Session 5A | Adult Spinal Deformity II Abstracts

Papers are listed in presentation order

Paper #55. Sarcopenia Using L3 and L4 Normalized Total Psoas Area Predicts Early Postoperative Mobility and Perioperative Adverse Events After Adult Spinal Deformity Surgery

Takashi Hirase, MD, MPH; Han Jo Kim, MD; Chukwuebuka Achebe, BS; Myles Allen, MbChB; Gregory Kazarian, MD; Michael Mazzucco, BS; Hiroyuki Nakarai, MD; Francis C. Lovecchio, MD

Hypothesis
Sarcopenia measured by L3 and L4 normalized total psoas area (NTPA) are associated with lower early postoperative mobility and higher rates of perioperative adverse events (AEs) among patients undergoing adult spinal deformity (ASD) surgery.

Design
Retrospective cohort study

Introduction
Sarcopenia measured by NTPA has been shown to predict perioperative outcomes after various types of spine surgery. However, there is limited data regarding its association with postoperative mobility and AEs in ASD surgery. The purpose of this study was to determine the relationship between NTPA and postoperative mobility and AEs among patients undergoing ASD surgery.

Methods
Patients that underwent ASD surgery at a single-center (2014-2023) were included in the study. Sarcopenia was analyzed by using NTPA at the L3 and L4 mid-vertebral body on preoperative magnetic resonance imaging (MRI). Receiver operating characteristic (ROC) curve analysis was used to determine gender-specific NTPA cut-off values for predicting perioperative AEs. Patients were categorized as sarcopenic if both L3 and L4 NTPA were below the cut-off values. Multivariate logistic regression was conducted to identify confounding predictors of perioperative AEs.

Results
279 patients (102 males, 177 females, mean age 61.2 ± 15.2 years) were included. ROC curve analysis demonstrated L3 NTPA <805 mm^2/m^2 for males and <505 mm^2/m^2 for females and L4 NTPA <912 mm^2/m^2 for males and <714 for females mm^2/m^2 as cut-off values predicting perioperative AEs. 103 patients (36.9%, 42 males, 61 females) were below these cut-off values and were in the sarcopenia cohort. The remaining 176 patients (63.1%, 60 males, 116 females) were in the non-sarcopenia cohort. There was no difference in the 5-item modified frailty index between the cohorts (p=0.844). The sarcopenia group had a higher overall perioperative AEs (70.9% vs 39.2%, p<0.001), and lower ambulation distances on postoperative day 1 and 2 compared to the non-sarcopenia group (p=0.024, p=0.043, respectively). On multivariate analysis, there were no other predictors of perioperative AEs.

Conclusion
Sarcopenia measured by L3 and L4 NTPA is associated with lower early postoperative mobility and higher rates of perioperative AEs among patients undergoing ASD surgery.

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Table 1: Characteristics and Perioperative Outcomes of the Study Population

Variable	Sarcopenia (n=103)	No Sarcopenia (n=176)	*P* Value
L3 NTPA, mm^2/m^2 (mean, SD)	469.0 ± 140.0	712.8 ± 201.7	<0.001*
L4 NTPA, mm^2/m^2 (mean, SD)	647.8 ± 147.4	924.2 ± 217.0	<0.001*
Age, years (mean, SD)	60.1 ± 16.5	61.7 ± 14.4	0.428
BMI, kg/m^2 (mean, SD)	25.9 ± 4.8	28.9 ± 6.4	<0.001*
ASA class (mean, SD)	2.3 ± 0.5	2.3 ± 0.5	0.814
CCI (mean, SD)	1.9 ± 1.4	2.0 ± 1.5	0.724
Smoker, n (%)	4 (3.9)	4 (2.3)	0.435
Diabetes, n (%)	10 (9.7)	15 (8.5)	0.741
mFI-5 (mean, SD)	0.93 ± 0.94	0.95 ± 0.89	0.844
DEXA t-score, (mean, SD)	-1.8 ± 1.6	-1.7 ± 1.1	0.765
BMD, mg/cc K_2HPO_4 (mean, SD)	114.1 ± 31.7	101.1 ± 36.4	0.278
EBL, mL (mean, SD)	1135.7 ± 1116.6	913.3 ± 774.3	0.079
Operative time, min (mean, SD)	255.1 ± 88.9	256.3 ± 101.1	0.920
Post-operative LOS (hours) (mean, SD)	140.5 ± 81.3	137.5 ± 65.1	0.750
30-day Reoperation (n, %)	2 (1.9)	3 (1.7)	0.889
30-day Readmission (n, %)	2 (1.9)	3 (1.7)	0.889
Perioperative Adverse Events (n, %)			
Any adverse events	73 (70.9)	69 (39.2)	<0.001*
Post-op anemia requiring transfusion	42 (40.8)	31 (17.6)	<0.001*
Ileus	16 (15.5)	14 (8.0)	0.049*
Urinary retention	14 (13.6)	11 (6.3)	0.038*
Wound complication (dehiscence, infection)	1 (0.9)	2 (1.1)	0.897
Delirium	8 (7.8)	6 (3.4)	0.107
Atelectasis	2 (1.9)	1 (0.6)	0.284
UTI	2 (1.9)	1 (0.6)	0.284
DVT	2 (1.9)	2 (1.1)	0.582
Epidural hematoma	1 (0.9)	1 (0.6)	0.704
Postoperative Ambulation Distance, ft (mean, SD)			
POD 1	42.5 ± 59.0	63.6 ± 79.3	0.021*
POD 2	89.7 ± 81.9	116.5 ± 106.1	0.028*
POD 3	112.4 ± 82.7	121.2 ± 85.4	0.473
POD 4	128.8 ± 100.6	122.9 ± 79.1	0.704

**Statistically significant values*
SD, standard deviation; NTPA, Normalized Total Psoas Area; BMI, body mass index; ASA, American Society for Anesthesiologists; CCI, Charlson Comorbidity Index; DEXA, dual energy X-ray absorptiometry; EBL, estimated blood loss; LOS, length of stay; UTI, urinary tract infection; DVT, deep vein thrombosis; POD, postoperative day

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Paper #56. Lower Hounsfield Units and Severe Paraspinal Sarcopenia Are Independent Predictors of Increased Risk for Proximal Junctional Kyphosis and Failure Following Thoracolumbar Fusions Terminating in the Upper Thoracic Spine

Zachariah W. Pinter, MD; Anthony L. Mikula, MD; Giorgos Michalopoulos, MD; Nikita Lakomkin, MD; Zach Pennington, MD; Ahmad Nassr, MD; Brett A. Freedman, MD; Arjun Sebastian, MD; Mohamad Bydon, MD; Jeremy L. Fogelson, MD; Benjamin D. Elder, MD, PhD

Hypothesis

Severe paraspinal sarcopenia and lower Hounsfield Units (HU) at the upper instrumented vertebra (UIV) will be independent predictors of increased risk of developing proximal junctional complications including proximal junctional kyphosis (PJK) and proximal junctional failure (PJF).

Design

Retrospective review

Introduction

The purpose of the present study was to assess the impact of sarcopenia on the development of PJK and PJF following thoracolumbar spine fusion surgery from the upper thoracic spine to the pelvis using opportunistic evaluation of paraspinal fatty degeneration on preoperative MRI.

Methods

We performed a retrospective review of patients who underwent posterior spine fusion surgery that extended caudally to the pelvis and terminated cranially between T1-6 between 2010 and 2017. The cohort was divided into two groups: (1) patients without PJK or PJF and (2) patients with PJK and/or PJF. These subgroups were then compared based upon demographics, preoperative and 1-year postoperative sagittal alignment parameters, bone mineral density (BMD), and paraspinal sarcopenia. We utilized student's T-test and ANOVA to compare means within and between groups, respectively. Multivariable analyses were performed to determine risk factors for PJK and PJF. P values <0.05 were considered significant.

Results

We identified 81 patients for inclusion in this study. Mean HU at the UIV was 186.1 ± 47.5 in the cohort of patients without PJK or PJF, which was substantially higher than values recorded in the PJK/PJF subgroup (142.4 ± 40.2)($P<0.001$). Severe multifidus sarcopenia was identified at a much higher rate in the subgroup of patients who developed proximal junction pathology (66.7%) than in the subgroup of patients who developed neither PJK nor PJF (8.0%; $P<0.001$). Multivariate analysis demonstrated both low HU at the UIV and moderate-severe paraspinal sarcopenia to be risk factors for the development of PJK and PJF.

Conclusion

The results of this study suggest severe paraspinal sarcopenia and diminished bone density at the UIV impart an increased risk of developing PJK and PJF in patients undergoing thoracolumbar fusions from the upper thoracic spine to the pelvis, while markers of systemic frailty such as mFI and CCI are not associated with an increased risk of these complications.

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TABLE 5. Odds Ratios for Development of Proximal Junctional Kyphosis

Variable	Odds Ratio	95% Confidence Interval	P value
Age	1.1	0.99 - 1.23	0.07
Gender (Female)	1.6	0.36 - 7.1	0.54
Mean UIV HU	0.84	0.72 - 0.98	**0.03**
Moderate-Severe Multifidus Sarcopenia	23.8	5.5 - 103.8	**<0.001**

*Abbreviations: BMI (Body Mass Index), UIV (upper instrumented vertebra), HU (Hounsfield Units)

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Paper #57. Sarcopenia as a Predictor of Prolonged Length of Stay in Adult Spinal Deformity Surgery

Chukwuebuka Achebe, BS; Han Jo Kim, MD; Takashi Hirase, MD, MPH; Myles Allen, MbChB; Robert Uzzo, MBA; Tejas Subramanian, BS; Chad Z. Simon, BS; Atahan Durbas, MD; Jung Mok, MD; Austin Kaidi, MD; Kasra Araghi, BS; Justin T. Samuel, BS; Cole Kwas, BS; Michael Mazzucco, BS; Matthew E. Cunningham, MD, PhD; Francis C. Lovecchio, MD

Hypothesis

Sarcopenia is associated with increased length of stay (LOS) after adult spinal deformity (ASD) surgery.

Design

Retrospective single-center cohort study

Introduction

ASD surgery is plagued by variations in episodes of care. By understanding how muscle health influences early recovery, predictive models may better anticipate patient and health care system needs after surgery.

Methods

This retrospective single-center study included patients undergoing 5 or more levels of fusion to the pelvis for a diagnosis of ASD (2013-2021). Sarcopenia was assessed by normalized psoas muscle cross sectional area (NTPA) at L3 and L4 levels and lumbar crossing indentation value (LCIV) at the L4/L5 intervertebral disc, using preoperative MRI scans. The lowest quartile in sex-specific muscle health metrics was deemed sarcopenic according to the corresponding metric. Prolonged LOS was defined as exceeding the 75th percentile. Multivariate logistic regression was performed to control for ASA classification, estimated blood loss (EBL), and number of instrumented levels.

Results

221 patients (71 males, 150 females, mean age 63 ± 10.9 years) were included in the study. The 75th percentile of LOS was 157 hrs. Analysis revealed that non-sarcopenic status, as assessed by LCIV, was significantly associated with decreased odds of prolonged LOS (OR = 0.305, CI = 0.147-0.634, p = 0.0015). Increased EBL was associated with increased odds of prolonged LOS (OR = 1.001, CI = 1.000-1.001, p = 0.0063). The number of spinal levels was also associated with increased odds of prolonged LOS (OR = 1.179, CI = 1.06-1.31, p = 0.0023). The overall model showed good discriminatory power with an AUC = 0.78.

Conclusion

Our findings indicate that certain metrics of muscle health are predictive of length of stay. Further research will be needed to determine whether muscle health may be a modifiable risk factor that can influence early postoperative outcomes.

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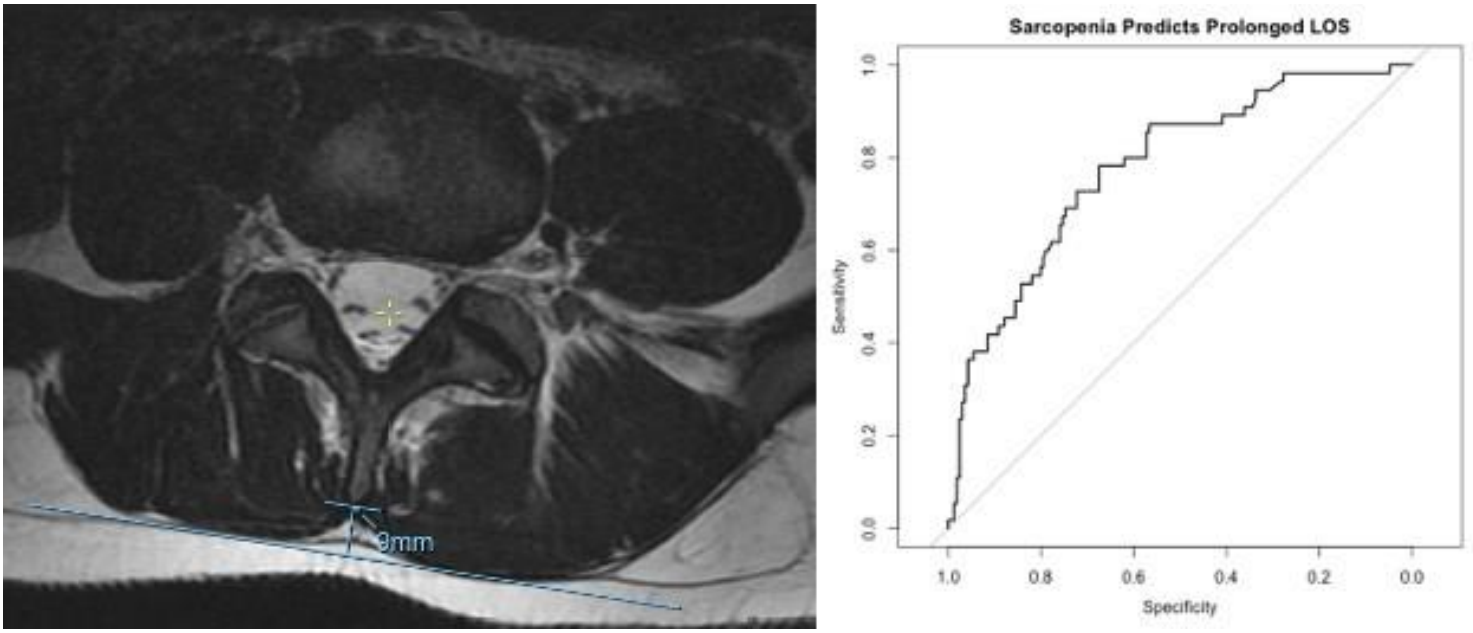

(Left) LCIV measurement of non-sarcopenic patient. (Right) ROC curve for multivariate logistic regression based on muscle health metrics including NTPA at L3 & L4 and LCIV at L4/L5

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Paper #58. Machine Learning Finds the Sweet Spot Between Under Correction Leading to Pseudarthrosis and over Correction Leading to Proximal Junctional Kyphosis

Sarthak Mohanty, BS; Justin Reyes, MS; Josephine R. Coury, MD; Erik Lewerenz, BS; Fthimnir Hassan, MPH; Joseph M. Lombardi, MD; Ronald A. Lehman, MD; *Zeeshan M. Sardar, MD*; Lawrence G. Lenke, MD; Multi-Ethnic Alignment Normative Study (MEANS) Group

Hypothesis

Machine learning in asymptomatic volunteers predicts optimal PI-LL values to minimize pseudarthrosis and PJK in ASD correction.

Design

Retrospective with external validation in a single-center cohort

Introduction

Traditional age-adjusted spinopelvic alignment formulas risk under correction in ASD patients. Leveraging machine learning, this study develops surgical PI-LL targets by analyzing alignment in asymptomatic volunteers.

Methods

A predictive model was built for PI-LL mismatch from 468 asymptomatic adults(80% training, 20% validation) across multiple centers. The eXtreme Gradient Boosting algorithm utilized PI, age, & sex. Fig 1B illustrates alignment targets, stratified by age & PI. To validate targets, we analyzed 458 ASD surgical patients with 2Y follow-up. These patients were classified as under-(UC), adequately-(AC), or over-corrected(OC), based on the model's targets±5°(Fig 1B). Key outcomes were pseudarthrosis/implant failure & PJK. Outcomes were analyzed using multivariable regression models, adjusted for significant variables identified in univariate analyses. Data shown as [UC vs AC vs OC,P(ANOVA)].

Results

Mean absolute error between observed & predicted PI-LL were 3.04° & 5.02° for training & validation groups(Fig 1A). In the surgical ASD cohort, 149(32.5%), 159(32.8%),& 150(34.7%) patients were UC, AC, & OC respectively. Differences were observed in instrumented levels(12.3 vs 12.7 vs 13.8,P=0.0028), baseline PI-LL(30.3° vs 22.1° vs 17.8°,P<0.0001), & T1PA(30.9° vs 26.0° vs 23.4°,P<0.0001). Pseudarthrosis rate was 9.82%(45/548), with highest incidence in UC cohort(15.4% vs 8.18% vs 6.0%,P=0.0161). PJK rate was 10.0%(46/458), most prevalent in OC group(19.3% vs 6.04% vs 5.03%,P<0.0001). The adjusted multivariable model(P<0.0001, AUC=0.76) found that AC(aOR: 0.45,P=0.046),& OC(aOR: 0.41,P=0.044) had lower odds of pseudarthrosis compared to UC patients(Fig 1C). In an adjusted PJK model(AUC=0.687,P<0.0001), AC had lower odds of PJK compared to OC (OR: 0.45,P=0.0034 (Fig 1C). Both models found the current classification supersedes baseline alignment and magnitude correction in association with pseudarthrosis & PJK.

Conclusion

Machine learning-derived PI-LL targets demonstrate a critical balance in deformity correction. Deviation from these tailored alignment targets increases risk of pseudarthrosis when under corrected and PJK when over corrected.

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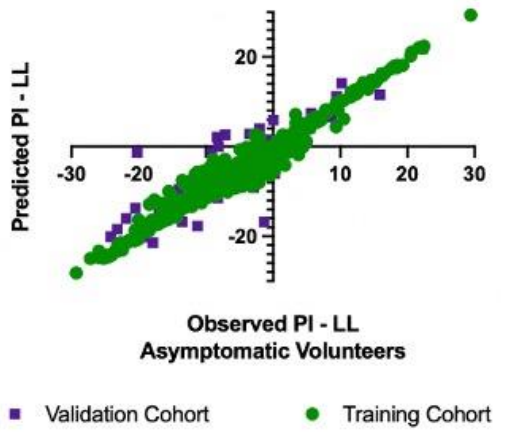
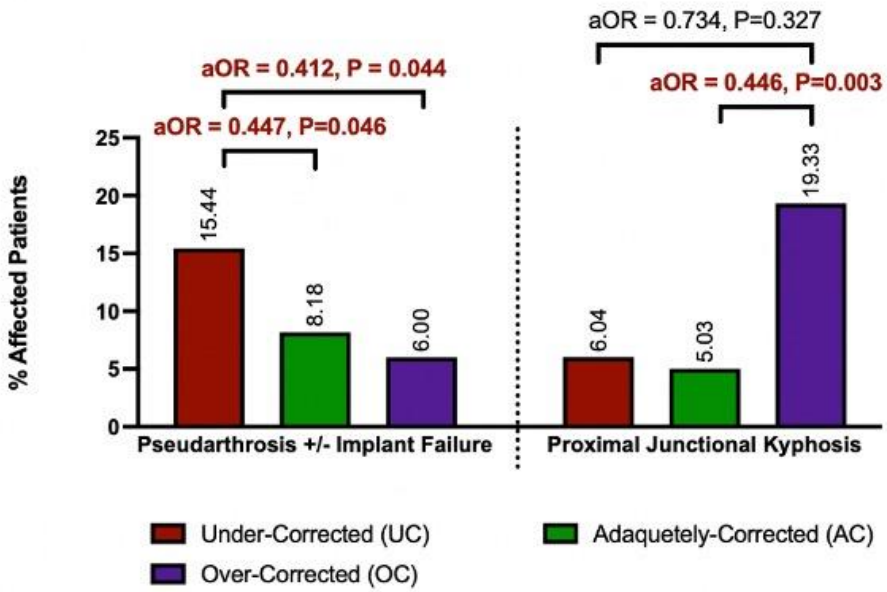
A **Observed Versus Machine Learning Predicted PI - LL**



B

Age Cohort	Pelvic Incidence (PI) 30-40	40-50	50-60	60-70	70+
<35	-11.52 (± 5°)	-7.23 (± 5°)	-5.58 (± 5°)	0.04 (± 5°)	3.74 (± 5°)
35-45	-5.36 (± 5°)	-4.52 (± 5°)	-6.39 (± 5°)	-0.54 (± 5°)	8.69 (± 5°)
45-55	-5.84 (± 5°)	-8.02 (± 5°)	-0.46 (± 5°)	3.05 (± 5°)	13.53 (± 5°)
55-65	-3.51 (± 5°)	0.15 (± 5°)	3.03 (± 5°)	6.68 (± 5°)	13.99 (± 5°)
65-75	-2.82 (± 5°)	2.89 (± 5°)	3.03 (± 5°)	6.49 (± 5°)	15.12 (± 5°)
75+	-0.54 (± 5°)	0.82 (± 5°)	7.32 (± 5°)	11.77 (± 5°)	17.44 (± 5°)

C **Outcomes by Correction Status**



Adjusted Odds Ratio (aOR) Adjusted For:

- **Demographics:** BMI
- **Overall, Health Status:** Osteoporosis, Charleson Comorbidity Score
- **Surgical Variables:** VCR, BMP, PJK Prophylaxis, Total Number of Osteotomies, Three Column Osteotomy
- **Preoperative Alignment:** SRS-Schwab Classification
- **Magnitude Correction from Baseline:** ΔPT, ΔPI - LL, ΔLL, ΔTK, Δ T1PA

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Paper #59. Radiomics-Powered Radiographic Image Analysis for Enhanced Mechanical Complications Prediction and Surgical Planning in Adult Spine Deformity

Ferran Pellisé, MD, PhD; Sleiman Haddad, MD, PhD, FRCS; Susana Núñez Pereira, MD; Caglar Yilgor, MD; Maggie Barcheni, MS; Anika Pupak, BS; Manuel Ramirez Valencia, MD; Javier Pizones, MD, PhD; Ahmet Alanay, MD; Ibrahim Obeid, MD; Frank S. Kleinstueck, MD; Fabio Galbusera, PhD; Oleguer Sagarra, PhD; European Spine Study Group

Hypothesis

Processed image (PrIm) algorithms outperform traditional radiographic measurements (TRM) in predicting postoperative mechanical complications (MC) in adult spinal deformity (ASD).

Design

AI-leveraged retrospective study analyzing preoperative, 6-week and 2-year follow-up data of surgical ASD patients, from a prospective international registry.

Introduction

Radiomics, a technique employing machine learning to extract quantitative features from processed radiographic images, holds promise for improving clinical prediction models. It offers the potential to comprehensively characterize spinal shape and alignment.

Methods

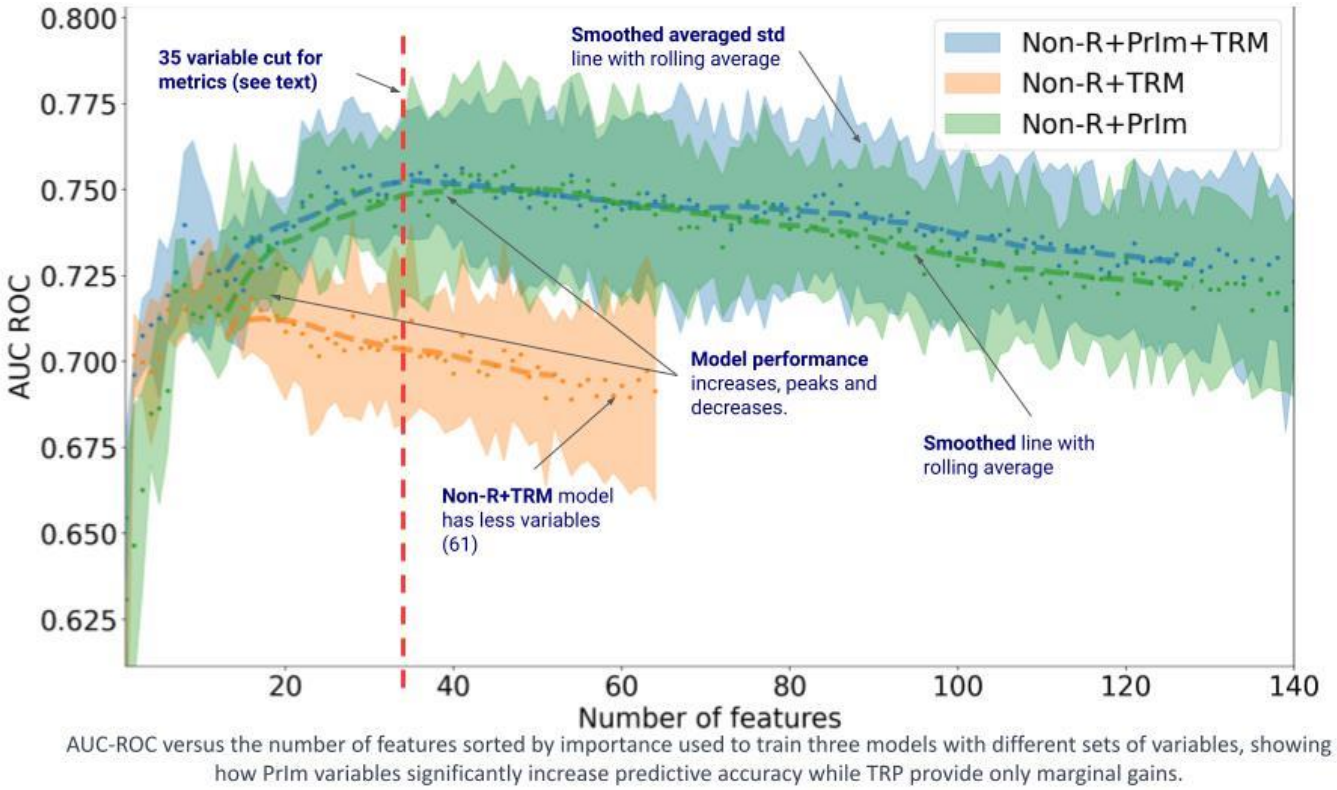
Processed full-spine standing radiographic images were analyzed using an automatic vertebral centroid generation algorithm to map postero-anterior and lateral spinal shape. Distances and angles between each vertebra and the pelvic centroid were automatically obtained. Machine learning models were constructed using Catboost, combining non-radiographic variables (Non-R: demographic, PROMS, surgical), TRM, and PrIm features. AUC-ROC, sensitivity, specificity, and Brier score (0= perfectly calibrated / 1=poor) were used to evaluate prediction accuracy. SHAP values were employed to assess variable contributions and address overfitting/noise.

Results

690 patients (81% female, 52±19 years, 9.7±3.9 fused levels, 18.6% 3CO, 43.5% pelvic fixation, 24.3% MC) were analyzed. The PrIm + Non-R model outperformed the present “Gold Standard” model (TRM + Non-R): AUC-ROC 0.75 vs 0.71 ($p=0.009$), accuracy 0.72 vs 0.62 ($p<0.001$), specificity 0.79 vs 0.60 ($p<0.001$), sensitivity 0.52 vs 0.70 ($p<0.001$), and Brier score 0.17 vs 0.21 ($p<0.001$). Adding TRM to PrIm+Non-R model did not improve model estimates (Fig). SHAP adjusted models summed 35 variables and revealed PrIm's superior predictive importance, contributing 66% to the model compared to Non-R (Surgical factors 16%, PROMS 11% and demographics 7%). Personalized SHAP decision plots identified the most critical vertebral centroids associated with MC risk, both globally and individually.

Conclusion

Radiomics, powered by full-spine processed radiographic images, enable the most accurate predictive models for MC in ASD. This novel approach offers clinicians a powerful and time-efficient tool for personalized surgical planning, ultimately enhancing ASD surgical outcomes.



AUC-ROC versus the number of features sorted by importance, showing how PrIm variables significantly increase predictive accuracy while TRP provide only marginal gains.

AUC-ROC versus the number of features sorted by importance.

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Paper #60. Nomogram to Predict Unplanned Intensive Care Unit Admission Following Adult Spinal Deformity

Mohammad Daher, BS; Andrew Xu, BS; Sarah Criddle, MD; Mariah Balmaceno-Criss, BS; Lawrence G. Lenke, MD; Virginie Lafage, PhD; Christopher P. Ames, MD; Douglas C. Burton, MD; Stephen J. Lewis, MD, FRCS(C); Renaud Lafage, MS; Robert K. Eastlack, MD; Munish C. Gupta, MD; Gregory M. Mundis Jr., MD; Jeffrey L. Gum, MD; Kojo D. Hamilton, MD, FAANS; Richard Hostin, MD; Peter G. Passias, MD; Themistocles S. Protopsaltis, MD; Khaled M. Kebaish, MD; Han Jo Kim, MD; Frank J. Schwab, MD; Christopher I. Shaffrey, MD; Justin S. Smith, MD, PhD; Breton G. Line, BS; Shay Bess, MD; Bassel G. Diebo, MD; Eric O. Klineberg, MD; Alan H. Daniels, MD; International Spine Study Group

Hypothesis

A nomogram to predict unplanned ICU admissions following ASD surgery can be created and tested

Design

Lasso regression of prospectively collected data.

Introduction

We surveyed spine surgeons and examined patients who were admitted to the ICU outside of the standard protocol. This study then aimed to define a nomogram that predicts ICU admissions within a large study group.

Methods

Patients who underwent ASD surgery were included. Risk factors for ICU admission after spine surgery were identified from previous literature. These variables were added to a Lasso regression to determine the ones with the highest impact on ICU admission. After feature selection, logistic regression was optimized to predict ICU admission. The receiver operating characteristics (ROC) curve was plotted and coefficients as well as odds ratio for each of the selected variables was calculated. The nomogram was developed on 60% of the cohort and tested on 40%.

Results

557 patients were included with 8.2% (46 patients) sustaining major intraoperative or in-hospital medical adverse events requiring moderate or severe intervention, and 22% (125 patients) were admitted to the ICU. Of those, only 20/125 patients had major medical adverse events. Lasso regression identified ASA, pre-operative albumin, kidney disease at baseline, and estimated blood loss (EBL) to be the highest predictors of ICU admission. The ROC curve was plotted for ICU admission with an area under the curve of 0.8. The nomogram was developed to predict ICU admission using these 4 variables (Figure 1). After being tested on 40% of the cohort, it had an accuracy of 78%, a sensitivity of 60% and a specificity of 97%. Furthermore, the model had a threshold of 80 points for ICU admission which could be calculated using points assigned to the values of the 4 included variables. The nomogram may also be able to predict unnecessary ICU admissions, reducing costs by $1560 (median ICU admission cost).

Conclusion

This novel nomogram predicts post-operative ICU admission following ASD surgery utilizing EBL, ASA score, history of kidney disease, and pre-operative Albumin with an accuracy of 78%. While this model helps predict global practice patterns associated with our pool of surgeons, ICU admissions remain an area of need for further research and standardization. Future studies can build on this nomogram to provide guidelines and predictive models for appropriate ICU admission.

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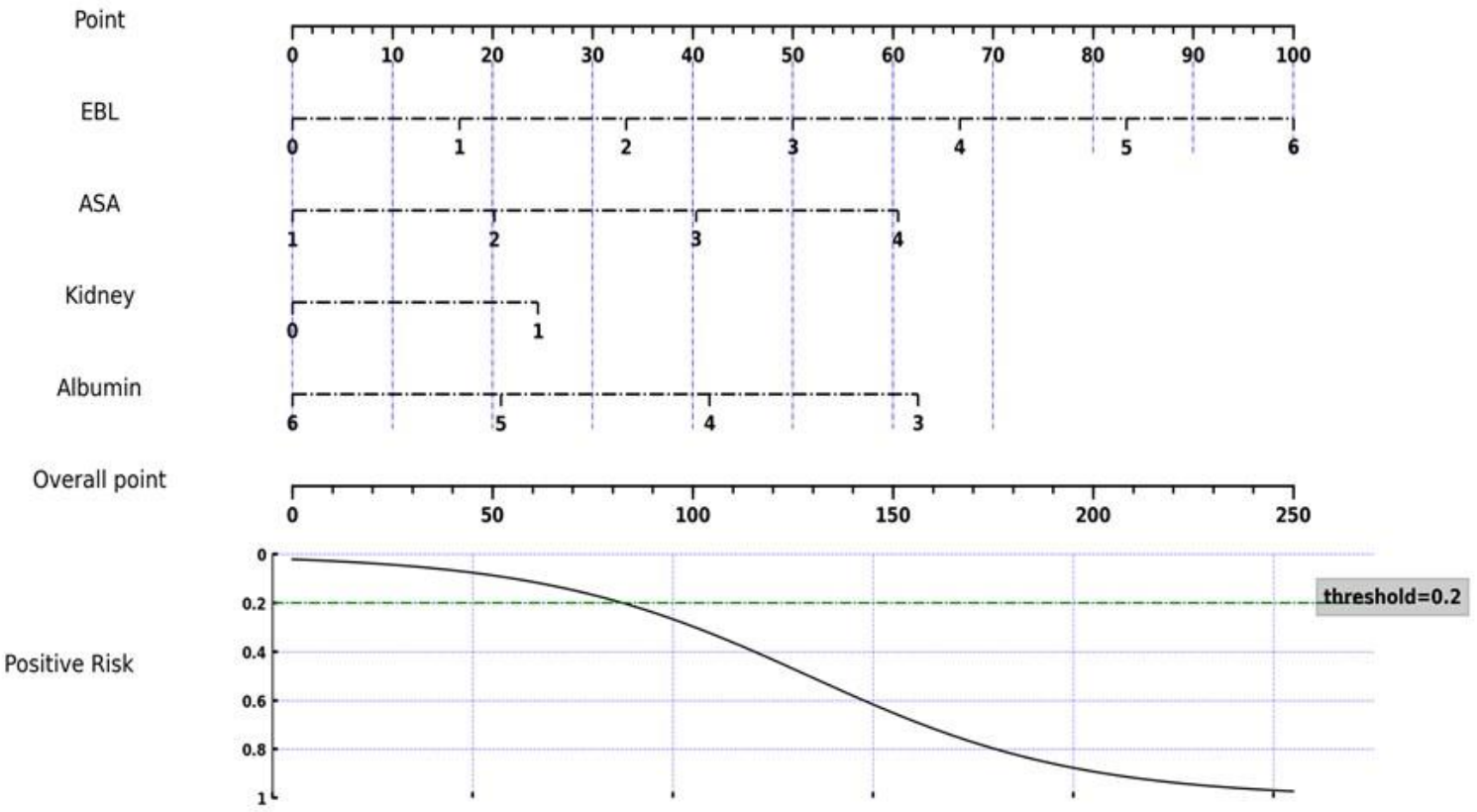

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Paper #61. Modified Pedicle Subtraction Osteotomy for Osteoporotic Vertebral Compression Fractures: A Retrospective Study of 104 Patients

Junyu Li, MD; Jiahao Zhang, MD; Siming Xian, MD; Wenbin Bai, MD; Yihao Liu, MD; Zhuoran Sun, MD; Yongqiang Wang, MD; Miao Yu, MD; Weishi Li, MD; *Yan Zeng, MD*

Hypothesis
Modified PSO can be an effective solution for the treatment of OVCF.

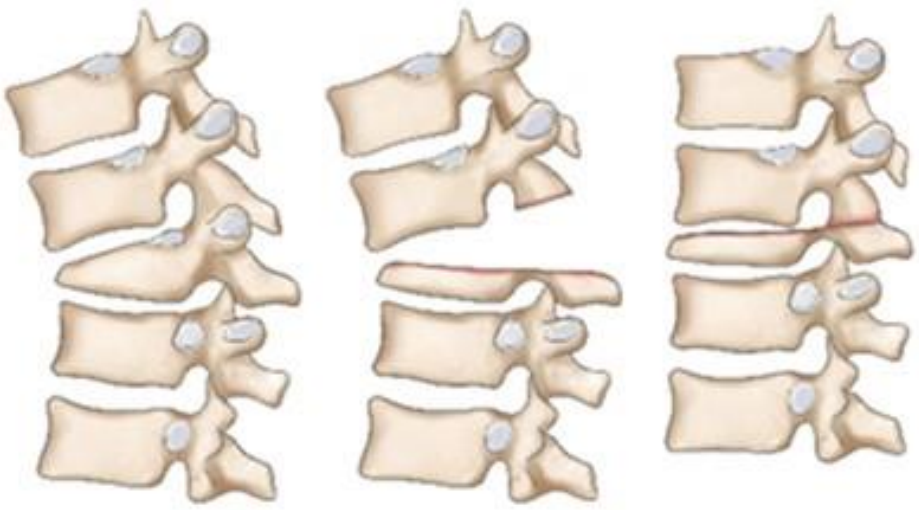
Design
retrospective comparsion

Introduction
Osteoporotic vertebral compression fractures (OVCF) caused by osteoporosis is a common clinical fracture type. There are many surgical treatment options for OVCF, but there is a lack of comparison among different options. Therefore, we counted a total of 104 cases of OVCF operations with different surgical plans, followed up the patients, and compared the surgical outcome indications before, after and during the follow-up.

Methods
104 patients who underwent posterior osteotomy(Modified PSO, SPO, PSO, VCR) and kyphosis correction surgery at our hospital between April 2006 and August 2021 with a minimum follow-up period of 24 months were included. All cases were injuries induced by a fall incurred while standing or lifting heavy objects without high-energy trauma. The mean CT value was 71 HU, which was below 110 HU, indicating severe osteoporosis. The indications for surgery included gait disturbance due to severe pain with pseudarthrosis, increased kyphotic angle, and progressive neurological symptoms. Pre- and postoperative CL, TLK, TK, PrTK, TKmax, GK, LL, PI, SS, PT, SVA,TPA,were investigated radiologically. Additionally, We evaluated estimated blood loss, surgical time and perioperative symptom.

Results
The results show, after operation, TLK (39.42±14.26° vs 9.02±8.30°, P<0.001), TK (34.05±17.71°vs 21.83±11.90°, P=0.003), TK max (51.78±11.96°vs 18.35±9.93°, P<0.001), PT (26.31±13.60°vs 14.4±17.84°, P=0.009), SVA (38.44±27.52 vs 21.44±13.02, P=0.010), CL (16.12±15.92° vs 8.15±7.58°, P=0.038) and TPA (24.9±13.18°vs 16.18±10.28°, P=0.045) were improved significantly in modified Pedicle subtraction osteotomy (mPSO). During follow-up, TLK (39.42±14.26°vs 11.68±8.48°, P<0.001) and TK max (51.78±11.96°vs 23.53±9.8°, P<0.001) were improved significantly in Modified PSO group. In additon, estimated blood loss (790ml vs 1198ml, P=0.035), surgical time (244min vs 301min, P=0.010) were favorable in Modified PSO group.

Conclusion
To conclude, mPSO could acquire a favorable degree of kyphosis correction as well as early and high bone union. Compared with other surgical methods, it also has the advantages of less surgical trauma and shorter operation time. It can be an effective solution for the treatment of OVCF.



Improved PSO osteotomy schematic diagram

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Paper #62. Critical Analysis of Clinical Failures Despite Appropriate Realignment in Adult Spinal Deformity

Jamshaid Mir, MD; Brett Rocos, MD, FRCS; Ankita Das, BS; Tobi Onafowokan, MBBS; Daniel B. Chen, BS; Nathan Lorentz, MD; Stephane Owusu-Sarpong, MD; Neel Anand, MD; Bassel G. Diebo, MD; Kojo D. Hamilton, MD, FAANS; Han Jo Kim, MD; Andrew Chen, BS; Zeeshan M. Sardar, MD; Jordan Lebovic, BA; Djani Robertson, MD; Praveen V. Mummaneni, MD, MBA; Nima Alan, MD; Renaud Lafage, MS; Virginie Lafage, PhD; Christopher I. Shaffrey, MD; Dean Chou, MD; M. Burhan Janjua, MD; Justin S. Smith, MD, PhD; Peter G. Passias, MD; *Kristen E. Jones, MD, FAANS*

Hypothesis

Patient and surgical factors vary in those that develop major mechanical complications despite being proportioned in global alignment and proportionality (GAP) score.

Design

Retrospective cohort

Introduction

The GAP score is a pelvic-incidence-based proportional method of analyzing the sagittal plane that predicts mechanical complications in patients undergoing surgery for adult spinal deformity. Setting surgical goals according to the GAP score may decrease the prevalence of mechanical complications. However, addressing these targets does not always prevent mechanical complications or reoperations.

Methods

Surgical ASD patients fused from at least L1 and proximal to the sacrum with 2-year follow-up were isolated. Proximal and distal junctional kyphosis and/or failure, rod breakage, and other implant-related complications were considered mechanical complications. Cohort was stratified based on GAP categories [Proportioned (GAP-P), Moderately Disproportioned (GAP-MD), and Severely Disproportioned (GAP-SD)]. GAP-P were evaluated based on the development of major mechanical complications and PJF (MMC) vs no MMC (nMMC).

Results

321 patients (64±9 yrs, 78% F, 27.5±5.1 kg/m2, CCI 1.9±1.7, frailty 3.5±1.5) were isolated. By postoperative GAP proportionality: 34% of patients were GAP-P, 39% GAP-MD, and 27% GAP-SD. Although lower than those not proportioned, GAP-P still had 33% MMC, (33% vs 48%, p<.05). Isolating those in GAP-P to evaluate for variances in those that developed MMC, found no difference in baseline patient factors. Preoperatively, MMC had higher lumbosacral coronal Cobb angle (22° vs 17°, p=.045), and T4-T12 kyphosis (37° vs 30°, p=.041) compared to nMMC. The use of PJK prophylaxis was significantly lower in MMC (26% vs 49%, p=0.3). No difference in surgical approach, osteotomies, 3CO, or IBF. Postoperatively, MMC still had higher lumbosacral coronal Cobb angle (8° vs 5°, p=.03), and T2-T12 kyphosis (55 vs 49, p=.04). No difference in other parameters including UIV slope. Patients with postoperative lumbosacral coronal Cobb >5° had a 4x likelihood of MMC (4.2 [1.14-15.48], p=0.031).

Conclusion

Being proportioned according to GAP decreased rates of major mechanical complications and reoperation. Despite that, 30% of patients still developed major mechanical complications and PJF. In those proportioned, thoracic kyphosis, and lumbosacral Cobb angle predictive of developing major mechanical complications.

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Paper #63. Behavioral Patterns of Mechanical Complications in Adult Deformity Surgery

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Hypothesis

Mechanical complications, often aggregated under a unified composite variable, exhibit substantial variations in nature and characteristics.

Design

Retrospective observational study of adult spinal deformity (ASD) patients from a prospective multicenter database

Introduction

The most prevalent mechanical complications post adult deformity surgery are proximal junctional problems, pseudoarthrosis (PA), and rod breakage (RB). Despite these complications being typically studied together, we hypothesize that they are different entities in nature and characteristics. This study aims to differentiate and cluster their behavioral patterns based on evolution and predisposing factors.

Methods

All ASD operated patients from the database were analyzed for Proximal Junctional Kyphosis (PJK), Proximal Junctional Failure (PJF), pseudarthrosis, rod breakage, and no complications. Kaplan-Meier survival analysis with Log-Rank tests and multivariate Cox regression models, encompassing biological variables, radiographic alignment, and surgical parameters, were utilized to identify complication-related factors.

Results

1,505 patients were analyzed, with 260 (17.3%) developing mechanical complications: PJK (65), PJF (43), PA (56), and RB (96). Similar time-to-event patterns were observed for PJK and PJF (Log-Rank test p=0.446) (160 days [Q1=72; Q3=492]), and PA and RB (Log-Rank test p=0.782) (695 days [Q1=371; Q3=1059]), clustering them in pairs. Survival curves differed significantly between PJK/PJF and PA/RB (Log-Rank test p<0.001). Multivariate models associated (p<0.05) PJK/PJF occurrence with age (OR=1.039), Short Form 36 Physical Component Summary Scale (SF36-PCS) (OR=0.963), and alignment parameters (Relative Lumbar Lordosis [OR=1.025], Relative Spinopelvic Alignment [OR=1.064]), and the number of instrumented levels (OR=1.123). PA/RB occurrence was associated (p<0.05) with age (OR=1.017), Body Mass Index (OR=1.044), SF36-PCS (OR=0.975), alignment parameters (Relative Spinopelvic Alignment [OR=1.034]), and the number of instrumented levels (OR=1.127).

Conclusion

Clustered complications PA/RB exhibit delayed onset compared to PJK/PJF. While influencing variables overlap, PJK/PJF is more related to altered alignment parameters, while PA/RB is more influenced by biological factors.

Table 1. Multivariate Cox Regression Model with PJK/PJF as composite dependent variable

			95% CI	
	p	OR	Min	Max
Age	0.000	1.039	1.020	1.059
Gender	0.152	1.426	0.878	2.318
BMI	0.859	1.004	0.960	1.050
Smoking	0.625	0.972	0.868	1.089
SF36-PCS	0.003	0.963	0.940	0.987
N instrum levels	0.000	1.123	1.073	1.176
RLL	0.033	1.025	1.002	1.049
RSA	0.000	1.064	1.032	1.098

Table 2. Multivariate Cox Regression Model with PA/RB as composite dependent variable

			95% CI	
	p	OR	Min	Max
Age	0.034	1.017	1.001	1.033
Gender	0.271	1.315	0.808	2.139
BMI	0.042	1.044	1.002	1.088
Smoking	0.923	0.995	0.906	1.093
SF36-PCS	0.019	0.975	0.955	0.996
N instrum levels	0.000	1.127	1.077	1.178
RLL	0.698	0.995	0.972	1.019
RSA	0.049	1.034	1.000	1.068

Multivariate Cox Regression Models

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Paper #64. The Varus Knee Phenomenon in Spinal Deformity Patients

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Hypothesis

Spinal deformity patients with severe sagittal and coronal malalignment are predisposed to presenting with the varus knee phenomenon in standing films, which will correct postoperatively when global spine alignment is restored.

Design

A retrospective, single-center case control study.

Introduction

In spinal deformity patients, non-pelvic extraspinal compensatory measures (e.g. hip extension, knee flexion, and ankle dorsiflexion) have been described in the literature to maintain sagittal spinal alignment, however, there is paucity of literature describing coronal compensatory changes. This study aims to present the prevalence of compensatory varus knee phenomenon in spinal deformity patients in the preoperative setting and the effects of postoperative global spinal alignment restoration to the lower extremity mechanical axis.

Methods

A retrospective, single-center radiographic review of 314 patients receiving spinal deformity surgery by a single surgeon between July 2015 to 2018 were included. The mechanical axis deviation (MAD) was the distance measured from the lower extremity mechanical axis to the center of the tibial spine. The varus knee position was defined when the center of the knee was 20 mm lateral to the MA of the lower extremity. Sagittal vertical axis (SVA) and knee flexion angle (KFA) were also measured pre- and postoperatively.

Results

Among the 223 adult patients, 44 (20%) had malalignment preoperatively, with significant improvements in MAD, SVA, and KFA noted postoperatively. Within the malaligned group, the MAD decreased from 28.2±15.6mm to 20.2±17.5mm on the right lower extremity ($p=0.02$); on the left, MAD decreased from 28.5±16.5mm to 20.2±15.8mm ($p=0.003$). SVA decreased from 73.2±68.9mm to 39.5±36.0mm ($p=0.003$). KFA decreased from 15.1±8.0˚ to 12.3±8.9˚ ($p=0.009$). Among those with varus malalignment, MAD changed on the right from 29.9±17.4mm to 21.1±19.1mm ($p<0.001$). On the left, MAD changed from 31.8±17.4mm to 20.3±14.1mm ($p=0.002$). SVA changed from 76.4±73.9mm to 37.8±36.6mm ($p<0.001$). KFA likewise decreased from 16.1±11.6˚ to 12.6±9.8˚ ($p=0.02$).

Conclusion

The coronal lower extremity malalignement in spinal deformity patient is present in 19.7% of the adult cohort. More than 50% of adult patients with the varus knee phenomenon self-corrected to neutral lower extremity mechanical axis after spinal deformity correction. Within the varus group, the spinal deformity surgery improved the SVA, KFA, and mechanical axis deviation.

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Adult Group (>=19 years) N (%) or Mean±SD	Mechanically Aligned (<20mm) (n=179)	Mechanically Malaligned (>20mm) (n=44)	p-value†
Age (years)	44.5±18.5	50.7±19.6	0.051
Diagnosis			-
AdIS	122 (54.8)	18 (8.1)	
ADS	24 (10.8)	13 (5.8)	
Congenital Scoli	12 (5.4)	0 (0)	
Kyphosis	11 (4.9)	2 (0.9)	
NMS/Syndromic	10 (4.5)	11 (4.9)	
Primary	91 (40.8)	27 (12.1)	0.21
Preop MAD R (mm)	7.4±5.4	28.2±15.6	**<0.0001**
Postop MAD R (mm)	7.5±5.6	20.2±17.5	**<0.0001**
p-value*	0.28	**0.019**	-
Preop MAD L (mm)	7.5±4.7	28.5±16.5	**<0.0001**
Postop MAD L (mm)	7.2±5.7	20.2±15.8	**<0.0001**
p-value*	0.070	**0.0031**	-
Preop SVA (mm)	41.1±44.0	73.2±68.9	**0.0002**
Postop SVA (mm)	28.0±21.8	39.5±36.0	**0.0071**
p-value*	0.12	**0.0027**	-
Preop KFA (°)	7.9±7.0	15.1±8.0	**0.0002**
Postop KFA (°)	7.8±5.9	12.3±8.9	**0.0026**
p-value*	0.53	**0.0087**	-
# of patients with Mechanical Malalignment (%)	7 (3.1)	22 (9.9)	**<0.0001**
Postop varus (%)	7 (3.1)	15 (6.7)	
Postop valgus (%)	0 (0)	7 (3.1)	

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Paper #65. Effects of Knee Osteoarthritis on Compensatory Mechanisms Post- SpinalDeformity Correction

Yoon Ha Hwang, MD; Kyunghyun Kim, MD, PhD; Yoon Ha, MD, PhD; Jaeyoung So, MD

Hypothesis

In cases of adult spinal deformity with concomitant severe knee osteoarthritis, it is hypothesized that postoperative radiological restoration and clinical improvement may be adversely affected.

Design

Retrospective, propensity score matched cohort study.

Introduction

We investigated the relationship among regional alignments, the chronological sequence of compensatory mechanism changes, restoration of sagittal malalignment, and the effect of knee osteoarthritis on vanishing compensatory mechanism and clinical outcomes in deformity correction surgery.

Methods

We reviewed medical records and EOS radiographs of 75 patients with adult spinal deformity (ASD) undergoing thoracolumbar fusion between May 2018 and June 2022, with a minimum of 2 year of postoperative follow-up. Data collection focused on changes in various spinal and lower extremity alignments, including global angle, pelvic shift, knee angles (KA), and ankle angles (AA). We conducted propensity-matched comparisons to elucidate the impact of (OA) on vanishing compensatory mechanisms between the knee osteoarthritis group (KOA) and the non-knee osteoarthritis group (NKOA) based on the Kellgren-Lawrence Grading (KLG). Additionally, the study assessed patient-reported outcome measures such as the Oswestry Disability Index, Scoliosis Research Society questionnaire, and the 36-Item Short-Form Health Survey.

Results

A significant linear correlation was observed between the change in T1 pelvic angle (Δ TPA) and the changes in various spinal and lower extremity parameters during follow-ups. Meaningful correlation coefficients for thoracic kyphosis, sacro-femoral angle (SFA), and AA, initially not observed, were confirmed during the final follow-up. KOA group exhibited limited restorative changes in compensatory spinal and lower extremities (KA: 1.1 ± 5.5 vs 7.1 ± 9.3, $p=0.015$). Clinical outcomes showed improvement in both groups, with the NKOA group demonstrating more significant progress in SF-36 ($p<0.05$).

Conclusion

Restoring sagittal alignment leads to the disappearance of compensatory mechanisms in a temporal pattern, with lower extremity improvements continuing for over a year. Severe knee OA over KLG 3 impedes this restoration and results in poorer clinical outcomes.

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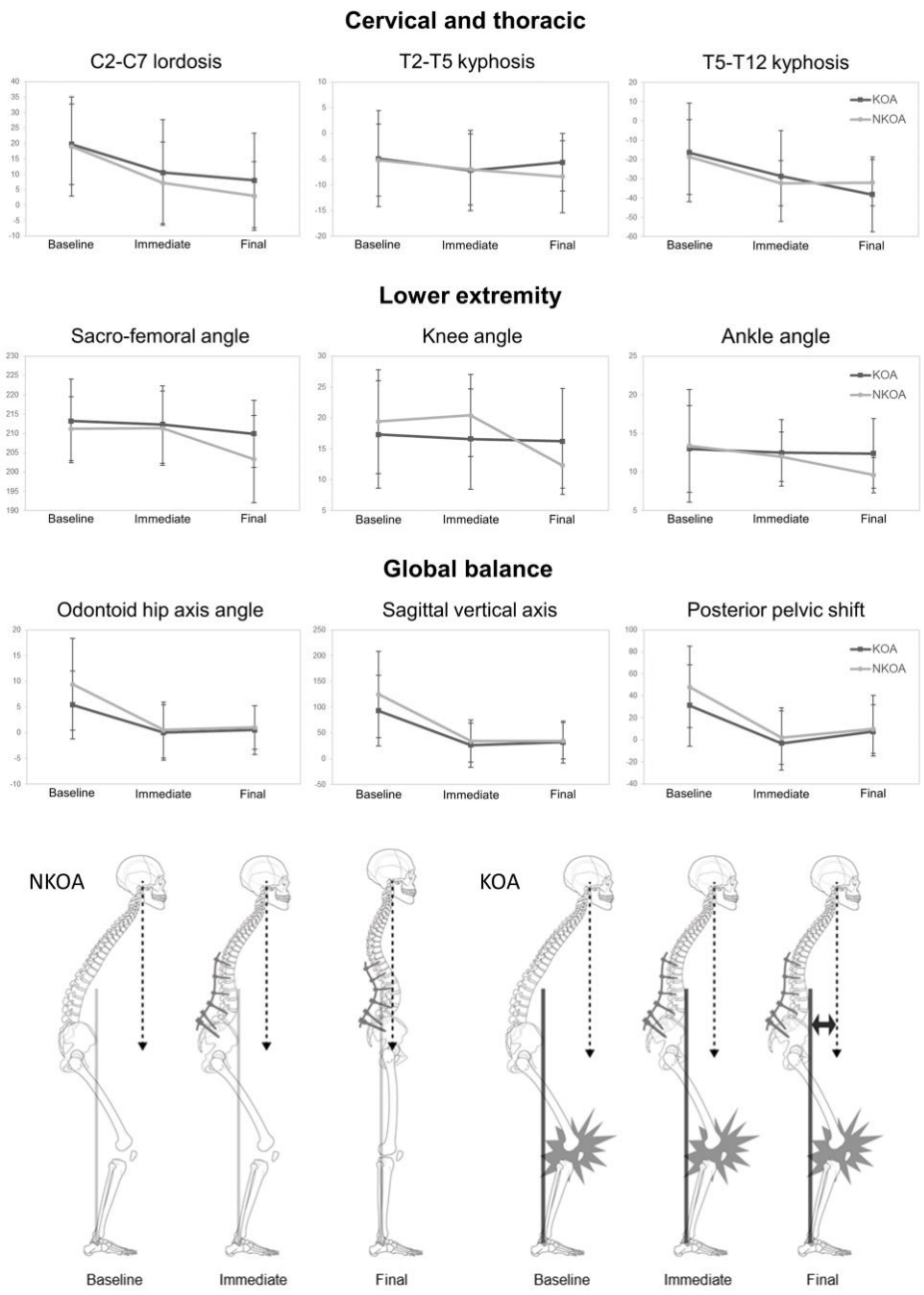

Baseline, immediate, and final follow-up data for regional and global parameters are presented, showing sagittal balance restoration differences in knee osteoarthritis (KOA) and NKOA through diagrams.

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Paper #66. Impact of Knee Osteoarthritis and Arthroplasty on Full Body Sagittal Alignment in Adult Spinal Deformity Patients

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Hypothesis
Knee osteoarthritis (KOA) and arthroplasty (TKA) affect sagittal spinopelvic alignment and patient reported outcome measures (PROMs) in adult spinal deformity (ASD) patients.

Design
Retrospective review of prospectively collected data.

Introduction
Limited studies have examined the impact of KOA and TKA on ASD patients. This study aims to assess how KOA and KA affect full body sagittal alignment parameters and PROMs.

Methods
Patients underwent ASD surgery with pre-operative full-body radiographs were included. OA was graded by two reviewers using the Kellgren Lawrence (KL) classification. In analysis #1: patients were grouped into: bilateral KL<3 (G1), unilateral KL>2 (G2), and bilateral KL>2 (G3). For analysis #2 patients with severe KOA were excluded, and patients were then grouped intopatients with bilateral mild KOA KL<3 (Mild) and patients with unilateral/bilateral (TKA). Patients were propensity-score matched for age, frailty, HOA, PI, and T1PA. Comparative analyses were performed on patient demographics, baseline radiographic sagittal alignment, and/or PROMs (PROMIS, SRS, VR12, ODI). Multivariate regression controlling for age, frailty, PI, T1PA, and KOA, was done to identify independent alignment predictors associated with KOA.

Results
290 patients in analysis#1 (199 G1, 31 G2, 60 G3), G2 and G3 were older (G1: 50.3, G2:63.3, G3:62.3 years) and G2 were frailer G1 (G1: 2.6, G2:4.1) ($p<0.05$). No difference was observed in sex or comorbidities. On univariate analysis, PT, PI-LL, SVA, sacro-femoral, knee flexion, ankle dorsiflexion angles, pelvic shift, and GSA were significantly worse in G2 and G3 (Figure 1). On multivariate analysis, only knee flexion ($R=0.63$, $\beta=0.13$, $p=0.01$) and ankle dorsiflexion ($R=0.47$, $\beta=0.14$, $p=0.02$) angles were independently associated with KOA. In analysis#2 (48 mild OA, 48 TKA), no difference was found in sagittal alignment parameters or PROMs.

Conclusion
ASD patients with severe KOA present with a worse full body sagittal deformity (higher GSA, SVA and PI-LL). However, KOA was only independently associated with greater knee flexion and ankle dorsiflexion. In a matched subanalysis, TKA patients exhibited similar PROMs and radiographic full body alignment vs. patients with mild OA.

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Variable	Bilateral non-severe knee osteoarthritis (n=199)	Unilateral severe knee osteoarthritis (n=31)	Bilateral severe knee osteoarthritis (n=60)	p-value
Pelvic tilt	20.7 ± 11.2	26.3 ± 9.5*	27.0 ± 9.2*	<0.001
PI-LL	8.0 ± 23.7	19.6 ± 19.2*	16.3 ± 20.3*	0.005
Sagittal vertical axis	34.7 ± 55.4	65.4 ± 75.0*	51.7 ± 53.1	0.009
Sacro-Femoral angle	203.6 ± 10.5	205.1 ± 11.1	207.4 ± 8.4*	0.047
Knee flexion angle	-0.02 ± 7.3	7.8 ± 9.4*	4.5 ± 8.7*	<0.001
Ankle dorsiflexion angle	2.3 ± 4.0	6.6 ± 4.5*	5.1 ± 4.1*	<0.001
Pelvic shift	13.1 ± 41.8	34.4 ± 42.1*	30.5 ± 46.1*	0.004
Global sagittal alignment	2.1 ± 5.1	5.7 ± 6.4*	4.5 ± 5.4*	<0.001
*: Statistically significant difference when compared to G1 in post-hoc analysis				

Figure 1: Results of Univariate comparison in analysis#1 and anteroposterior and Lateral standing radiographs of patients with bilateral mild knee osteoarthritis (A), unilateral severe knee osteoarthritis (B), bilateral severe knee osteoarthritis (C), and bilateral total knee arthroplasty (D).

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Paper #67. Does Achievement of Ideal L1PA Using Mis Techniques in Asd Correction Lead to Better Outcomes?

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Hypothesis
Achieving optimal L1 PA using MIS correction of ASD will lead to better outcomes and a reduction in revision rates.

Design
Retrospective cohort review of multi-center prospectively collected database

Introduction
Previous research has suggested there is an ideal L1 vertebral pelvic angle (L1PA) and the T4 pelvic angle is nearly equivalent, which aligns the T4-L1 Hip axis. Early data from open technique cohorts suggests that achieving ideal L1 PA after surgical correction is associated with lower rates of surgical revision. We investigated how frequently ideal L1PA was achieved with MIS correction of ASD, as well as its potential impact on mechanical failure and revision risks.

Methods
Inclusion criteria was diagnosis of ASD (scoliosis≥20°, SVA≥5cm, PT≥25°, or TK≥60°) and min 2yr follow-up. Ideal L1PA was defined as (0.5xPelvic Incidence)-21. Patients were determined to have achieved ideal alignment if their 6-week postop XR demonstrated an L1PA within 5 degrees of Ideal L1PA. Logistic regression was performed to assess the effect of L1PA on surgical reoperations and HRQOL.

Results
1108 patients met inclusion criteria. 131 patients were in the MIS group and 973 patients were in the open group. Baseline parameters were similar between MIS and open groups: T4PA (20.0 vs 18.1, p=.107), L1PA (11.7 vs 12.1, p=.698), SVA (68.3 vs 58.9, p=.079), PI-LL (17.3 vs 14.5, p=.101), maximum Cobb (28.4 vs 38.4, p=.09) and pelvic tilt (22.3 vs 23.0, p=.569). 63% of patients in the MIS group achieved ideal L1PA after surgical correction compared to 61% in the open group (p=.342). Preoperative L1 PA decreased on average 2.1 degrees to 9.9 degrees in a combined cohort. Achieving ideal L1PA alignment in the MIS group was associated with reduced risk of reoperation (15% vs. 33%, p<0.01), and greater increase in SRS-22 (0.85 vs 0.40, p<0.01). Achieving ideal L1PA in the open cohort did not result in a reduction in reoperation rate (21% vs 23%, p=.484). In both cohorts, rod breakage rates (4% vs 9%, p=.17) and PJK rates (15.2% vs 12.2%, p=.16) were not different when comparing ideal to nonideal L1PA.

Conclusion
Optimal alignment as defined by L1PA can be achieved similarly to open techniques when utilizing MIS for correcting ASD, and reaching that target successfully may reduce the risk of reoperation and improve outcomes.

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Paper #68. The T4-L1-Hip Axis Captures the Roussouly Concepts Using Continuous Measures

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Hypothesis

The T4-L1-Hip Axis effectively describes spinal shape using continuous measures and is consistent with the Roussouly Classification.

Design

Cross-sectional cohort

Introduction

The Roussouly classification describes 4 normal spine shapes. However, this approach is prone to misclassification bias. The T4-L1-Hip axis describes sagittal alignment by defining the L1 pelvic angle (L1PA) relative to pelvic incidence (PI), and the T4-L1PA mismatch (T4PA – L1PA), with measurement error < 2°. We sought to determine if the T4-L1-Hip axis approach captures the Roussouly concepts and is consistent with the Roussouly classification.

Methods

Asymptomatic volunteers ages 18-40 with no signs of disk degeneration or coronal deformity were included. Radiographic measurements were obtained from full spine radiographs (EOS Imaging, SA, France). Roussouly type (R type) was determined for each volunteer. The relationship between L1PA and PI, and T4-L1PA mismatch were examined for each Roussouly type. To determine consistency with the Roussouly classification, a multivariable regression model was fit to estimate Roussouly type by L1PA, PI, and T4-L1PA mismatch.

Results

Of 320 volunteers included, 193 (60%) were female and median age was 37 (IQR, 27-47). Median PI was 52° (45, 58), median L1PA was 4° (0, 8), median T4-L1PA mismatch was -1° (-3, 1). 33 (10%) volunteers were identified as R Type 1, 47 (15%) as Type 2, 161 (50%) as Type 3, and 79 (25%) as Type 4. PI and L1PA were strongly associated (r2 = 0.6) and consistent across R types (Fig 1A). L1PA was strongly associated with T4PA (r2 = 0.8) and consistent across R types (Fig 1B). The T4-L1PA mismatch varied slightly by R type, reflected by the small association with PI (Fig 1C, 1D). A regression model estimating R type by PI, L1PA, and T4-L1PA mismatch showed high discrimination (C = 0.96) and high accuracy (Brier score = 0.056).

Conclusion

L1PA, PI, and the T4-L1PA mismatch effectively captures the Roussouly concepts using continuous measures, offering the opportunity for personalized alignment based upon PI. As precision-medicine moves forward in ASD, alignment targets are needed for the individual, rather than categories, which are prone to misclassification and inter-rater reliability issues.

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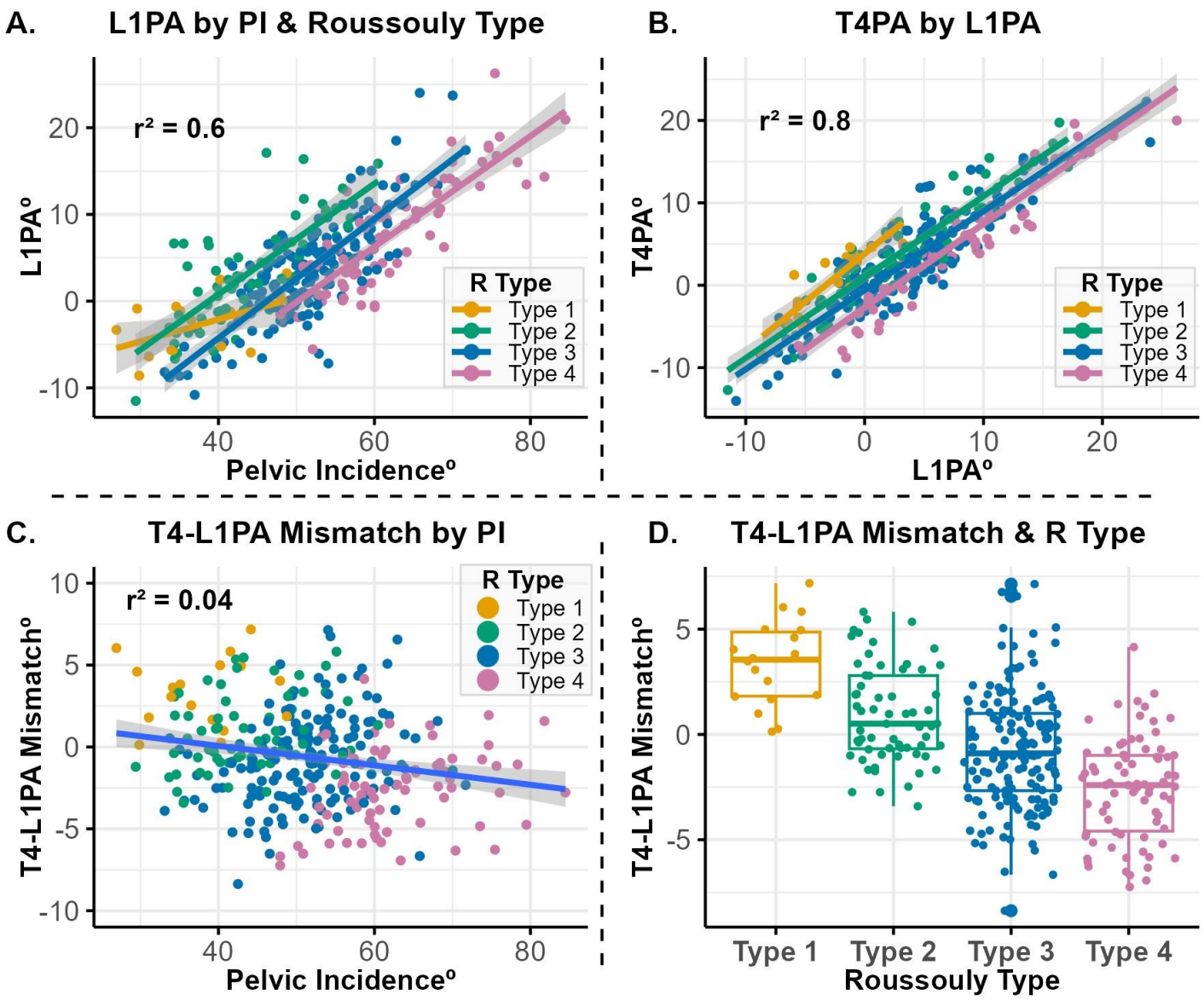

A) L1PA by PI & R type; B) T4PA by L1PA & R type; C) T4-L1PA Mismatch by PI & R type; D) T4-L1PA Mismatch & R Type

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Paper #69. Characteristics of L1PA Based on Corrections in the Proximal Vs. Distal Lumbar Spine for Adult Sagittal Plane Imbalance

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Hypothesis
Change in L1 pelvic angle (L1PA) depends on change in distal lumbar lordosis (DLL) but not on change in proximal lumbar lordosis (PLL) (Figure).

Design
Single-center retrospective radiographic analysis.

Introduction
Over the last several decades, Cobb angles have been the dominant parameter used to evaluate spinal alignment. However, the limitations of Cobb angles have inspired new research into vertebropelvic angles (VPA) as a novel method to describe alignment. Within this context, the role of Cobb angles in the analysis of sagittal alignment must be re-examined. Here, we aim to clarify the relationships between DLL, PLL, L1PA, and L4PA in the pre- and postoperative radiographic assessment of adult spinal deformity (ASD).

Methods
ASD patients who underwent meaningful (ie, exceeding measurement error) proximal and distal lordosis correction (absolute ΔCobb > 10°) were included (2013-2021). Preoperative and immediate postoperative radiographs were used to determine Cobb angles and VPAs. DLL was defined as L4-S1 Cobb and PLL as L1-L4 Cobb. Unadjusted and adjusted analyses were performed to examine relationships between L1PA, L4PA, and lumbar lordosis (LL).

Results
A total of 99 ASD patients were included with median lumbar lordotic apex of L4. Mean age was 60.6 years, mean BMI was 27.7, and 71.7% were female. Median pre-to-post changes were as follows: ΔLL -20° (IQR -30.8°, -9.2°), ΔPLL -6° (IQR -18.1°, 8.4°), ΔDLL -10.4° (IQR -22.8°, 2.0°), ΔL1PA -5° (IQR -10.0°, -0.0°), and ΔL4PA -0.2° (IQR -2.4°, 2.0°). Univariate correlations demonstrated that ΔLL was correlated with ΔL1PA ($r=0.663$, $p<0.001$) and ΔL4PA ($r=0.372$, $p<0.001$). Furthermore, ΔDLL was highly correlated to ΔL1PA ($r=0.709$, $p<0.001$) and ΔL4PA ($r=0.504$, $p<0.001$), while ΔPLL was not correlated to ΔL1PA or ΔL4PA. Multilinear regression adjusting for age, sex, BMI, and preoperative PI showed that ΔDLL was a strong independent predictor of ΔL1PA (model $r^2=0.587$, $p<0.001$) and ΔL4PA (model $r^2=0.296$, $p<0.001$). ΔPLL was not independently associated with ΔL1PA or ΔL4PA.

Conclusion
ΔL1PA correlates strongly with ΔDLL but not ΔPLL. Distal VPAs, such as L4PA, change minimally with ASD correction and may not be useful parameters to assess spinal alignment. Given that Cobb angles and VPAs describe related but distinct aspects of alignment, future research must identify alignment goals for both LL and L1PA.

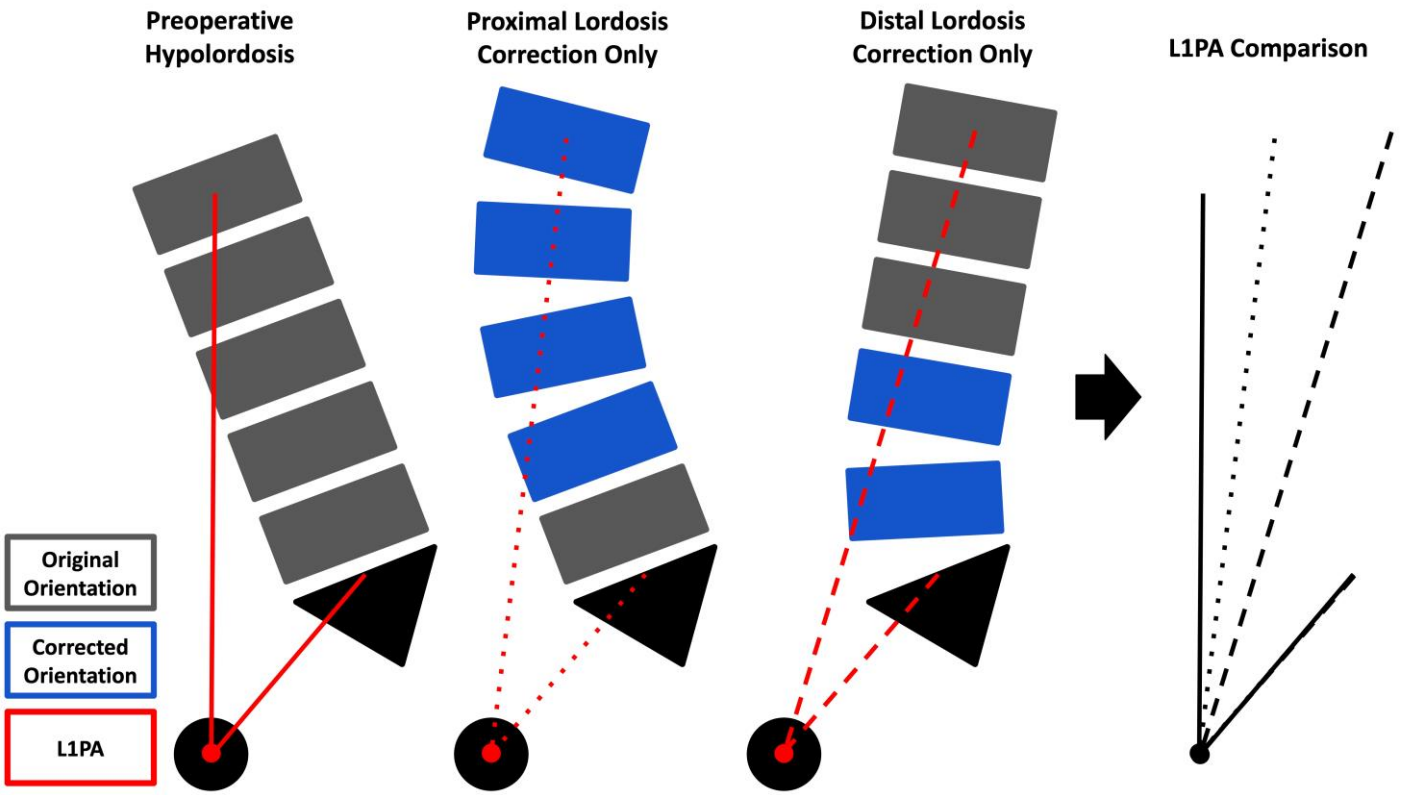

Figure. ΔDLL has a greater effect on ΔL1PA