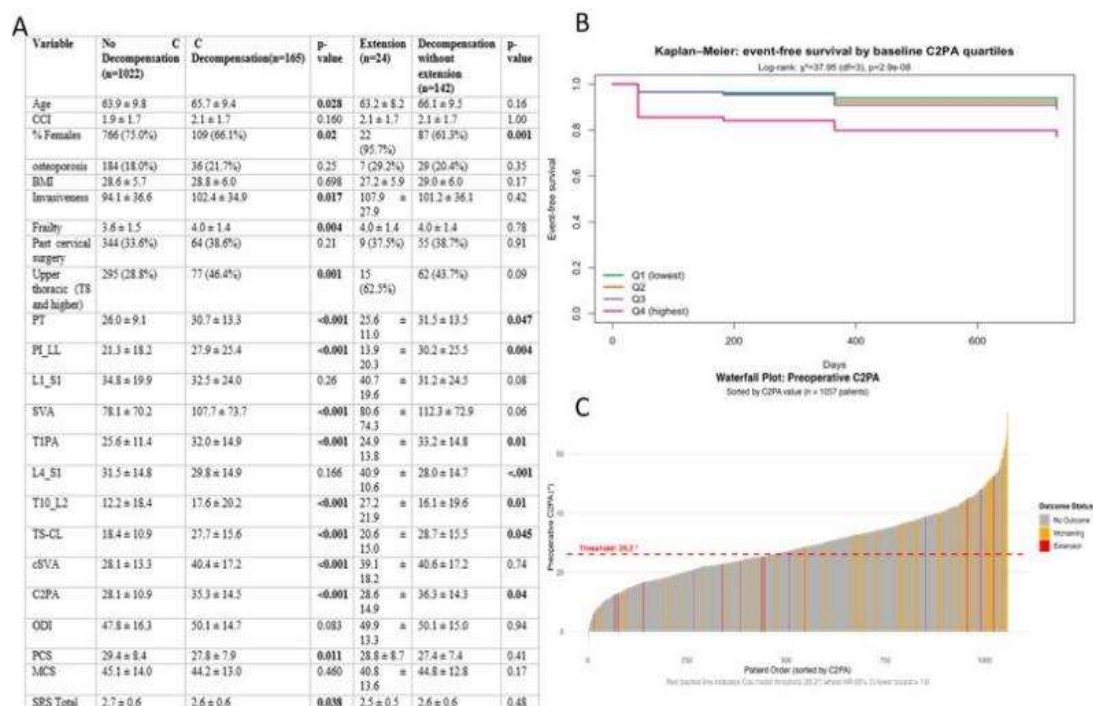


Figure legend: **(A):** Table showing the differences between patients with and without a cervical spine decompression and patients with both a decompression and extension to the cervical spine and patients with only decompression. **(B):** Kaplan-Meier curve showing how baseline C2PA affects time to cervical spine decompression. **(C):** Waterfall plot reporting a threshold for baseline C2PA above which patients undergoing TL surgery are more prone to cervical spine decompression while controlling for pre-operative CS and TL alignment (C2PA, TS-CL, PI-LL), previous CS surgery, age, gender, BMI, frailty, comorbidities, invasiveness, and whether or not patients had a UIV above or below T8.

29. Does Proximal Thoracic Rod Contour Influence PJK Risk in Adult Spinal Deformity?

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Hypothesis

A kyphotic proximal thoracic rod contour between upper instrumented vertebra and L1 (UIV–L1) reduces the risk of proximal junctional kyphosis/failure (PJK/F) in adult spinal deformity (ASD) patients.

Design

Retrospective Cohort

Introduction

In lower thoracic to pelvis fusions, we evaluated whether UIV–L1 rod contour was associated with PJK/F.

Methods

A retrospective cohort study (2009–23) was conducted of ASD surgery patients with lower thoracic UIV (T9–T12) and ≥ 2 -year follow-up. Primary exposure was postoperative UIV–L1 rod contour, assessed by drawing a straight reference line connecting the points on the rod corresponding to the midpoint of the UIV and L1. Alignment of the rod with this reference line was classified as neutral, whereas anterior and posterior deviations from the line were classified as lordotic and kyphotic, respectively (Figure 1). The primary outcome was PJK/F, defined as UIV/UIV+2 angle $\geq 10^\circ$ and $\geq 10^\circ$ change from the preoperative measurement. Secondary outcomes were reoperation for mechanical complications and other mechanical complications (rod fracture, pseudarthrosis, implant failure). Sub analysis was performed in patients with high and low pelvic incidence (PI), binarized at 50° .

Results

Among 90 patients (age 69 ± 11 years, 72% female), the UIV distribution was: T9 18%, T10 51%, T11 19%, T12 12%. Postoperatively, 37% patients had a kyphotic rod contour while 63% had a neutral contour. There was no significant difference in the rate of PJK/F between patients with kyphotic or neutral rod (39% vs. 37%, $p=0.810$). Similar non-significant differences were seen for reoperation for mechanical complications (24% vs. 23%, $p=0.877$) or other mechanical complications (30% vs. 28%, $p=0.822$). Patients with a kyphotic rod trended toward a higher proximal junctional angle ($25 \pm 10^\circ$ vs. $20 \pm 10^\circ$, $p=0.371$) at last clinical follow-up. Specifically, among low PI patients, PJK/F rates were higher in those with a kyphotic rod (67% vs. 31%, $p=0.073$).

Conclusion

In ASD patients undergoing lower thoracic to pelvis fusions, postoperative UIV–L1 rod contour was not associated with the risk of PJK/F or other mechanical complications. Specifically, a kyphotic rod contour at the proximal thoracic segment did not confer a protective effect compared with a neutral contour. Proximal rod contour alone may be insufficient to mitigate PJK/F risk, and other aspects of proximal alignment likely play a more dominant role.

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	Neutral	Kyphotic	P-value
All Patients			
PJK/F	36.8%	39.4%	0.810
Reoperation for Mechanical Complications	22.8%	24.2%	0.877
Rod Fracture, Pseudarthrosis, Implant Failure	28.1%	30.3%	0.822
High Pelvic Incidence			
PJK/F	48.0%	25.0%	0.141
Reoperation for Mechanical Complications	20.0%	25.0%	0.717
Rod Fracture, Pseudarthrosis, Implant Failure	32.0%	43.8%	0.445
Low Pelvic Incidence			
PJK/F	30.8%	66.7%	0.073
Reoperation for Mechanical Complications	15.4%	25.0%	0.645
Rod Fracture, Pseudarthrosis, Implant Failure	23.1%	16.7%	0.260



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30. The Gradual Decay of the Proximal Junctional Angle following Thoracolumbar fusion of Adult Spine Deformity

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Hypothesis

The natural history of the proximal junction is one of gradual kyphosis, with a discernable annual average change.

Design

Retrospective cohort study

Introduction

Proximal junctional kyphosis (PJK) is a common complication after adult spinal deformity surgery, in many cases necessitating revision surgery. No studies have examined change in alignment of the proximal junction over time among patients who do not ultimately undergo revision surgery.

Methods

This study utilized a multi-center database of patients undergoing adult spinal deformity surgery. Inclusion criteria were those eligible for minimum 2-year follow-up, undergoing long-segment (i.e., >5 levels) instrumented arthrodesis with LIV at the sacropelvis.

Results

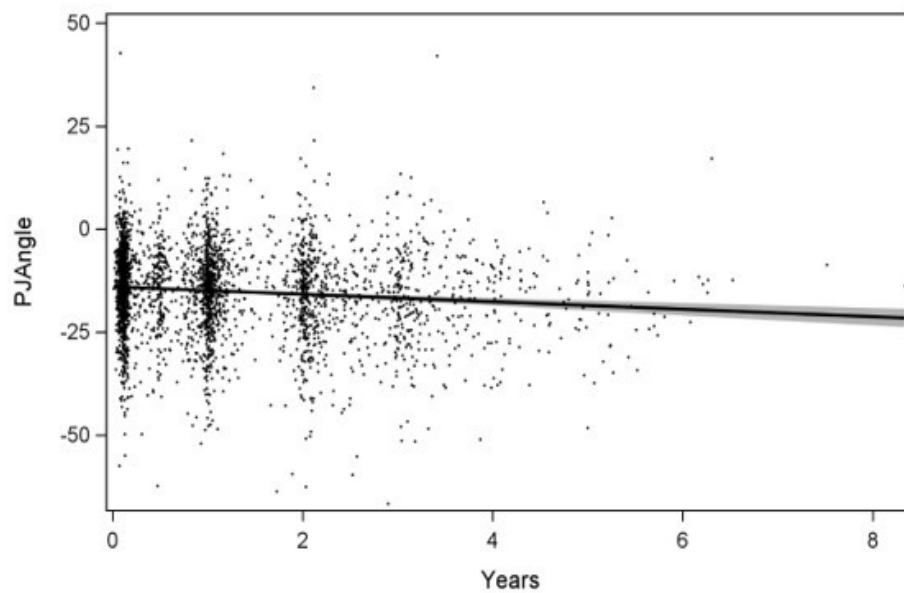
In total, 1,076 patients were included (mean age at surgery 64.0, SD 9.5; 74.3% female). The mean immediate post-operative proximal angle was 14.0 degrees kyphotic (SD 10.0). A total of 3,081 follow-up visits were recorded, with 17.9% (n=193) of patients with greater than 5-year terminal follow-up. Among all patients, PJK increased by 0.9 degrees annually ($p<0.0001$). This trend persisted upon multiple iterations of sub-analysis, including only patients who did not undergo revision surgery (1.0 degrees annually, $p<0.0001$), only patients with >5-year follow-up (0.8 degrees annually, $p=0.0030$), and patients meeting both criteria (0.9 degrees annually, $p=0.0009$). Importantly, the majority of patients tended to exhibit more PJK at each subsequent follow-up – 54.6% of patients had greater PJK at 6 months post-operatively than at 6 weeks post-operatively, 51.1% at 1 year vs. 6 months, 61.0% at 2 years vs. 1 year, and 61.1% at 3 years vs. 1 year.

Conclusion

In this study of adult spinal deformity patients undergoing long-segment instrumented fusion to the sacropelvis, the fate of the proximal junction was one of gradual kyphosis, at a rate of approximately 1 degree annually. This is directionally more rapid and focal than documented annual increases in thoracic kyphosis among the general population. Patients should be counseled that, even if they do not require revision surgery, they should expect gradual proximal junctional kyphosis as time passes post-operatively.

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Figure 1: Proximal junctional angle measurements over time among all patients. Individual follow-up measurements are plotted as dots, with regression trendline indicated in black with 95% confidence interval in gray.



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‡SRS Funded Research Grant

31. Does Postoperative UIV–L1 Alignment Predict Proximal Junctional Kyphosis After Adult Spinal Deformity Surgery?

Harsh Jain, MBBS; Advith Sarikonda, BS, BA; Ranbir Ahluwalia, MD; Tyler Zeoli, MD; Iyan Younus, MD; Hani Chanbour, MD; Bayard Wilson, MD; Byron F. Stephens, MD; Scott Zuckerman, MD

Hypothesis

Insufficient kyphosis at the proximal end of a lower thoracic to pelvis fusion, measured with the upper instrumented vertebra–L1 (UIV–L1) angle, increases the risk of proximal junctional kyphosis/failure (PJK/F).

Design

Retrospective Cohort

Introduction

In adult spinal deformity (ASD) patients undergoing lower thoracic to pelvis fusions, we evaluated whether postoperative UIV–L1 Cobb angle orientation predicted PJK/F.

Methods

A retrospective cohort study (2009-23) was performed of ASD patients with lower thoracic UIV (T9-T12) (≥ 2 -year follow-up). Primary exposure was postoperative UIV-L1 sagittal Cobb angle, binarized as neutral (-3° to 3°) and non-neutral. Non-neutral group was further analyzed as kyphotic ($>3^\circ$) and lordotic ($<-3^\circ$). Primary outcome was PJK/F: UIV/UIV+2 angle $\geq 10^\circ$ and $\geq 10^\circ$ change from the preoperative measurement. Secondary outcomes were reoperation for mechanical complications and other mechanical complications. Sub-analysis was performed for high and low pelvic incidence (PI), binarized at 50° . Multivariable regression controlled for age, sex, body mass index and UIV level.

Results

Among 90 patients, (age 69 ± 11 years, 72% female), UIV distribution was: T9 18%, T10 51%, T11 19%, T12 12%. Median postoperative UIV-L1 Cobb angle was 9° (IQR: 4° - 19°), with 3% lordotic, 20% neutral, 77% kyphotic. Neutral vs. Non-Neutral: Patients with a neutral alignment had a lower rate of PJK/F (17% vs. 43%, $p=0.039$), while no association was seen with reoperation for mechanical complications (28% vs. 22%, $p=0.618$) or other mechanical complications (17% vs. 32%, $p=0.201$). A non-neutral UIV-L1 independently increased the risk of PJK/F (OR=5.4, 95%CI: 1.2-24.9, $p=0.029$). Similar trends were seen in patients with both high and low PI (Table). Kyphotic vs. Neutral vs. Lordotic: Patients with neutral alignment had the lowest rate of PJK/F, while lordotic patients had the highest (41% vs. 17% vs. 100%, $p=0.014$). No difference was seen in reoperation for mechanical complications (28% vs. 22%, $p=0.618$) or other mechanical complications (23% vs. 28% vs. 0%, $p=0.573$).

Conclusion

In lower thoracic to pelvis fusions, a neutral UIV–L1 alignment conferred lowest PJK/F rate, while deviation toward either lordosis/kyphosis significantly increased risk, with lordotic alignment demonstrating the highest risk. Achieving a neutral UIV–L1 alignment may represent a modifiable target to mitigate the risk of PJK/F.

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	Neutral	Non-Neutral	P-value
All Patients			
PJK/F	16.7%	43.1%	0.039
Reoperation for Mechanical Complications	27.8%	22.2%	0.618
Rod Fracture, Pseudarthrosis, Implant Failure	16.7%	31.9%	0.201
High Pelvic Incidence			
PJK/F	16.7%	32.4%	0.648
Reoperation for Mechanical Complications	33.3%	26.5%	1.000
Rod Fracture, Pseudarthrosis, Implant Failure	16.7%	47.1%	0.216
Low Pelvic Incidence			
PJK/F	0.0%	52.6%	0.156
Reoperation for Mechanical Complications	50.0%	20.0%	0.334
Rod Fracture, Pseudarthrosis, Implant Failure	50.0%	10.0%	0.260

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32. Development of a Novel Sagittal Segmental Phenotyping System for Mechanical Complication Risk Stratification in Degenerative Lumbar Scoliosis Surgery

Weipeng Qiu, MD; Zhuoran Sun, MD; Weishi Li, MD

Hypothesis

We hypothesize that integrating segmental inclination and curvature into degenerative lumbar scoliosis (DLS) sagittal evaluation may optimize current classification systems, and improve the prevention of mechanical complications following surgery.

Design

A retrospective cohort study.

Introduction

Sagittal alignment critically influences the management of degenerative lumbar scoliosis (DLS). As the concept of precision assessment evolves, ideal sagittal reconstruction has become increasingly refined, requiring attention not only to regional curvature and global balance but also to harmonious segmental distribution.

Methods

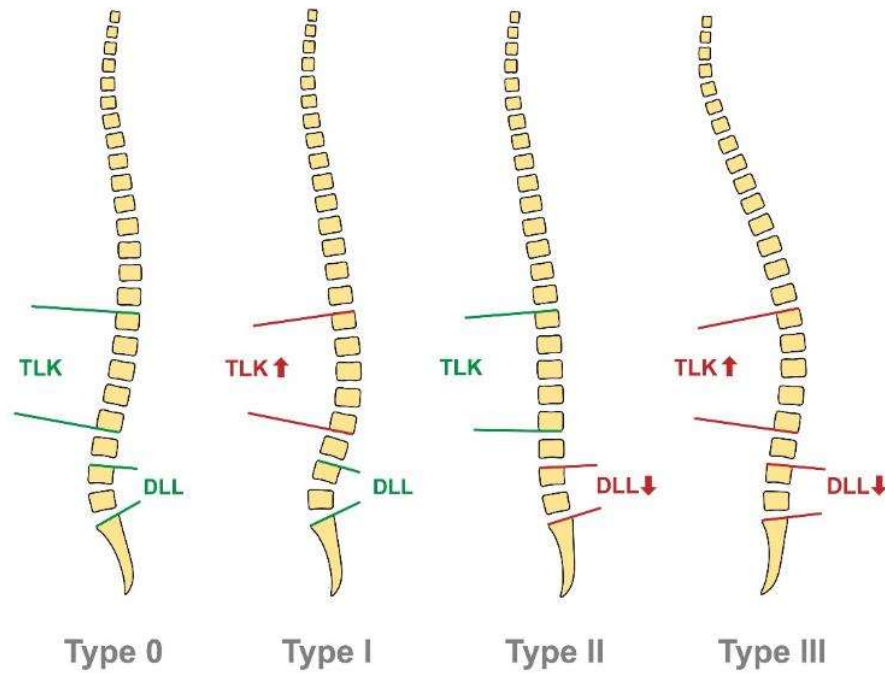
A total of 151 DLS patients undergoing posterior long-segment fusion from January 2010 to December 2022 with a minimum 2-year follow-up were included. Full-spine radiographs were obtained preoperatively, postoperatively, and at final follow-up. In addition to conventional sagittal parameters, two novel segmental inclination parameters were introduced: thoracic tilt (TT) and lumbar tilt (LT). Postoperative mechanical complications were recorded, and patient-reported outcomes were also assessed.

Results

A segmental sagittal phenotype based on distal lumbar lordosis (DLL) and thoracolumbar kyphosis (TLK) was defined as follows: Type 0 (normal): DLL $>30^\circ$, TLK $<20^\circ$; Type I (thoracolumbar kyphosis): DLL $>30^\circ$, TLK $>20^\circ$; Type II (loss of distal lordosis): DLL $<30^\circ$, TLK $<20^\circ$; Type III (global kyphosis): DLL $<30^\circ$, TLK $>20^\circ$. Significantly negative LT and positive TT were observed in Types I and III, whereas Type II showed markedly positive LT. The incidence of mechanical complications differed significantly across phenotypes: lowest in Type 0 (12.9%) and highest in Type III (65.0%). Multivariate regression identified the sagittal phenotype as an independent predictor of mechanical complications, with Type I (OR=6.073, $P=0.007$), Type II (OR=3.755, $P=0.027$), and Type III (OR=13.769, $P<0.001$) carrying significantly increased risk compared to Type 0.

Conclusion

The proposed DLL-TLK-based sagittal segmental phenotype effectively discriminates distinct sagittal profiles in DLS. This novel classification reliably predicts postoperative mechanical complications and can inform personalized strategies for sagittal alignment reconstruction.



Schema of the DLL-TLK-based sagittal segmental phenotype

33. Lumbar Alignment Transitions: The Relationship of Lumbar Lordosis Distribution with Proximal Junctional Kyphosis and Pseudoarthrosis

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Hypothesis

Distribution of lumbar lordosis predicts rates of mechanical complication.

Design

Retrospective cohort study.

Introduction

Spinal deformity surgery requires careful restoration of sagittal alignment to optimize long-term outcomes. The distribution of lumbar lordosis, particularly across the lumbosacral transition zone, influences both proximal junctional mechanics and fusion integrity. While global lordosis targets are well established, the role of segmental lordosis remains poorly defined in predicting mechanical complications. Understanding how lower-segment lordosis mediates these opposing risks may guide surgical planning and improve outcomes in long-segment fusions.

Methods

Adult spinal deformity patients from a single tertiary-care center with ≥ 2 -year follow-up or follow-up to proximal junctional kyphosis (PJK) or pseudoarthrosis were included. Patients with both outcomes were excluded. Lower lumbar lordosis (L4–S1) and its percent share of total lumbar lordosis were calculated. Logistic regression estimated odds ratios (OR) and 95% confidence intervals per 10% increase in lower-segment lordosis for PJK and pseudoarthrosis. Predicted risks across the observed lower lordosis range were evaluated using Pareto optimization with an equal-weight weighted-sum objective to identify the lordosis distribution minimizing combined complication risk.

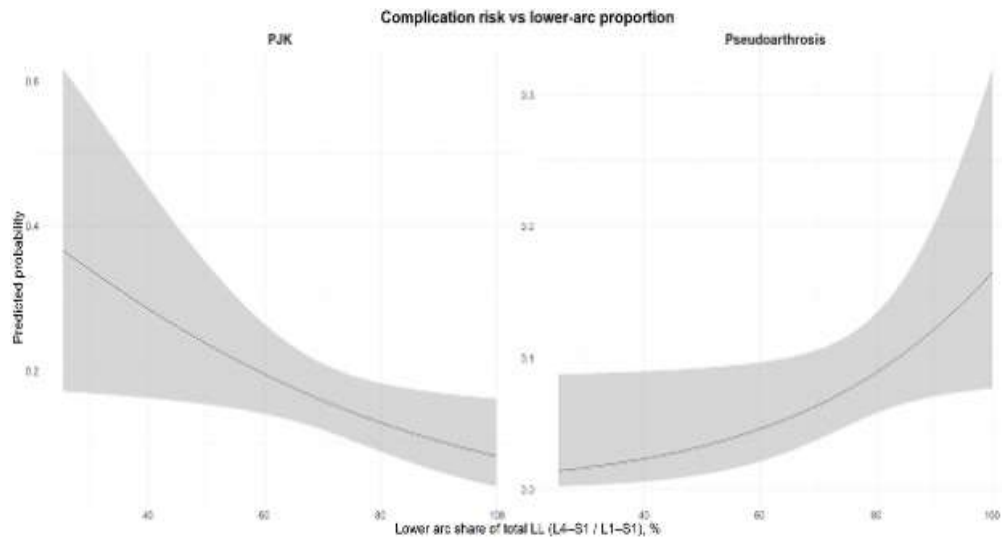
Results

Among 258 patients, pseudoarthrosis occurred in 29 (11.2%) and PJK in 52 (20.1%). Each 10% increase in lower lumbar lordosis share was associated with decreased odds of PJK (OR 0.78, 95% CI 0.62–0.97; $p=0.027$) and increased odds of pseudoarthrosis (OR 1.42, 95% CI 1.01–2.01; $p=0.046$). Pareto analysis identified an optimal lower-segment lordosis share of 79.5%, corresponding to predicted risks of 12.9% for PJK and 8.7% for pseudoarthrosis, representing the lowest combined junctional complication burden.

Conclusion

Lower lumbar lordosis percentage of total lumbar lordosis demonstrates opposing associations with junctional outcomes: greater lower-segment lordosis reduces the risk of PJK but increases the risk of pseudoarthrosis. These findings highlight the importance of balancing lower lordosis to optimize fusion integrity while minimizing junctional complications. Future studies should seek to determine optimal lower segment lordosis cutoffs to reduce risks of all junctional adverse events.

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Complication risk v lower arc proportion.

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34. Dynamic Gait-Related Sagittal Decompensation After a 10-Minute Walking Test Predicts Revision-Requiring Proximal Junctional Kyphosis

Junseok Bae, MD; SangHo Lee, MD, PhD

Hypothesis

Fatigue-related sagittal decompensation after a standardized 10-minute walking test is more strongly associated with revision-requiring proximal junctional kyphosis (PJK) and mechanical failure than static preoperative alignment parameters.

Design

Retrospective review of prospectively collected data

Introduction

In adult spinal deformity (ASD), static radiographs may not reflect functional deterioration caused by fatigue of compensatory mechanisms during daily activities. Although proximal junctional kyphosis is common after surgery, only a subset progresses to clinically significant failure requiring revision. Dynamic assessment under physiological stress may better identify patients at risk for meaningful mechanical complications.

Methods

Adult patients who underwent thoracolumbar deformity correction with sacropelvic fixation (upper instrumented vertebra $\geq$ L1) and had a minimum 24-month follow-up were reviewed. All patients underwent full-length standing lateral radiographs, followed by a standardized 10-minute walking test without rest and immediate repeat radiographs. Sagittal parameters including sagittal vertical axis (SVA), pelvic tilt, lumbar lordosis, PI–LL mismatch, thoracic kyphosis, and T1 pelvic angle were measured before and after walking. Outcomes included radiographic PJK, revision surgery for symptomatic PJK, and mechanical failure such as screw pull-out, vertebral fracture, or rod failure. Associations between dynamic sagittal changes and outcomes were analyzed.

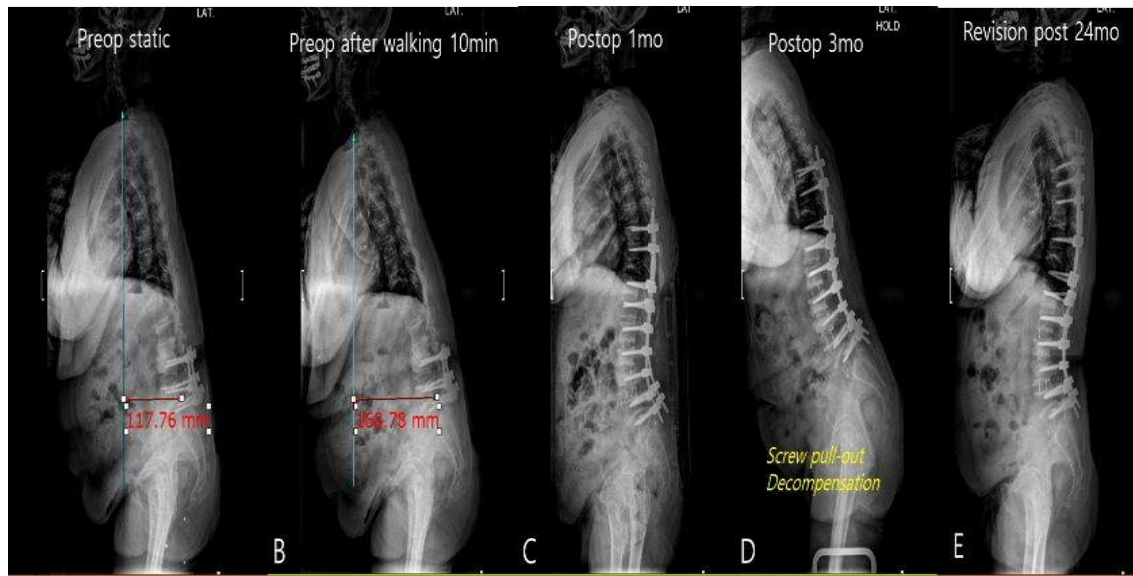
Results

Radiographic PJK developed in 16% of patients, with half requiring revision surgery. Mechanical failure occurred in a separate subset, all of whom underwent revision surgery. Mean SVA increased significantly after walking compared with pre-walk measurements. Post-walk SVA correlated significantly with revision surgery for PJK and mechanical failure, whereas static preoperative SVA and PI–LL mismatch showed weaker associations. Dynamic sagittal deterioration after walking was not associated with radiographic PJK alone but was strongly associated with revision-requiring PJK.

Conclusion

Fatigue-related sagittal decompensation following a 10-minute walking test predicts revision-requiring PJK and mechanical failure after ASD surgery. Dynamic functional assessment under physiological stress may improve risk stratification beyond static alignment parameters.

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35. Predicting Proximal Junctional Kyphosis in Adult Spinal Deformity Surgery in the Early Postoperative Period with High Accuracy Using a Machine Learning-Based Scoring Model

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Hypothesis

A machine learning (ML)-derived scoring model can accurately detect proximal junctional kyphosis (PJK) in the early postoperative period.

Design

Retrospective Review

Introduction

Early detection of PJK is critical for risk stratification and postoperative management following adult spinal deformity. However, no clinically practical and validated tool currently exists for early postoperative risk assessment.

Methods

530 adult spinal deformity (ASD) patients undergoing surgery with ≥ 4 instrumented levels from a single-institution, multi-surgeon cohort were reviewed, all with ≥ 2 -year follow-up. Over 100 clinical variables were analyzed. A stepwise machine learning (ML) framework incorporating random forest modeling, Boruta feature selection, and multivariate logistic regression was used to develop a scoring model for early detection of symptomatic PJK (proximal junctional angle (PJA) $\geq 10^\circ$ and $\Delta PJA \geq 10^\circ$ with pain at the proximal junction during time of diagnosis). Features selected by Boruta were thresholded by random forest and weighted based on logistic regression beta coefficients. The cohort was randomly split into training (50%) and testing (50%) sets. Model performance was evaluated using accuracy, sensitivity, specificity, and area under the receiver operating characteristic curve (AUC).

Results

4.7% of patients (n=25) progressed to symptomatic PJK. The model included seven features: pain at/near the upper instrumented vertebrae (UIV) at the first postop visit (score=3); lower thoracic (T7-T12) UIV (score=2); upper thoracic (T1-T6) UIV; BMI <20 , osteopenia/osteoporosis; fixation to pelvis/sacrum; and $\Delta PJA \geq 5^\circ$ from preop to first postop visit (each score=1). On the test cohort, the model achieved an accuracy of 91.3%, sensitivity of 85.7%, specificity of 91.6%, and AUC of 0.93. Higher cumulative scores were associated with increased rates of PJK. Patients were stratified into low (0–4), moderate (5–6), and high (7–9) risk groups, with corresponding PJK rates of 0.2%, 14.0%, and 53.8%, respectively.

Conclusion

This ML-derived scoring model enables highly accurate early postoperative detection of symptomatic PJK following ASD surgery. By integrating modifiable preoperative risk factors, surgical characteristics, and early postoperative clinical and radiographic changes, the model provides a practical tool for early risk stratification.

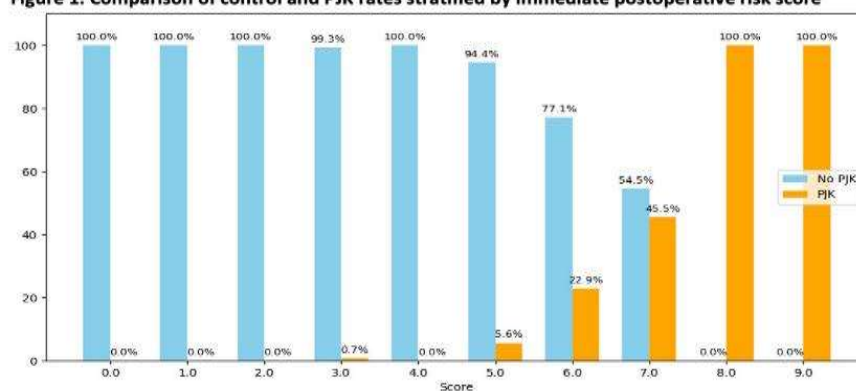
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Table 1. Selected features and corresponding scores for immediate postoperative scoring system

Variable	Score
Pain/Symptoms Near UIV	3
UIV Lower Thoracic (T7-T12)	2
UIV Upper Thoracic (T1-T6)	1
BMI < 20	1
Osteopenia/Osteoporosis	1
Fixation to Pelvis/Sacrum	1
Δ PJA > 5°	1

Table 2. PJK rates in cohort stratified by immediate postoperative risk score

	Cumulative Score	PJK (n)	No PJK (n)	Rate
Low Risk	0	0	7	0%
	1	0	80	0%
	2	0	145	0%
	3	1	133	0.7%
	4	0	67	0%
Moderate Risk	5	2	34	5.6%
	6	8	27	22.9%
High Risk	7	10	12	45.5%
	8	3	0	100%
	9	1	0	100%

Figure 1. Comparison of control and PJK rates stratified by immediate postoperative risk score

36. Do Supplementary Rod Constructs Influence the Rate of Proximal Junctional Kyphosis? A

Multicenter Study

Ahmed Sulieman, MD; Tej Azad, MD; Harsh Jain, MBBS; Advith Sarikonda, BS, BA; Virginie Lafage, PhD; Renaud Lafage, MS; Breton Line; Richard Hostin, MD; Peter G. Passias, MD; Bassel G. Diebo, MD; Eric O. Klineberg, MD; Jeffrey Gum, MD; Michael P. Kelly, MD; Han Jo Kim, MD; Robert K. Eastlack, MD; Alan H. Daniels, MD; Gregory M. Mundis Jr, MD; Themistocles S. Protopsaltis, MD; Kojo D. Hamilton, MD, FAANS; Justin S. Smith, MD, PhD; Munish C. Gupta, MD, MBA; Frank Schwab, MD; Christopher I. Shaffrey, MD; Stephen J. Lewis, MD, FRCS(C); Christopher P. Ames, MD; Lawrence G. Lenke, MD; Shay Bess, MD; Sang Hun Lee, MD, PhD; Byron F. Stephens, MD; Scott Zuckerman, MD; *Khaled M. Kebaish, MD*; International Spine Study Group

Hypothesis

Supplementary rod constructs are associated with increased proximal junctional pathology due to increased construct stiffness

Design

Retrospective analysis of prospective multi-center adult spine deformity (ASD) database

Introduction

Supplemental rod constructs are frequently used in ASD surgery to reduce rod-related mechanical complications. However, their effect on proximal junctional kyphosis (PJK) and junctional alignment remains unclear

Methods

ASD patients undergoing fusion from T8–T11 to the pelvis with ≥ 2 -year follow-up were included. Patients were grouped into dual-rod constructs and supplemental-rod constructs (supplemental rod with distal fixation at S1 or below). Primary outcome was PJK; secondary outcomes were 2-year proximal junctional angle (PJA) and mechanical complications. Multivariable regression models evaluated associations adjusting for age, osteoporosis, postoperative T1 Pelvic Angle (PA) and T4PA–L1PA mismatch

Results

A total of 284 patients were analyzed (dual-rod $n=219$, supplemental-rod $n=65$). 60% ($n=39$) had a 3-rod construct, and 40% ($n=26$) had a 4-rod construct. Demographics were comparable between the groups. The supplemental rod group had a higher rate of three column osteotomies (25% vs 12%, $p=0.01$) but similar number of levels fused. Both groups had similar baseline and postoperative radiographic measurements with exception of the PJA which was higher in the supplemental rod group at 6 weeks (14.8 vs 17.6, $p=0.03$) and 2 years postoperatively (16.8 vs 20.1, $p=0.03$). Rod fractures and revisions were significantly higher in the dual rod group compared to the supplemental rod group (17% vs 6%, 27% vs 14% respectively, both $p=0.03$). PJK rate was similar between constructs (54.8% vs. 52.3%, $p=0.72$) and supplemental rods were not associated with PJK on multivariate analysis (OR 0.87, $p=0.8$). With respect to the PJA, 4-rod constructs had greater 2-year PJA compared to dual-rod constructs ($\beta -4.7$, $p=0.03$).

Conclusion

In long fusions from the lower thoracic spine to the pelvis, supplemental rods were associated with a lower rate of rod fractures and revision surgeries without an increased rate of PJK/F. Supplemental rod constructs may modestly increase the proximal junctional angle at 2 years postoperatively

§ Hibbs Award Nominee – Best Clinical Paper, † Hibbs Award Nominee – Best Basic Science/Translational Science Paper, ‡SRS Funded Research Grant

Table 1: Complication rates between the dual rod constructs cohort and the supplementary rods constructs cohort.

Complications	Double Rod (n=219)	Supplementary Rod (n=65)	P value
Revision Surgery	59 (26.94%)	9 (13.85%)	0.03
Rod Fracture	37 (16.89%)	4 (6.15%)	0.028
Rod dislodgement	1 (0.46%)	0 (0.00%)	>0.99
Adjacent segment disease	8 (3.65%)	3 (4.62%)	0.718
PJK	120 (54.79%)	34 (52.31%)	0.724
Pseudoarthrosis	7 (3.20%)	1 (1.54%)	0.687
Reoperation for rod fracture	14 (6.39%)	1 (1.54%)	0.204
Reoperation for rod dislodgement	1 (0.46%)	0 (0.00%)	>0.99
Reoperation for adjacent segment disease	3 (1.37%)	1 (1.54%)	>0.99
Reoperation for PJK	24 (10.96%)	6 (9.23%)	0.691
Reoperation for Pseudoarthrosis	7 (3.20%)	0 (0.00%)	0.357

Values represent n (%). PJK: Proximal Junctional Kyphosis.

Table 2: Multivariate logistic regression comparing proximal junctional kyphosis between 3-rods & 4-rods constructs to dual rod constructs. Multivariate linear regression comparing 2-year proximal junctional angle comparing 3-rods & 4-rods constructs to dual rod constructs.

PJK	OR	95% CI	P value	2 Year PJA	Coefficient	95% CI	P value
3 Rods	0.6208	0.1654 to 2.3291	0.48	3 Rods	-0.9533	-4.4640 to 2.5573	0.593
4 Rods	1.228	0.3599 to 4.1903	0.743	4 Rods	-4.7426	-8.9139 to -0.5713	0.026
Age	1.0117	0.9578 to 1.0685	0.678	Age	-0.1601	-0.3004 to -0.0198	0.025
Osteoporosis	1.1531	0.4179 to 3.1822	0.783	Osteoporosis	3.8976	0.7099 to 7.0853	0.017
Postoperative T1PA	0.9668	0.9109 to 1.0261	0.266	Postoperative T4PA-L1PA mismatch	-0.7493	-1.0931 to -0.4054	<0.001
Postoperative T4PA-L1PA mismatch	1.3079	1.1401 to 1.5004	<0.001	Postoperative T1PA	0.1032	-0.0593 to 0.2657	0.212

PJK: Proximal Junctional Kyphosis; PJA: Proximal Junctional Angle; T1PA: T1 Pelvic Angle; T4PA: T4 Pelvic Angle; L1PA: L1 Pelvic Angle

37. The Breakdown on Breakage: Why Pre-bent Rods Outperform Manual Contouring in ASD

Surgery

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Hypothesis

Pre-bent (PB) rod constructs in long-segment posterior spinal fusions (PSF) will have lower rates of hardware complications and greater construct complexity than manually bent (MB).

Design

Retrospective single-center cohort study comparing pre-bent and manually bent long fusions constructs in ASD patients.

Introduction

Optimal surgical outcomes in Adult Spinal Deformity (ASD) surgery are heavily contingent upon structural integrity and configuration of the spinal construct. The specific makeup of the construct—rod number, diameter, contouring method—is crucial in determining the distribution of mechanical loads and the subsequent risk of hardware failure and complications.

Methods

357 patients (192 PB, 165 MB) undergoing PSF for ASD (≥ 4 levels) were included. Radiographic and clinical variables included: rod fracture (RF), proximal junctional kyphosis (PJK), use of accessory bridging rods, and reoperation rates. These were assessed via radiographs and chart review. Satellite rods were defined as independent rods secured by pedicle screws without side-to-side connectors; accessory rods used connectors to the main rod without independent screw fixation.

Results

PB patients utilized more robust constructs, including 4-5 rod configurations (52.6% vs. 21.2%, $p < .001$) and 3-4 pelvic screw fixations (44.2% vs. 9.7%, $p < .001$). PB constructs more frequently employed S2-alar-iliac (S2AI) screws (59.4% vs. 23.0%, $p < .001$) and titanium rods (43.2% vs. 32.7%, $p = .042$), whereas MB constructs relied more on iliac screws (77.0% vs. 45.3%, $p < .001$). PB had a larger proportion of greater than 2 rods crossing over the thoracolumbar, lumbosacral junctions, and osteotomy sites ($p < .001$). Despite PB cases having higher surgical complexity—including more Ponte osteotomies (66.1% vs. 51.5%, $p = .005$) and corpectomies (4.2% vs. 0.6%, $p = .001$)—the rate of RF was significantly lower in the PB group (8.3% vs. 21.8%, $p < .001$) with breakages most commonly at L1-L2 and L2-L3. Rod loosening, screw fracture, and screw loosening rates were not significantly different amongst groups. Rates of pseudoarthrosis, ASD, PJK, and revisions were comparable.

Conclusion

By facilitating multi-rod configurations and reinforcing high-stress junctions, pre-bent systems offer superior mechanical stability. Notably, this increased construct rigidity reduces hardware failure without a concomitant increase in PJK, pseudarthrosis, or overall revision rates.

§ Hibbs Award Nominee – Best Clinical Paper, † Hibbs Award Nominee – Best Basic Science/Translational Science Paper,
‡SRS Funded Research Grant

38. The Over-Widening Phenomenon as a Risk Factor for Rod Fracture after Deformity Corrective Surgery using Anterior Column Realignment in Patients with Degenerative Sagittal Imbalance

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Hypothesis

Suboptimal lordosis distribution index (LDI) causes over-widening phenomenon (OWP), which is a significant risk factor for rod fracture (RF).

Design

A retrospective cohort study

Introduction

RF is one of the most common postoperative mechanical complications (MCs) after long-segment fusion using ACR in deformity corrective surgery for patients with DSI, yet the relationship between cage–endplate mismatch—referred to as the OWP—and RF has not been clarified. Therefore, this study aimed to demonstrate OWP as a potential risk factor for RF in patients with DSI undergoing deformity corrective surgery using ACR.

Methods

A total of 199 patients diagnosed with DSI who underwent deformity corrective surgery using ACR at a single institution between March 2020 and December 2023 were retrospectively analyzed. Finally, 35 patients with OWP (Group I) and 63 patients without OWP (Group II) were enrolled and compared. OWP was defined on immediate postoperative lateral radiographs as incomplete contact between the upper or lower cage endplate and the adjacent vertebral endplate (Figure 1). Demographic data, radiographic sagittal spinopelvic parameters, and perioperative factors were compared and analyzed. Multivariable logistic regression analyses were performed to identify risk factors for RF.

Results

The incidence of RF [Group I, 23/35 (65.7%) vs Group II, 24/63 (38.1%), $p=0.032$] and subsequent revision surgery [Group I, 13/23 (56.5%) vs Group II, 3/24 (14.3%), $p=0.019$] was significantly higher in Group I than in Group II. In Group I, the concordance rate between the level of OWP and the level of RF was 73.9%. Postoperative L4-S1 lordosis and changes in L4-S1 lordosis from pre- to postoperative were significantly greater in Group II than in Group I. Postoperative lordosis distribution index (LDI) was significantly lower in Group I (43.5%) than in Group II (57.7%) and was below the ideal range of 50-80%. On multivariable logistic regression, OWP was independently associated with RF as a risk factor (odds ratio 1.097, 95% confidence interval 1.011-1.189, $p=0.028$).

Conclusion

Suboptimal postoperative LDI was associated with OWP, and OWP, in turn, was a significant risk factor for RF.

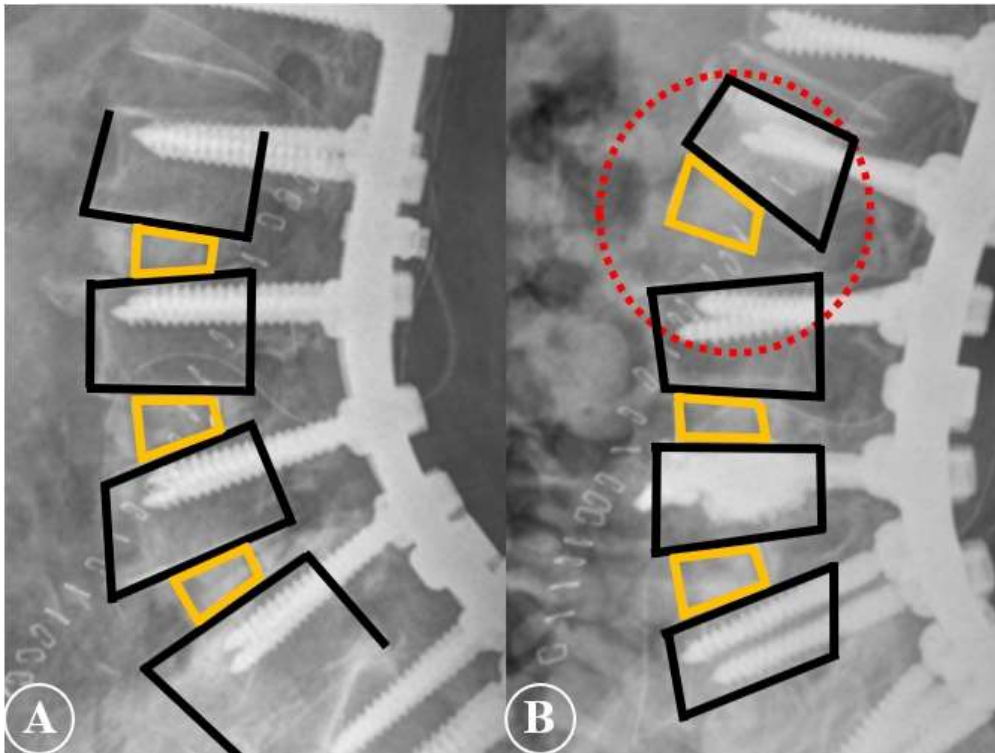


Figure 1. Unlike proper cage insertion (A) after the ACR procedure, OWP (B) results in a mismatch between the cage and the adjacent vertebral endplate.

39. Rod Fractures After Adult Spinal Deformity Surgery: What Happens After 2-years?

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Hypothesis

Rod fractures (RF) after adult spinal deformity (ASD) surgery occur frequently beyond 2 years and can be associated with neurological deficits and reoperation.

Design

Retrospective Cohort Study

Introduction

In patients with ≥ 5 -year follow-up after ASD surgery, we sought to report: 1) incidence and timing of RF at 2-years and 2-5 years, and 2) associated clinical/surgical consequences.

Methods

A retrospective cohort study evaluated patients undergoing ASD surgery (2009-23) with ≥ 5 -level fusion, sagittal/coronal deformity, and ≥ 5 -year follow-up. Primary outcome was incidence of RF postoperatively. RF were described regarding timing, rod characteristics, location, unilateral/bilateral involvement, rod displacement, neurological deficits, and need for reoperation. Descriptive statistics were reported.

Results

Of 227 patients (mean age 63.8 ± 17.2 years; 24.2% male), 67 (29.5%) experienced RF: 9/67 (13.4%) had ≥ 2 RFs, 7 (10.5%) had repeat RFs after reoperation, and 2 (3.0%) had multiple recurrent RFs. A total of 92 RFs occurred in 67 patients: 1-year 25 (27.2%), 2-years 49 (53.3%), 3-years 62 (67.4%), 4-years 68 (73.9%), 5-years 78 (84.8%), >5 -years 14 (15.2%). Most patients had 1 reoperation (43.3%), 12 (17.9%) had 2, and 1 (1.5%) each had 3 and 5 reoperations, all for RF/pseudarthrosis. Median time to first RF was 1.4 years (IQR 0.8–2.7). RF most frequently occurred at L3/4 (29.9%), L5/S1 (28.4%), and L4/5 (25.4%), with fewer events at L2/3 (10.5%), thoracic levels (6.0%), L1/2 (1.5%), and cervical levels (1.5%). Initial RF was unilateral in 74.6% and bilateral in 25.4%, and rod displacement occurred in 23.9%. New neurological deficits occurred in 8 (11.9%), due to kyphosis (50.0%), severe pain (25.0%), misplaced screw (12.5%), or pseudarthrosis (12.5%). Reoperation was required in 39 (58.2%), median 119 days from RF diagnosis (IQR 66–302).

Conclusion

Rod fractures are a common long-term complication after ASD surgery, affecting $\sim 30\%$ of patients over the 3 to ≥ 5 year period. Of these, 47% occurred after 2 years and 15% after 5 years. Most occurred in the lower thoracic/lumbar spine within the first 3 years and were usually unilateral. Neurological deficits occurred in 12%, mostly from kyphosis, and over half required reoperation. These results underscore the need for long-term monitoring of ASD patients and to follow rod fractures closely.

§ Hibbs Award Nominee – Best Clinical Paper, † Hibbs Award Nominee – Best Basic Science/Translational Science Paper, ‡SRS Funded Research Grant

40. Rethinking ASD in 3D: How Scoliosis Correction Interacts with Sagittal Alignment and PJK

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Hypothesis

Scoliosis correction is associated with sagittal alignment changes and increased proximal junctional kyphosis (PJK) risk

Design

Retrospective analysis of a prospective multicenter adult spine deformity (ASD) database

Introduction

Some ASD patients are sagittally balanced yet exhibit substantial coronal deformity. The degree of scoliosis correction may influence sagittal alignment and PJK risk, but these relationships are not well defined

Methods

Patients were included if they had a scoliotic curve $\geq 30^\circ$, T1 Pelvic Angle (PA) $< 30^\circ$, sagittal vertical axis (SVA) < 4 cm, and underwent fusion to the pelvis with upper instrumented vertebra (UIV) in the upper thoracic (UT; T2–T5) or lower thoracic (LT; T8–T11) spine, with ≥ 2 -year follow-up. Correlations were assessed between baseline scoliosis and scoliosis correction with postoperative sagittal parameters. PJK risk was evaluated using a generalized additive logistic regression model with a smooth term for scoliosis correction, adjusting for age, osteoporosis, postoperative T1PA and T4PA–L1PA mismatch

Results

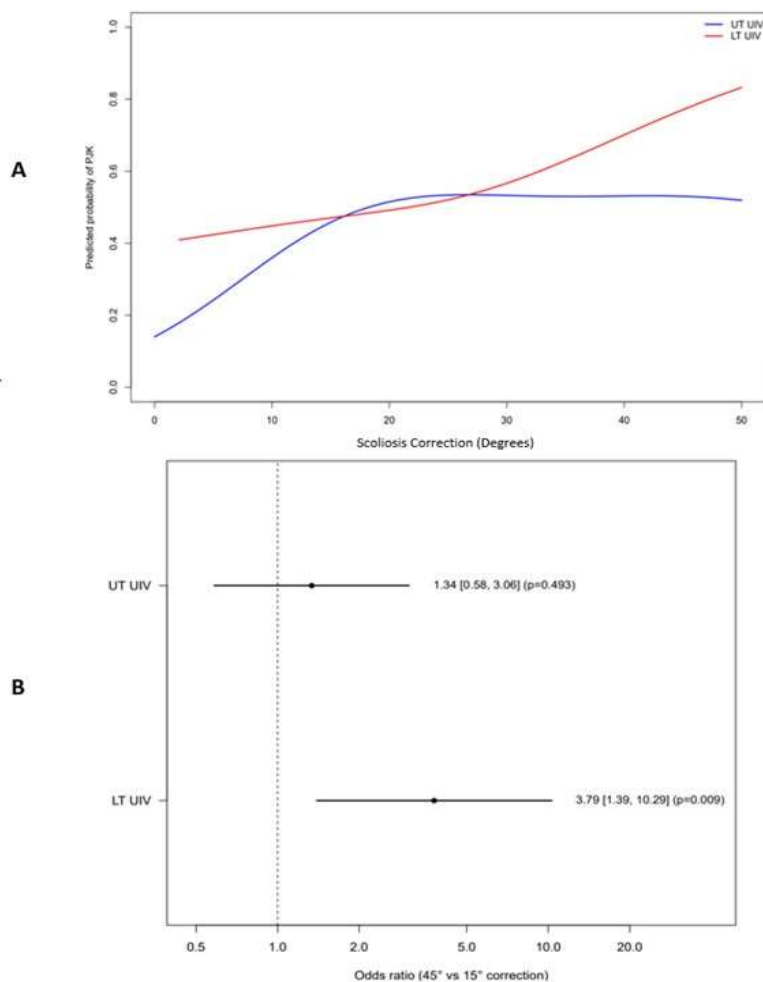
183 patients were included. At baseline, median scoliotic curve was 52° , median SVA was 1 cm and median T1PA was 15° . UT UIV was used in 89 patients (49%) and LT UIV in 94 (51%) patients. Most LT patients had lumbar curves (71%) versus 31% in UT, while UT patients were predominantly double thoracic lumbar curves (62%) versus 26% in LT. Baseline scoliosis negatively correlated with postoperative T1PA in both constructs (UT $p = -0.26$, $p = 0.02$; LT $p = -0.26$, $p = 0.02$) and SVA in UT constructs (UT $p = -0.26$, $p = 0.02$; LT $p = -0.03$, $p = 0.79$). Likewise, scoliosis correction negatively correlated with postoperative sagittal measures exclusively in UT constructs: T1PA (UT $p = -0.3$, $p = 0.02$; LT $p = -0.20$, $p = 0.10$) and SVA (UT $p = -0.3$, $p = 0.01$; LT $p = -0.10$, $p = 0.70$). In the adjusted model, scoliosis correction was a significant non-linear predictor of PJK in LT ($p = 0.03$) but not UT constructs ($p = 0.21$). Comparing a 45° vs 15° correction, PJK odds were higher in LT constructs (OR 3.79, $p < 0.01$) but not UT (OR 1.34, $p = 0.49$)

Conclusion

In ASD patients with primary coronal deformity, the magnitude of scoliosis correction is associated with unintended postoperative sagittal alignment changes and is associated with increased PJK risk in LT constructs. These findings support a 3D alignment strategy that calibrates scoliosis correction to UIV selection and postoperative sagittal targets to mitigate the risk of PJK

§ Hibbs Award Nominee – Best Clinical Paper, † Hibbs Award Nominee – Best Basic Science/Translational Science Paper, ‡SRS Funded Research Grant

Figure 1. Effect of scoliosis correction on the risk of proximal junctional kyphosis (PJK), stratified by upper instrumented vertebra (UIV). **(A)** Predicted probability of PJK across the range of scoliosis correction, shown separately for each UIV stratum. **(B)** Forest plot comparing the odds of PJK at 45° versus 15° of scoliosis correction within each UIV stratum.



§ Hibbs Award Nominee – Best Clinical Paper, † Hibbs Award Nominee – Best Basic Science/Translational Science Paper, ‡SRS Funded Research Grant

41. Evolution of Surgical Strategy in Adult Spinal Deformity: A Longitudinal Analysis of Sagittal Alignment and 2-Year Outcomes Across 18 Years

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Hypothesis

Alignment targets for adult spinal deformity have evolved over time, leading to improved sagittal alignment and outcomes.

Design

Retrospective multicenter registry (2008–2025)

Introduction

Despite advances in surgical techniques and the development of novel sagittal alignment targets, temporal trends of surgically achieved alignment goals have not been examined. The aim of this study was to evaluate the evolution of achieved alignment following ASD surgeries.

Methods

ASD patients from two large multicenter registries were included if they had pre-operative SRS-Schwab type N or L and underwent posterior fusion from thoracic (T1–12) to the ilium. Patients were grouped by surgery year: Epoch1 (2008–2013), Epoch2 (2014–2019), Epoch3 (2020–2025). Alignment parameters and outcomes were compared using ANOVA/Kruskal–Wallis. Variance was assessed via Levene testing.

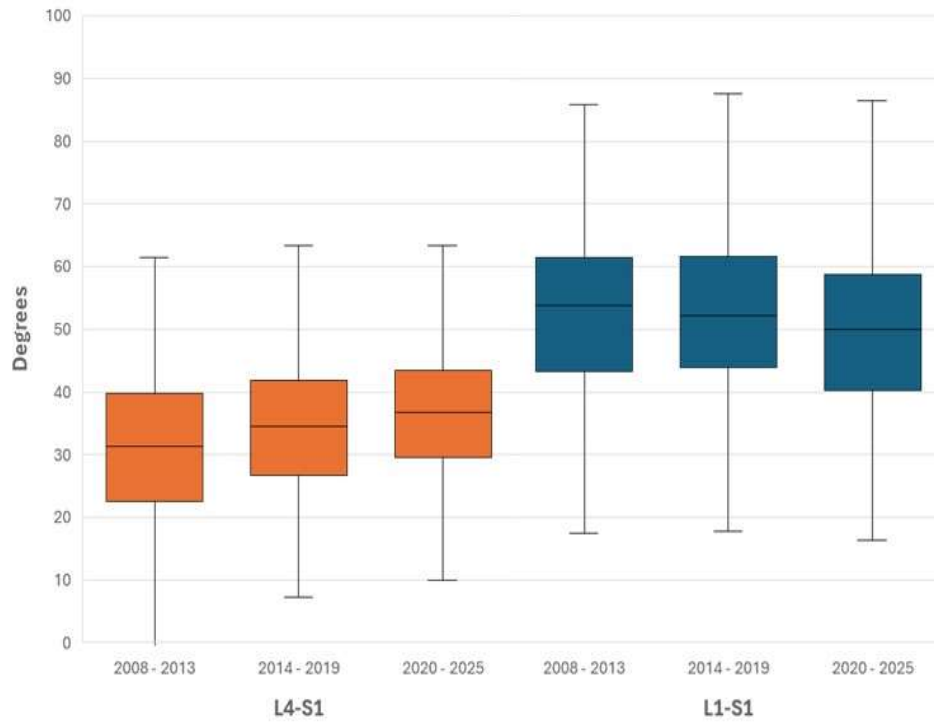
Results

1,166 patients were included (mean age: 68.1 ± 8.4 ; 67% F): 182 in Epoch1, 472 in Epoch2, and 512 in Epoch3. Over time, age increased (66 ± 11 vs. 69 ± 8 , $p < 0.001$), female proportion decreased (61% vs. 75%, $p < 0.001$), and patients had lower comorbidity burden ($p < 0.001$), ODI ($p = 0.003$), and higher baseline SRS-22 scores ($p < 0.001$). Baseline alignment was stable (PT, PI-LL, regional lordosis, or pelvic angles), except SVA, which decreased across epochs (11 vs 9.2cm, $p = 0.004$). At 6 weeks, L4–S1 lordosis was larger in recent Epochs ($p < 0.001$), while L1PA and its offset from norm were smaller (all $p < 0.01$). Alignment variance (PI-LL, SVA, L1PA) declined significantly. In terms of correction, later epochs showed less change in PT, PI-LL, SVA, and T4L1PA (all $p < 0.05$) but more changes in L4–S1, resulting in an overall better lordosis distribution. Severe radiographic PJK at 6 weeks progressively decreased across the epochs (10.5% vs. 3.9%, $p = 0.001$), while satisfaction and revision rates did not. Subgroup analysis showed similar evolution of sagittal alignment in Upper thoracic and Lower Thoracic constructs, with the latter showing more focus on segmental lumbar lordosis in later epochs.

Conclusion

ASD alignment strategies have evolved, emphasizing distal LL restoration and reducing variability. While radiographic improvements are evident, satisfaction and revision rates have not significantly improved, highlighting a gap between radiographic and clinical outcomes.

§ Hibbs Award Nominee – Best Clinical Paper, † Hibbs Award Nominee – Best Basic Science/Translational Science Paper, ‡SRS Funded Research Grant



§ Hibbs Award Nominee – Best Clinical Paper, † Hibbs Award Nominee – Best Basic Science/Translational Science Paper,
‡SRS Funded Research Grant

42. Fate of the Unfused Distal Lumbar Coronal Curve After Scoliosis Correction in Children versus Adults: A Collaborative Study Group Analysis

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Hypothesis

The unfused distal lumbar coronal curve (DLCC) in children will improve more rapidly compared to adults after scoliosis correction.

Design

Retrospective cohort study of pediatric and adult patients with idiopathic scoliosis.

Introduction

Fractional curve and DLCC behavior after scoliosis correction has been studied in children and adults, but no prior study has compared matched pediatric and adult cohorts to define age-related differences in DLCC behavior.

Methods

Patients undergoing thoracolumbar fusion for idiopathic scoliosis were included—Pediatric (ages 8–17; n=140): Lenke 5/6 (n=103) with LIV L1/2/3/4 = 0/2/74/27, or Lenke 3/4 with LIV L3/4 = 23/14; Adults (age ≥18; n=105): LIV L1/2/3/4 = 16/15/33/41, UIV > T12. Radiographic parameters and outcomes (SRS-22, mechanical complications) were assessed preop, 6 weeks, and 2 years. Pediatric (pDLCC) and adult (aDLCC) DLCCs were defined as the coronal Cobb angle between LIV and S1 >10°. Global coronal malalignment (GCM) was defined as C7PL–CSVL distance, with <3 cm considered balanced.

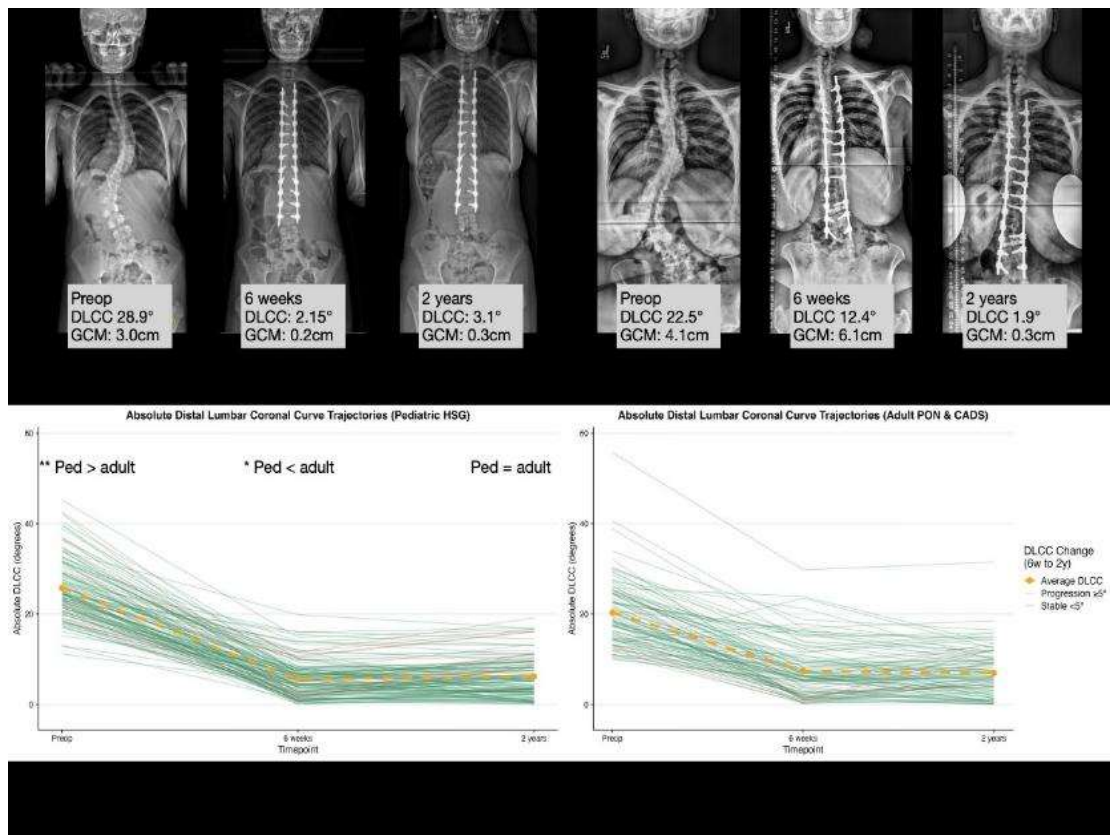
Results

Pediatric (14.9yo±2.2) and adult (34.5yo±15.1) patients had similar major curve magnitude and correction (57.6°±14.3 to 23.6°±8.6 vs 55.0°±17.3 to 21.8°±13.4; p>0.2). pDLCCs were larger preop vs aDLCCs (25.9°±6.5 vs 20.0°±7.4; p<0.001) and experienced greater correction at 6 weeks (Δ20.2° vs Δ12.9°; p<0.0001). pDLCC and GCM changed rapidly at 6 weeks and remained stable at 2 years, whereas adult GCM changed over 2 years (p<0.0001). pDLCC changed to improve GCM between preop->6w (p=0.04), while aDLCCs changed to improve GCM 6w->2y (p=0.049). More pediatric than adult patients had GCM<3 cm at 2yr fu (94.4% vs 80.4%; p<0.01). On multivariate linear regression, older age was associated with lower DLCC correction (β=-0.12, p=0.005). Residual pDLCC or aDLCC magnitude was not associated with SRS-22 subdomains (p>0.50), mechanical complications (p=0.25), or re-op (p=0.30).

Conclusion

Pediatric patients experience more rapid and greater magnitude correction of the unfused lumbar coronal curve after TL fusion compared to adults. Pediatric DLCC improved over the first 6 weeks postoperatively, whereas adult DLCC improved more gradually over 2 years. In both groups, DLCC changed correlated with improved GCM, with higher rates of coronal balance at 2yrs in children. Residual DLCC magnitude was not associated with revision surgery or SRS-22.

§ Hibbs Award Nominee – Best Clinical Paper, † Hibbs Award Nominee – Best Basic Science/Translational Science Paper, ‡SRS Funded Research Grant



§ Hibbs Award Nominee – Best Clinical Paper, † Hibbs Award Nominee – Best Basic Science/Translational Science Paper, ‡SRS Funded Research Grant