

1. The Role of L5–S1 in Determining Lumbar Shape: Segmental Determinants of Normal L1PA

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Hypothesis

Pelvic incidence (PI) and individual lumbar segments contribute differentially to variation in L1 pelvic angle (L1PA) in asymptomatic individuals.

Design

Cross-sectional cohort.

Introduction

Lumbar alignment targets in spinal deformity surgery are typically defined at a regional level; however, achieving these targets requires segmental alignment planning. Understanding the normal relationship between PI and segmental lordosis, as well as the relative contribution of each segment to the overall lumbar shape is critical for achieving physiologic alignment.

Methods

A multinational cohort of asymptomatic volunteers > 18 years old with no radiographic evidence of disc degeneration or scoliosis was studied. Radiographic measurements were obtained from full spine radiographs (EOS Imaging, SA, France). Segmental lumbar lordosis from L1–L2 through L5–S1 and L1PA were measured. Univariate linear regression assessed the association between PI and segmental lordosis. Multivariable linear regression evaluated the relative contribution of PI and individual segmental lordosis values to L1PA. The relative importance of each variable was quantified using ΔR^2 , calculated as the reduction in model R^2 following variable removal.

Results

Among 319 volunteers (60% female; median age 37 years [IQR, 27–47]), median PI was 52° (IQR, 45–58). Median segmental lordosis increased caudally from 2.1° (–0.2, 4.7) at L1–L2 to 22° (18, 27) at L5–S1. HPI demonstrated small-to-moderate positive associations with mid-lumbar segmental lordosis ($R^2 = 0.06–0.15$) but no meaningful association with L5–S1 lordosis ($R^2 \approx 0$) (Fig 1). For each 10° increase in PI, lordosis increased by 1.3° at L1–L2; 1.6° at L2–L3; 0.9° at L3–L4; and 1.7° at L4–L5. In multivariable modeling, PI and L5–S1 together explained over 90% of the variance in L1PA, with ΔR^2 contributions of 63% for PI and 28% for L5–S1.

Conclusion

In normal individuals, variation in L1PA is primarily determined by PI and L5–S1 lordosis, with L5–S1 acting independently of PI. Thus, attempting to achieve a target L1PA through increased correction of mid or cranial lumbar segments may produce a non-physiologic lumbar shape. Segmentally informed alignment strategies that respect the role of L5–S1 may better preserve normal lumbar alignment.

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

Segmental & Regional Lumbar Alignment

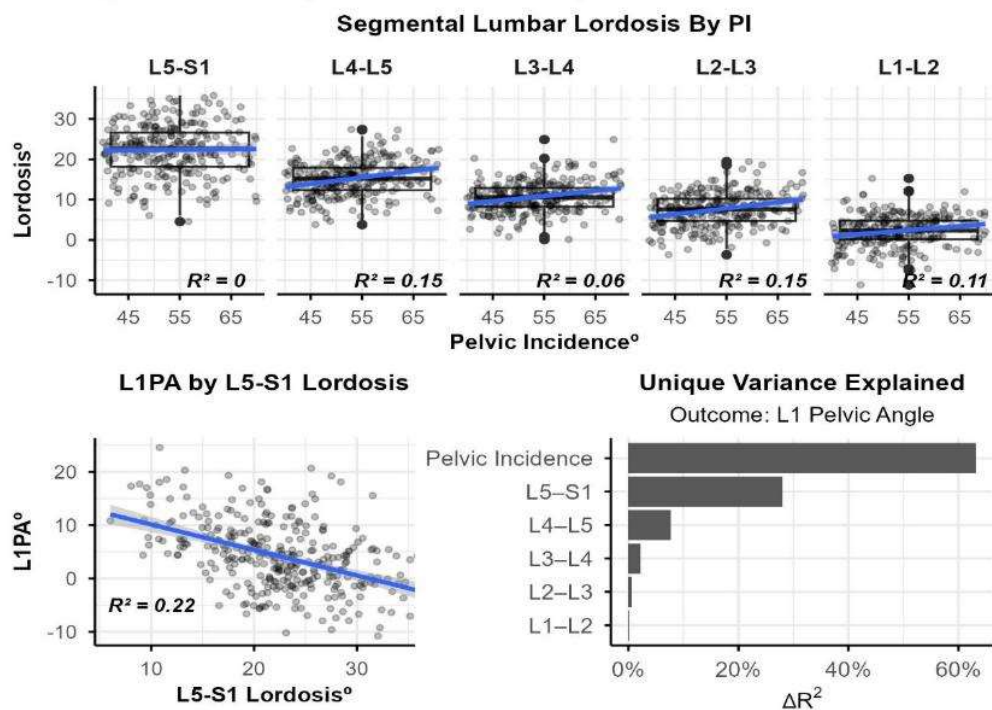


Fig 1. Segmental Lordosis by PI; L1PA by L5-S1 Lordosis; & L1PA variance explained by PI and segmental lordosis.

2. The Sacro-acetabular Angle: A Morphologic Property That Helps Predict Positional Spinopelvic Parameters

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Hypothesis

The SAA contributes significantly to the prediction of positional sagittal spinopelvic parameters.

Design

Cross-sectional descriptive study in asymptomatic adult volunteers.

Introduction

Morphologic spinopelvic parameters carry inherent utility when assessing and correcting malalignment. This is especially true when they can be related to positional parameters. The sacro-acetabular angle (SAA) is an angle subtended by the S1 superior endplate and a line connecting the anterior and posterior acetabular walls (Fig 1). This morphologic parameter defines the version required to maintain motion of the hip within the physiologic arc for a given activity. As SAA is not intrinsic to commonly used sagittal morphologic properties such as Pelvic Incidence (PI), understanding its normative relationships with other measures of alignment may help with predicting highly variable positional parameters.

Methods

Full length EOS radiographs of adult (18-40) volunteers were obtained and segmented using Keops® online imaging platform. Subjects' clinical and radiological parameters including PI, L1PA, PT, SS and LL were measured and recorded. Association between SAA and subjects' demographics and spinopelvic parameters were determined using linear regression analyses.

Results

Five hundred volunteers obtained EOS scans, with subsequent exclusion of subjects with incidental scoliosis, spondylolisthesis, previous lower limb surgery, ODI>10, lumbosacral transitional anatomy and inadequate imaging, leaving 378 subjects included in the final analysis. Significant correlation was identified between SAA and spinopelvic parameters, with improved predictive power when PI was included in the model. Relationships between SS, PT, LL and L1PA were respectively correlated with SAA and PI as follows: $SS = 0.41 \cdot PI + 0.39 \cdot SAA - 9.3$ ($R^2=0.70$) $PT = 0.59 \cdot PI - 0.39 \cdot SAA + 9.3$ ($R^2=0.55$) $LL = 0.24 \cdot PI + 0.63 \cdot SAA - 2.5$ ($R^2=0.48$) $L1PA = 0.54 \cdot PI - 18 \cdot SAA - 8$ ($R^2=0.64$)

Conclusion

The SAA, a sagittal plane morphologic property, improves prediction of positional measures of alignment when combined with the PI, helping to explain the variability in overall sagittal alignment observed in healthy volunteers with similar PI. Identification of further morphologic properties is essential to understanding the drivers of upright posture and to the prevention of mechanical failure in the correction of spinal deformity.

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

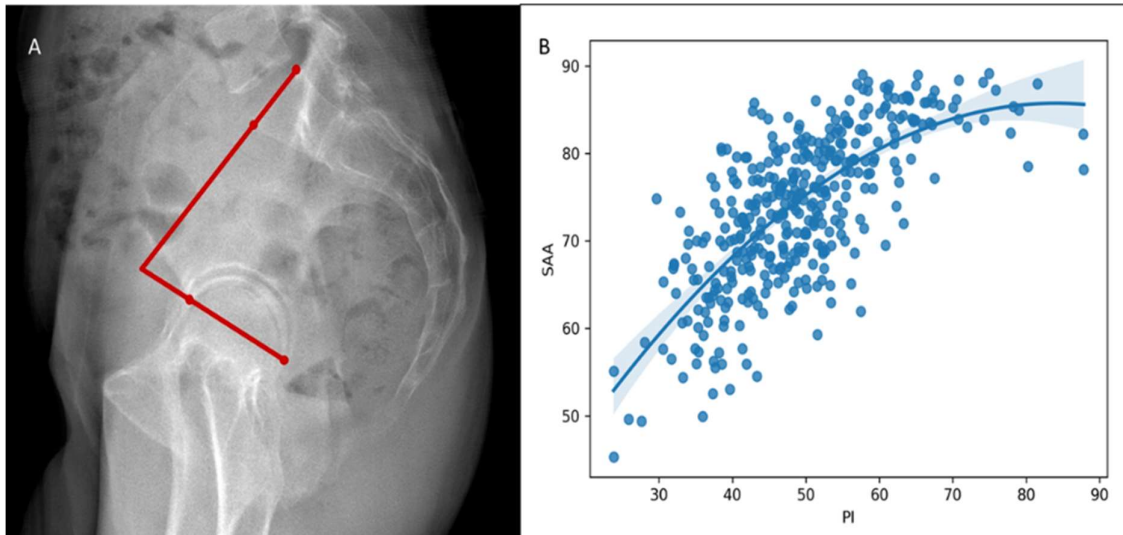


Fig 1: SAA (A) and its relationship to PI (B).

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3. Vertebral-Pelvic Angle-Based Classification Identifies Degenerative Sagittal Alignment Patterns

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Hypothesis

VPA-based classification identifies degenerative sagittal alignment patterns that independently predict physical function.

Design

Cross-sectional observational study.

Introduction

Objective criteria for defining degenerative sagittal alignment in adults are lacking. VPA parameters, L1 pelvic angle (L1PA) for lumbar alignment and T4-L1 pelvic angle mismatch (T4-L1MM) for thoracic harmony, provide continuous measures of sagittal alignment relative to pelvic morphology. We developed a VPA-based classification to identify degenerative patterns and evaluated their clinical impact.

Methods

We analyzed 599 community-dwelling adults (age 40-90 years). Full-spine lateral radiographs were obtained and participants with vertebral fractures, prior spine or lower limb surgery, or neurological diseases were excluded. Based on L1PA deviation from target ($0.5 \times PI - 21^\circ$; threshold $> +2^\circ$) and T4-L1MM (threshold $> +1^\circ$), participants were classified as Normal, Lumbar-type, Thoracic-type, or Combined-type. Primary outcomes included SF-36 Physical and Mental Component Summaries, 10-meter walk speed, and VAS lumbar pain. Multivariable regression adjusted for age, sex, and BMI.

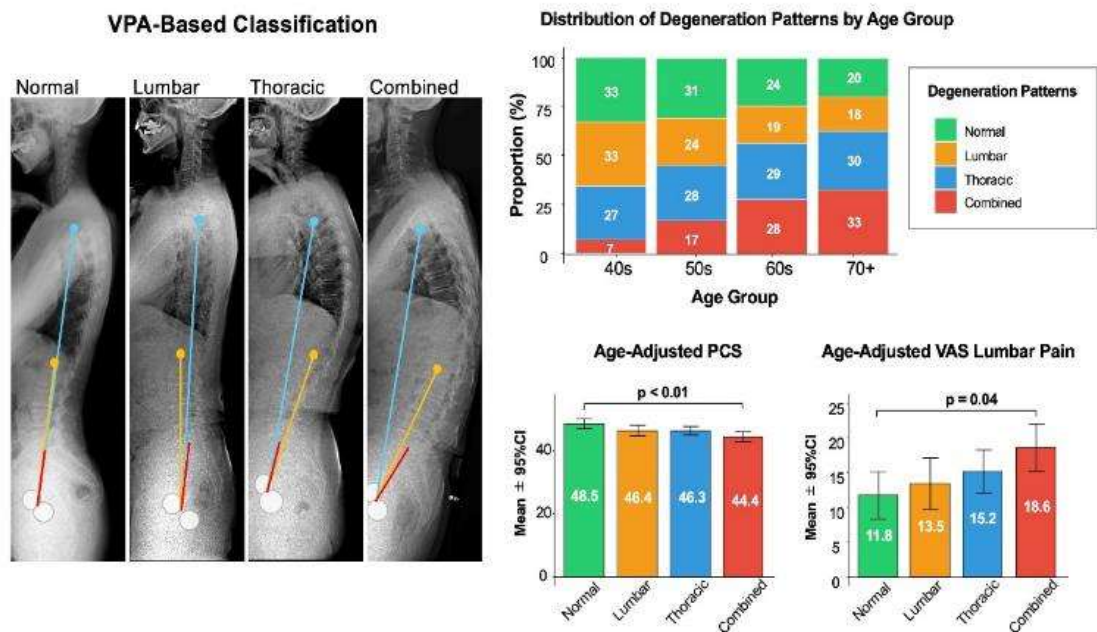
Results

Distribution was Normal 25.2% (n=151), Lumbar 21.4% (n=128), Thoracic 28.9% (n=173), and Combined 24.5% (n=147). Combined-type increased with age: 6.8% (40s) to 32.6% (70+, $p < 0.01$). After adjustment, Combined-type showed worse outcomes than Normal: Physical Component Summary 48.5 vs 44.4 (difference 4.1 points, 95%CI: 1.6-6.6, $p < 0.01$), gait speed 1.84 vs 1.58 m/s (difference 0.27 m/s, 95%CI: 0.15-0.38, $p < 0.01$), VAS pain 11.8 vs 18.6 (difference 6.9 points, 95%CI: 0.5-13.2, $p = 0.04$). Mental Component Summary showed no difference ($p = 0.25$), indicating physical-specific impairment. No significant interaction between age and deformity was detected ($p = 0.78$).

Conclusion

This VPA-based classification identified degenerative alignment in 74.8% of adults. Combined-type independently predicted physical impairment after adjusting for age, sex, and BMI, with consistent effects across all age groups.

Four degenerative patterns identified by VPA-based classification (left), Combined-type prevalence increased with age (upper right), and Combined-type showed significantly worse physical function and higher pain than Normal after age adjustment (lower right).



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

4. Association of Kyphotic and Lordotic Apices and the Thoracolumbar Inflection Point with Regional and Global Sagittal Alignment in 410 Asymptomatic Adults

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Hypothesis

Sagittal alignments apices and inflection point are associated.

Design

Cross-sectional radiographic analysis

Introduction

Sagittal alignment is essential for biomechanical efficiency, yet regional and transitional curvature landmarks remain underexplored. The thoracolumbar inflection point and the kyphotic and lordotic apices define sagittal alignment by governing distribution of curvature. However, their relationships remain poorly defined. This study evaluated the association of these landmarks with key sagittal parameters in a population of asymptomatic adults.

Methods

Standing lateral full-spine EOS radiographs of 410 asymptomatic adult volunteers (55.8% female; age 20–39 years) were analyzed. Sagittal alignment parameters including pelvic incidence (PI), Cobb angles, vertebral pelvic angles (VPAs), upper and lower thoracic arc length normalized to total thoracic arc length (UTK%, LTK%) were measured. Correlation matrices and multivariable regression analyses were used to assess associations between apex and inflection point locations and sagittal parameters.

Results

The thoracolumbar inflection point (TLIP) was most commonly located at the T12–L1 disc (range T8 to L4–L5). TLIP location demonstrated a strong correlation with T1–T12 pelvic angle ($r=0.70$), indicating a close relationship between regional curvature distribution and global thoracolumbar inclination. Multivariable regression revealed lumbar lordosis apex location was influenced by pelvic incidence, distal lumbar curvature (L4–S1 Cobb) and T1–T12 pelvic angle ($R^2=0.70$). TLIP location was predicted by a combination of pelvic morphology, UTK, and thoracolumbar alignment parameters, including pelvic incidence, UTK%, T1–T12 pelvic angle, T1–T12 Cobb angle, and L4–S1 Cobb angle ($R=0.85$). Thoracic apex location was similarly governed by pelvic incidence, thoracic curvature distribution, and thoracolumbar inclination ($R^2=0.78$).

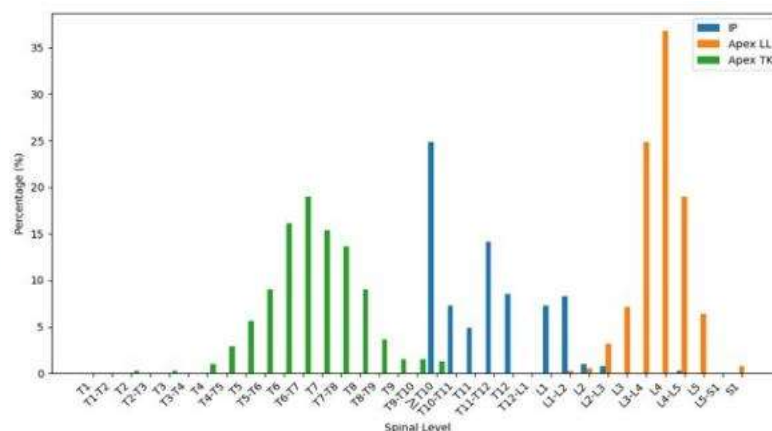
Conclusion

In asymptomatic adults, the locations of the thoracic and lumbar apices and the thoracolumbar inflection point are influenced by pelvic morphology and the regional distribution of sagittal curvature. The ability to predict apex and inflection point positions helps sagittal alignment restoration.

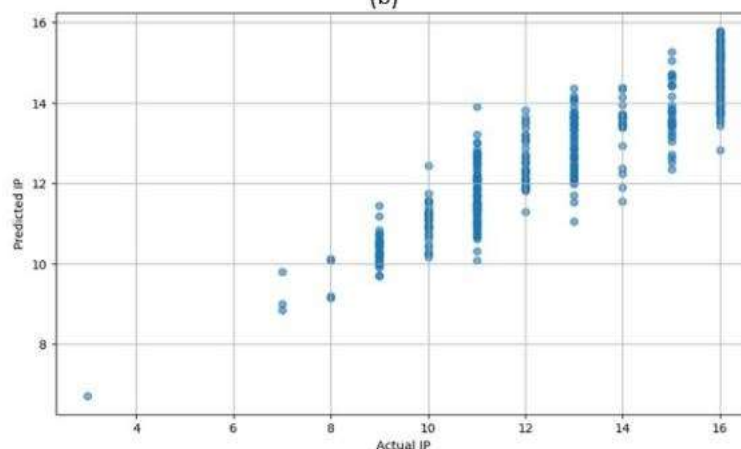
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PI	0.54	0.34	0.24
SS	0.50	0.37	0.24
L4S1_Cobb	-0.23	-0.26	-0.03
L1S1_Cobb	0.28	0.41	0.18
L4PA	0.68	0.43	0.24
L1PA	0.67	0.44	0.26
T4PA	0.38	0.08	-0.02
PI-L4S1	0.66	0.50	0.25
T1T12Cobb	-0.01	0.39	0.03
T1T12PA	-0.66	-0.70	-0.66
Apex_LL_num	1.00	0.68	0.35
IP_LL_TK_num	0.68	1.00	0.42
Apex_TK_num	0.35	0.42	1.00
LLL(%)	0.07	-0.10	-0.14
LTK(%)	-0.13	-0.29	0.70
UTK(%)	0.13	0.29	-0.70
LLL_angle	0.50	0.37	0.24
LTK_angle	0.10	0.48	0.14
UTK_angle	-0.06	0.00	-0.06
Cobb_LL	0.40	0.53	0.25
Cobb_TK	0.02	0.31	0.05
ApexPA_LL	0.71	0.46	0.24
IPPA_LL	0.52	0.16	0.15
IPL1PA	-0.55	-0.87	-0.35
Apex_LL_num			
IP_LL_TK_num			
Apex_TK_num			

(a)



(b)



(c)

(a) Correlation matrix, (b) percentage distribution of thoracolumbar inflection point and apices, (c) predicted vs. actual IP

5. Strategic Adjustment of Segmental Lumbar Lordosis to Optimize L1-Pelvic Angle Offset and Minimize Mechanical Complications After Long-Level Lumbar Fusion Surgery

Myung-Hoon Shin, MD, PhD

Hypothesis

Based on the geometric definition of the L1-pelvic angle (L1PA) as the sum of L1 tilt and pelvic tilt (PT), we hypothesize that segmental lumbar lordosis—divided into upper (L1-L4) and lower (L4-S1) components—exhibits differentiated regulatory effects on these distinct sagittal components.

Design

Retrospective cohort study

Introduction

While the L1PA is a recognized predictor of postoperative balance, it is a composite parameter (L1PA = L1 tilt + PT). Understanding how segmental lordosis specifically influences these individual components is crucial for precise surgical planning. This study aims to evaluate the PI-stratified impact of segmental lordosis on L1PA offset to optimize postoperative outcomes and minimize MC risk.

Methods

We retrospectively analyzed 103 patients (67 females, 36 males) who underwent lumbar fusion of ≥ 4 levels with a minimum 2-year follow-up. The mean age of the cohort was 68.78 ± 6.38 years, with a mean follow-up period of 35.74 ± 11.02 months. Radiographic parameters included PI, L1PA, LLL (L4-S1), and ULL (L1-L4). L1PA offset was calculated as the deviation from the target L1PA ($0.5 * PI - 19^\circ$). Patients were stratified into three groups based on PI: Low ($< 45^\circ$), Medium ($45-60^\circ$), and High ($> 60^\circ$). Multivariate regression and ROC curve analyses were performed to identify optimal segmental targets.

Results

Statistical analysis confirmed the specialized roles of lumbar segments: LLL showed a significant negative correlation with PT ($r = -0.375$, $p < 0.001$), establishing the foundational base by resetting pelvic compensation. Conversely, ULL demonstrated a significant positive correlation with L1 tilt ($r = 0.425$, $p < 0.001$), directly modulating the apical position of the L1 vertebra. A "Safe Zone" for L1PA offset was identified between -5 and $+2^\circ$, associated with the lowest MC rate of 15.4%. MC rates were significantly higher in overcorrection ($< -5^\circ$; 66.7%) and undercorrection ($> +2^\circ$; 52.2%).

Conclusion

Maintaining the L1PA offset within the safe window of -5 to 2° is critical for reducing mechanical complications. Our findings suggest a strategic model where LLL serves as the foundational engine for pelvic un-compensation through its primary impact on PT, while ULL acts as a precision handle for apical alignment by directly determining L1 tilt.

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Figure 1. Mechanical Complication Rate by L1PA Offset Range

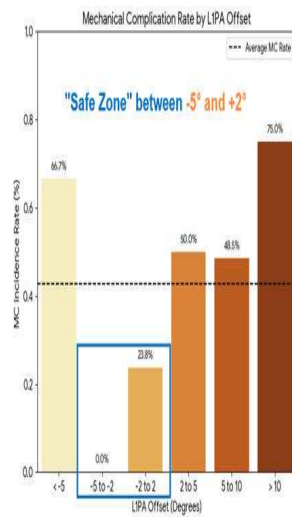
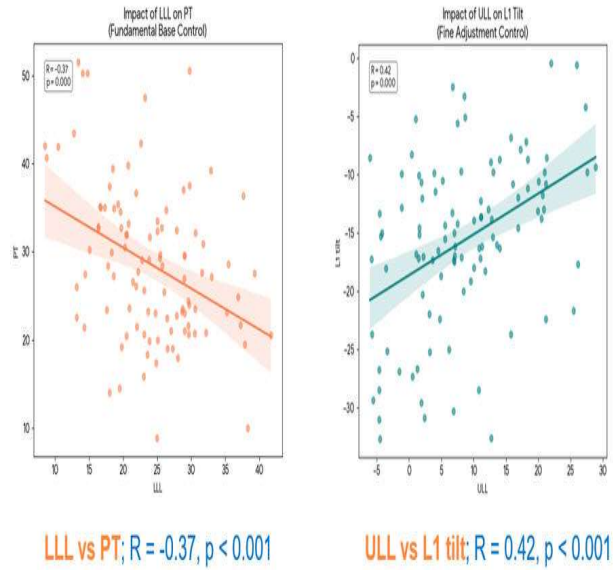


Figure 2. Segmental correlation analysis among ULL, LLL, L1 tilt and PT



Figures 1 and 2

6. Four Distinct Pelvic Response Patterns Following Adult Spinal Deformity Surgery: A Multivariate Trajectory Analysis

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Hypothesis

Distinct pelvic response patterns exist following low thoracic-to-pelvis fusion, with some patients demonstrating pelvic non-response despite adequate lordosis restoration.

Design

Retrospective study of ASD patients who underwent posterior spinal fusion from low thoracic spine to pelvis with preop, 6wk, and 2yr follow ups. Patients with PJK at 2Y or revision surgery were excluded.

Introduction

ASD surgery aims to restore sagittal alignment through lordosis restoration, with the expectation that the pelvis will reciprocally de-rotate to restore global balance. Longitudinal trajectory of pelvic positioning in successfully fused patients without major mechanical complications remains poorly characterized.

Methods

Multivariate Growth Mixture Modeling (GMM) identified latent trajectory classes based on longitudinal patterns across all main outcome measures simultaneously.

Results

GMM identified four distinct trajectories (Details in Table 1): Class 1 (Surgical Failures, n=22) worsened despite favorable baseline alignment. Class 2 (Non-Responders, n=147) demonstrated unchanged pelvic tilt despite successful PI-LL correction. Class 3 (Partial Responders, n=34) achieved excellent correction of severe baseline deformity with minimal regression. Class 4 (Ideal Responders, n=132) maintained good correction throughout follow-up. Frailty was significantly different between groups ($p = 0.039$), especially between Ideal and Non-responder ($p=0.036$). PI was different between groups, with Surgical Failures and Partial Responders having slightly larger PI than other groups (60.6° & 61.2° vs 55.3° & 55.8° , $p=0.008$). At 2Y, there were no significant differences between groups in L4-S1 (range: 31.9° - 35.1° , $p=0.67$), L1-S1 (range: 48.2° - 55.9° , $p=0.104$), T10-L2 (range: -9.3° to -12.7° , $p=0.069$), T4-T12 (range: -46.8° to -43.5° , $p=0.359$). All groups achieved similar scores at 2Y, but there were significant differences in magnitude of improvement, Partial Responders (-26.57) group showed significantly greater reduction in ODI compared to both the Surgical Failures (-13.16 , $p = 0.031$) and the Non-Responders (-16.44 , $p = 0.020$).

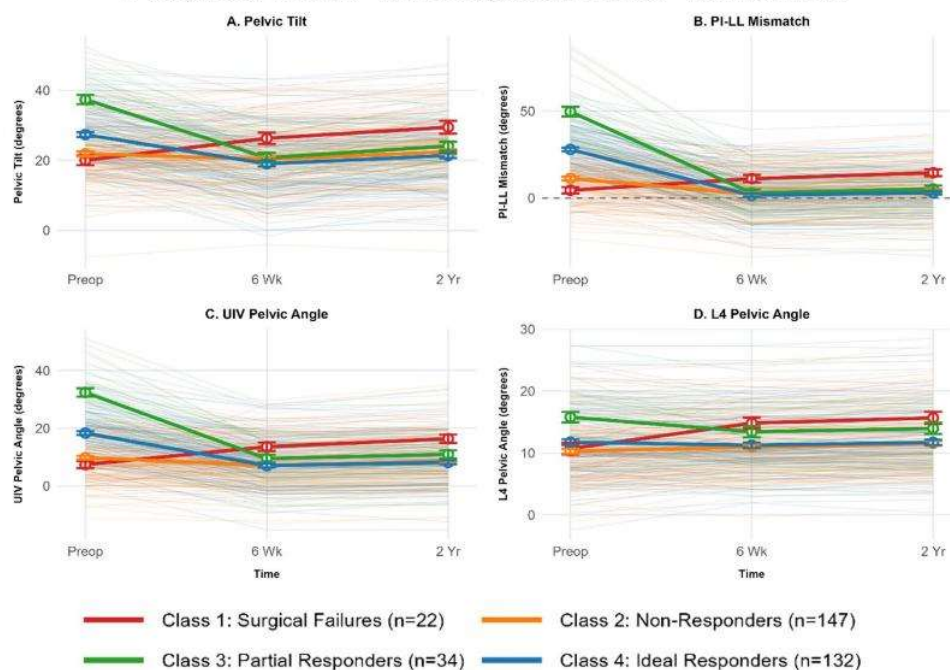
Conclusion

GMM identified four distinct PT patterns, with nearly half of patients (44%) demonstrating PT non-response despite similar LL restoration. These findings highlight the need for construct-specific alignment strategies that account for individual pelvic compensation capacity.

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Multivariate GMM 4-Class Solution: Sagittal Alignment Trajectories

N=335 patients; Thin lines = individual trajectories, Bold lines = class means $\pm$ SE



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

7. Gait Stability Seems To Deteriorate With Age And Sagittal Malalignment Severity

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Hypothesis

ASD with severe sagittal malalignment and of older age show more pronounced instability during gait.

Design

Retrospective analysis of prospectively collected data.

Introduction

Due to their spinal malalignment, ASD patients require increased energy expenditure to maintain stability in the Dubousset cone of economy, where the body center of mass (COM) oscillates. While recent studies showed that ASD patients often present with functional impairment, it is important to investigate factors influencing their gait stability.

Methods

174 ASD underwent biplanar Xrays, filled the ODI questionnaire and performed 3D gait analysis to calculate full-body kinematics. The COM was extracted in the 3 directions and normalized to subject's BMI. Corridors of normality, based on 44 controls, were established in the sagittal and horizontal planes and used to classify ASD patients into 4 groups: Inside corridors in both planes (Inside), outside sagittal corridor (Outside-Sag), outside horizontal corridor (Outside-Hor), outside corridors in both planes (Outside-Sag-Hor). Between-group comparisons were computed.

Results

ASD patients were classified as 55 Inside (mean age: 54y), 46 Outside-Hor (62y), 35 Outside-Sag (62y), and 38 Outside-Sag-Hor (66y, Fig.1). Outside-Sag-Hor patients had an increased SVA (67 vs 22mm), PI-LL (16 vs -3°) and an increased ODI (47 vs 33) compared to the Inside group. During gait, Outside-Sag-Hor patients had an increased ODHA angle both in sagittal (10 vs 5°) and frontal planes (5 vs 2°) and an increased trunk flexion (13 vs 6°). They presented a decreased hip (34 vs 42°) & knee (47 vs 59°) range of motion and a decreased walking speed (0.64 vs 0.98m/s; all $p < 0.05$). Spino-pelvic and kinematics of Outside-Sag and Outside-Hor groups ranged between the Outside-Sag-Hor and Inside groups.

Conclusion

32% of ASD were able to walk within an economic zone, most probably due to their younger age and conserved muscle strength. ASD with moderate sagittal malalignment tend to walk outside the COM corridor in one plane. Older ASD with severe sagittal malalignment present gait instability in both planes. Thus, gait stability seems to deteriorate with age and sagittal malalignment severity. Future studies should investigate whether early rehabilitation programs may help avoid migration from one group to another.

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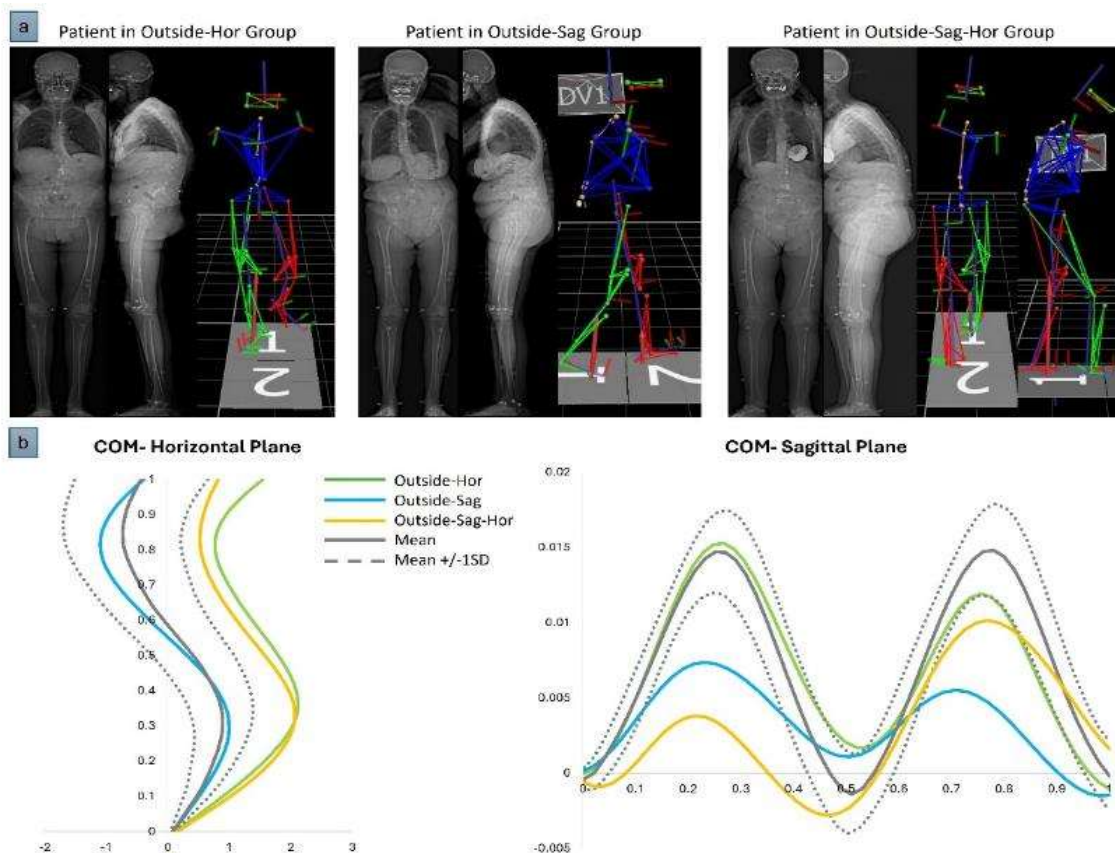


Fig.1-Examples of patients from each gait instability group (a) and their COM trajectory in the horizontal and sagittal planes (b).

8. Mechanical Complications in Functional vs Normative Alignment Targets in Adult Spinal Deformity: Should There be Adjustments for Age?

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Hypothesis

Functional PI-specific alignment targets result in fewer mechanical complications than normative strategies.

Design

Multicenter retrospective cohort study of a prospectively collected ASD database.

Introduction

Adult spinal deformity (ASD) realignment targets are increasingly tailored to pelvic incidence (PI). The T4–L1 hip axis aims to restore ideal parameters, while other studies suggest PI-specific targets that match expected functional status for age may reduce mechanical complications such as proximal junctional kyphosis (PJK) and proximal junctional failure (PJF).

Methods

Patients undergoing posterior spinal fusion for ASD with UIV>T4, LIV at S1, and 2-year follow-up were included. Alignment cohorts were defined using 6-week postoperative T4PA. Functional alignment was defined as T4PA within $\pm 3^\circ$ of a patient-specific target derived from PI and age-normative SF-36 Physical Component Score (PCS). Age-normative alignment was defined as T4PA within $\pm 3^\circ$ of an age- and PI-adjusted normative target. Age-independent normative alignment was defined as T4PA within $\pm 2^\circ$ of a PI-based target with $L1PA = (0.5 \times PI) - 19$ and $L1PA$ –T4PA mismatch between -3° and $+1^\circ$. Outcomes included PJK ($\geq 10^\circ$ change), severe PJK ($\geq 20^\circ$ change), PJF, revision surgery, and health-related quality of life (HRQL). A composite severe failure endpoint included severe PJK, PJF, or revision for PJK/PJF.

Results

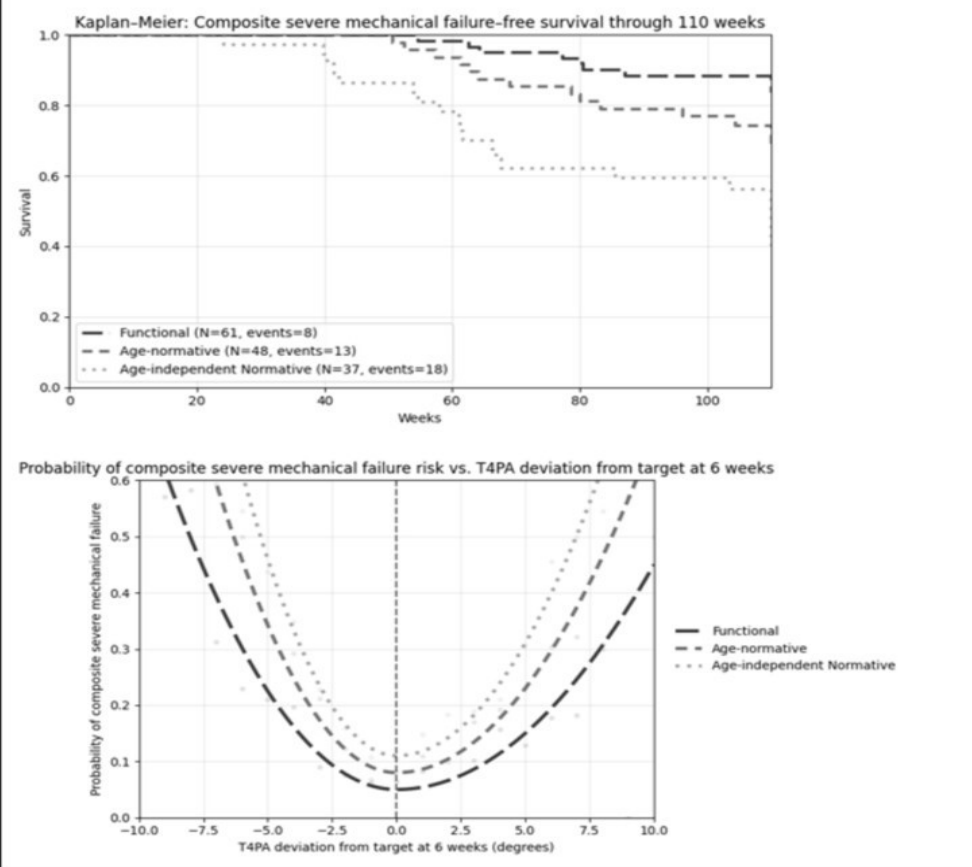
Across strategies, increasing deviation from target T4PA at 6 weeks increased severe mechanical failure risk, with both overcorrection and undercorrection contributing. Functional alignment demonstrated significantly lower severe mechanical complications than both normative strategies. Composite severe failure occurred in 6.6% at 6 weeks and 11.5% at 2 years in the functional group, compared with 16.7% and 25.0% in the age-normative group and 24.3% and 37.8% in the age-independent normative group ($p \leq 0.01$). Two-year revision rates were lowest with functional alignment (4.9% vs 7.7% vs 11.6%). HRQL improved in all groups, with greater gains in disability and physical function in the functional cohort.

Conclusion

Functional, age-adjusted alignment targets using T4PA are associated with fewer severe mechanical complications following ASD surgery. Individualizing sagittal correction to age-related functional status may improve mechanical durability while preserving clinical benefit.

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Figure 1. Kaplan–Meier Analysis of Composite Severe Mechanical Failure–Free Survival Through 110 Weeks by Alignment Strategy and Probability of Composite Severe Mechanical Failure as a Function of T4 Pelvic Angle Deviation from Target at 6 Weeks



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‡SRS Funded Research Grant

9. Full Body Radiographs with Knee Flexion Assessment in Sagittal Deformity: Does Lower Extremity Compensation Independently Inform Alignment Correction?

David D. Liu, MD; Breton Line; Feyza Achilova; Bassel G. Diebo, MD; Virginie Lafage, PhD; Renaud Lafage, MS; Richard Hostin, MD; Peter G. Passias, MD; Eric O. Klineberg, MD; Jeffrey Gum, MD; Han Jo Kim, MD; Robert K. Eastlack, 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; Brett Rocos, MD, FRCS; Jeffrey Mullin, MD; Frank Schwab, MD; Christopher I. Shaffrey, MD; Stephen J. Lewis, MD, FRCS(C); Christopher P. Ames, MD; Lawrence G. Lenke, MD; Sang Hun Lee, MD, PhD; Khaled M. Kebaish, MD; Shay Bess, MD; Alan H. Daniels, MD; International Spine Study Group

Hypothesis

Lower limb compensation is adequately assessed by pelvic tilt (PT), and therefore knee flexion (KF) is not independently associated with degree of sagittal correction.

Design

Retrospective cohort study

Introduction

Full-body imaging allows measurement of lower-limb alignment, with KF and PT representing compensation for sagittal malalignment. However, full-body radiographs are costly and not universally available. We evaluated the association of KF with degree of postop deformity correction and PT.

Methods

Adult spinal deformity patients with full-body radiographs without PJK were measured for KF, PT, PI, LL, thoracic kyphosis, SVA, and T4-L1 PA mismatch at preop and postop. Change in lordosis (Δ LL) from surgery was calculated. Regression analyses evaluated relationships between KF, radiographic correction, PT, ODI, and SRS-22 at preoperative, 6-week, and 2-year timepoints with Bonferroni correction. Multivariable regression and principal component analysis (PCA) were used to assess whether KF was independently associated with alignment changes.

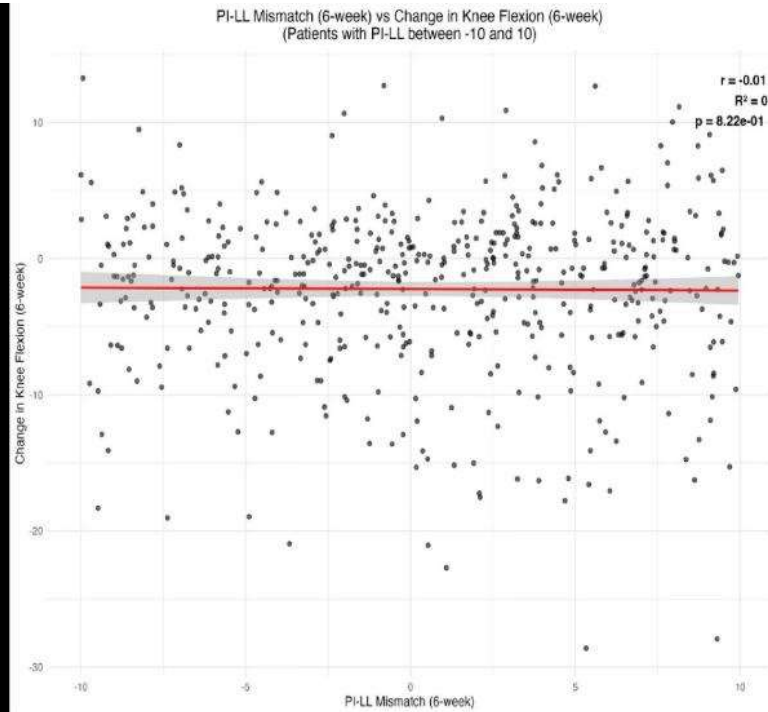
Results

A total of 679 patients were included. Preop KF was strongly associated with Δ LL ($r=0.48$, $p<0.0001$). However, after regression of seven PCA dimensions of alignment and KF with Δ LL, KF had no association with Δ LL ($r=0.04$, $p=0.25$), Δ PI-LL ($r=-0.05$, $p=0.13$), or Δ SVA ($r=0.02$, $p=0.57$). Conversely, in patients with satisfactory postop alignment ($|PI-LL|<10$), 6-week KF was not associated with preop KF ($r=0.04$, $p=0.30$) or change in KF ($r=-0.01$, $p=0.82$). These findings were replicated on a surgeon level. KF was correlated with pathologic PT ($PT > 20$) at almost all timepoints (preop $p<0.001$, 6wk/2yr $p<0.02$, 1yr $p=0.06$), but not with normal PT ($PT < 20$; $p=0.13$ to 0.89). Finally, KF was not associated with ODI at any timepoint ($p=1.0$) and not associated with SRS-22 preop or at 6 weeks ($p>0.05$). Higher KF correlated with lower SRS-22 at 2 years ($r=-0.26$, $p<0.001$).

Conclusion

Knee flexion (KF) was not independently associated with sagittal correction after controlling for other well-known spinopelvic parameters which are available without full-body radiographs. Residual KF remains associated with residual pelvic tilt. These findings suggest that knee flexion severity assessment compensation may not be required specifically for sagittal alignment planning, though its overall clinical utility warrant further investigation.

§ 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

10. Go Big or Lay-Up in Revision Adult Spinal Deformity Surgery? Contrasting the Trade-Off Between Achieving Optimal Alignment with Early Complication vs. Suboptimal Alignment Without Complication

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Hypothesis

In patients with a prior lumbar fusion undergoing adult spinal deformity (ASD) surgery, optimally aligned patients with an early complication have better patient-reported outcome metrics (PROMs) than those with suboptimal alignment without an early complication.

Design

Retrospective analysis of prospective multicenter study

Introduction

We compared 2-year PROMs and neurologic complications between patients with: 1) optimal postoperative alignment and an early complication vs. 2) suboptimal alignment without an early complication.

Methods

A retrospective cohort study (2009-18) was performed of patients undergoing ASD surgery. Inclusion criteria were: ≥ 2 -year follow-up, prior lumbar fusion, and preoperative sagittal malalignment. Optimal sagittal alignment was defined as L1-pelvic angle (L1PA) $\pm 5^\circ$ of goal. Cohort was binarized as: 1) optimal alignment with an early complication vs. 2) suboptimal alignment without an early complication. Outcome variables were 2-year Scoliosis Research Society (SRS) satisfaction scores, Oswestry Disability Index (ODI), EQ-5D, Short Form 36 (SF-36) physical function scores, all subdomains, and neurologic function. Bivariate analysis was performed.

Results

Of 312 patients, 27 (8.7%) had optimal alignment but developed an early complication while 126 (40.4%) had suboptimal alignment without an early complication. At baseline and 2-years, both groups had similar total PROMs and satisfaction. Regarding PROM subdomains, those with optimal alignment had better 2-year mental health (SF-36 Q9B: 4.8 ± 0.6 vs. 4.1 ± 1.0 , $p=0.002$), vitality (SF-36 Q9C: 4.8 ± 0.6 vs. 4.3 ± 1.0 , $p=0.023$), social functioning (4.7 ± 0.5 vs. 4.2 ± 1.1 , $p=0.008$), and satisfaction with back relief (4.0 ± 0.9 vs. 3.4 ± 1.2 , $p=0.048$). There were no significant differences in rates of new motor deficits (7.4% vs. 4.8%, $p=0.631$) or new radiculopathy (3.7% vs. 4.8%, $p=1.000$).

Conclusion

Though patients with optimal alignment and an early complication vs. suboptimal alignment without complication had similar total PROMs, upon subdomain testing, optimal alignment, even with an early complication, conferred better long-term mental health, social functioning, vitality, and perceived back pain relief.

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

PROM	Optimal Alignment, with Early Complication	Suboptimal Alignment, No Early Complication	p-value
Baseline			
SRS Q4: Pain	1.2±0.5	1.5±1.0	0.017
6-Months			
SF36 Q3C: Physical Function – Ability to Climb Flight of Stairs	1.0±0.0	1.7±0.9	0.003
SF36 Q3E: Physical Function – Ability to Walk One Block	1.3±0.5	2.0±0.7	0.047
SF36 5A: Bodily Pain	5.0±0.0	3.4±1.2	<0.001
SF36 5C: Role Limitations Due to Physical health	5.0±0.0	3.5±1.4	<0.001
SSF36 9C: Energy/Fatigue	5.0±0.0	4.2±1.3	0.009
LSDI Q7: Difficulty Rising <u>From</u> Sitting Position	2.0±0.0	2.5±0.7	0.013
2-years			
SF36 Q9B: Mental Health – Feeling Downhearted/Blue	4.8±0.6	4.1±1.0	0.002
SF36 9C: Energy/Fatigue	4.8±0.6	4.3±1.0	0.023
SF36 9F: Mental Health - Feeling Calm <u>an</u> Peaceful	4.7±0.6	4.0±1.1	0.035
SF36 11A: Social Functioning – Does Physical or Emotional Health Interfere with Normal Social Activities?	4.7±0.5	4.2±1.1	0.008
SRS Q20 <u>;</u> Satisfaction with Level of Back Pain Relief	4.0±0.9	3.4±1.2	0.048

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

11. Radiographic evaluation of ASD and its relationship with longitudinal changes in sagittal spinal alignment

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Hypothesis

Radiographic parameters reflecting lumbopelvic congruence and T4-L1-HA would predict longitudinal changes in sagittal alignment better than PI-LL mismatch.

Design

Longitudinal study using a community-based cohort with repeated radiographic assessment.

Introduction

SRS-Schwab adult spinal deformity (ASD) classification in 2012 popularized a pelvic incidence (PI) - lumbar lordosis (LL) mismatch $< 10^\circ$ as a benchmark. However, following studies indicated PI should explain only a fraction of the variation in LL. Age-related LL changes are also influenced by pelvic compensation, lumbopelvic congruity, and global balance. In 2022, the hip axis connecting T4 and L1 vertebral bodies to the center of the femoral head (T4-L1-HA) was reported as an alternative to sagittal vertical axis (SVA). This study investigated the relationship between radiographic ASD predictors and longitudinal changes in sagittal spinal alignment in a community-based cohort.

Methods

Female volunteers were recruited from a population registry and upright entire spine radiographs were used for radiographic measurement; thoracic kyphosis (TK), LL, PI, pelvic tilt (PT), sacral slope (SS), SVA, and T4-L1-HA. Baseline ASD predictors were defined as follows: PI-LL normal ($< 10^\circ$) and mismatch ($\geq 10^\circ$), T4-L1-HA normal ($\leq 3^\circ$) and mismatch ($\geq 4^\circ$), pelvic compensation normal (PT/PI $< 34\%$) and aggravated ($> 50\%$), lumbopelvic congruence (LL/SS = 1.1~1.5), and incongruence (LL/SS > 1.5), according to previous studies.

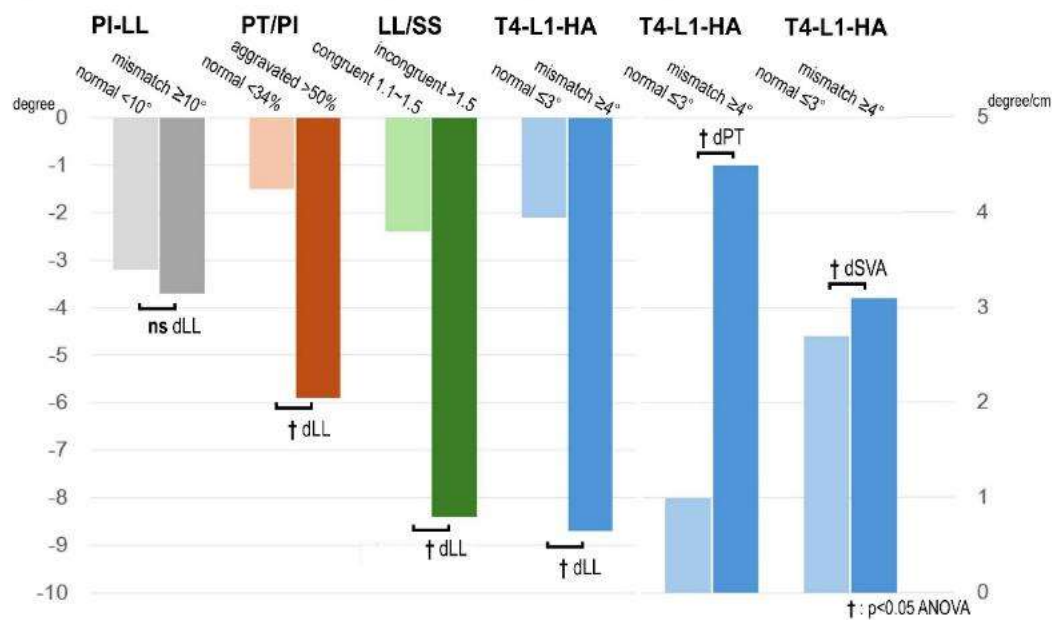
Results

A total of 169 women (mean age 64.6 ± 4.9 years) were followed for 8.6 ± 3.7 years. Longitudinal changes were significant in LL ($38.5 \pm 15.7^\circ \rightarrow 34.8 \pm 18.0^\circ$), SVA ($17.4 \pm 35.5\text{mm} \rightarrow 40.7 \pm 39.2\text{mm}$), PT ($23.8 \pm 9.8^\circ \rightarrow 25.5 \pm 11.3^\circ$), and T4-L1-HA ($2.8 \pm 5.6^\circ \rightarrow 4.9 \pm 6.3^\circ$). Baseline radiographic predictor of PI-LL was not related to longitudinal change in LL, while PT/PI and LL/SS showed significant associations with LL. Baseline T4-L1-HA predicted LL, PT and SVA modifications (Figure 1).

Conclusion

The T4-L1-HA showed a significant association with longitudinal changes, with cases of mismatch exhibiting greater changes in LL, PT and SVA. Recent studies have highlighted the variability in spinal alignment prediction using PI. This longitudinal study suggests that assessments not involving PI, such as lumbopelvic congruity and T4-L1-HA are important for understanding longitudinal modifications in ASD.

Figure 1. Baseline predictors and longitudinal radiographic changes



Baseline predictors and longitudinal radiographic changes

12. Why Success After Adult Spinal Deformity Surgery Depends on How Success is Defined: Insights from a Composite Outcome Framework

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Hypothesis

To identify surgical and radiographic factors associated with multidimensional composite success after ASD surgery

Design

Retrospective multicenter study of 994 ASD treated between 2008 and 2018 with minimum 2-year follow-up

Introduction

ASD surgery outcomes are traditionally assessed using single metrics (e.g., disability, improvement, or revision). A multidimensional framework incorporating disability improvement, pain relief, and revision-free survival may better reflect comprehensive success.

Methods

Composite success required achievement in all 3 domains: disability (ODI ≤ 20 or improvement > 14), leg pain (NRS ≤ 3 or improvement > 3), and absence of reoperation for mechanical or neurologic complications. Associations between surgical techniques, postoperative alignment, and outcomes were evaluated using univariate analyses and multivariable logistic regression.

Results

Composite success was achieved in 42.8% (425/994) of patients, with individual domain success rates of 60.9% (disability), 64.8% (leg pain), and 81.2% (no reoperation). Domain-specific analyses revealed divergent and sometimes opposing effects of surgical procedures (Figure). On univariate analysis, composite success was associated with less extensive surgical intervention: lower rates of decompression (55% vs 63%), 3CO (14% vs 20%), LIV to ilium (75% vs 83%) (all $p < 0.05$), as well as modestly but significantly better postoperative sagittal alignment (PT, TPA and SVA, all $p < 0.03$). Multivariate analysis identified 3CO (OR 0.64, $p = 0.020$), LLIF (OR 0.70, $p = 0.050$), LIV to ilium (OR 0.62, $p = 0.005$), post-operative TPA $< 20^\circ$ (OR 1.5, $p = 0.003$) and lumbar Cobb $> 15^\circ$ (OR 1.6, $p < 0.001$) as independently associated with composite success. However, after adjustment for baseline characteristics and deformity severity, no surgical technique or alignment parameter remained independently predictive

Conclusion

Although several surgical strategies and alignment targets were associated with better 2-year outcomes on univariate analysis, these associations did not persist after adjustment for baseline patient and deformity characteristics. Composite success appears more strongly driven by underlying patient factors than by specific procedures or radiographic thresholds. Finally, predictors differed across domains, reinforcing that reliance on a single metric may misrepresent patient benefit

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		Decomp.	Osteo?	3CO?	Any IBF?	ALIF?	PLIF / TLIF?	LLIF?	LIV Ilium?	UIV: T1-6	UIV: T7-12	UIV: L1-5
ODI < 20	No	367 (65.07%)	387 (68.5%)	117 (20.71%)	386 (68.32%)	146 (25.84%)	190 (33.63%)	108 (19.12%)	481 (85.28%)	204 (36.1%)	263 (46.5%)	92 (16.3%)
	Yes	225 (52.45%)	307 (71.56%)	57 (13.29%)	272 (63.4%)	109 (25.47%)	116 (27.04%)	69 (16.12%)	318 (74.13%)	186 (43.4%)	188 (43.8%)	53 (12.4%)
	p-value	0.000	0.329	0.002	0.119	0.942	0.027	0.241	0.000		0.044	
ODI MCID	No	282 (57.32%)	331 (67.14%)	94 (19.07%)	309 (62.68%)	113 (22.92%)	151 (30.63%)	88 (17.85%)	377 (76.63%)	196 (39.8%)	213 (43.2%)	76 (15.4%)
	Yes	310 (61.88%)	363 (72.46%)	80 (15.97%)	349 (69.66%)	142 (28.4%)	155 (30.94%)	89 (17.8%)	422 (84.23%)	194 (38.7%)	238 (47.5%)	69 (13.8%)
	p-value	0.155	0.073	0.211	0.023	0.050	0.095	1.000	0.003		0.478	
Leg Pain < 3	No	240 (66.85%)	250 (69.44%)	80 (22.22%)	253 (70.28%)	94 (26.11%)	121 (33.61%)	70 (19.44%)	304 (84.68%)	123 (34.2%)	167 (46.4%)	69 (19.2%)
	Yes	352 (55.52%)	444 (70.03%)	94 (14.83%)	405 (63.88%)	161 (25.43%)	185 (29.18%)	107 (16.9%)	495 (78.08%)	267 (42.1%)	284 (44.8%)	76 (12%)
	p-value	0.000	0.886	0.004	0.043	0.821	0.153	0.343	0.012		0.003	
Les Pain MCID	No	356 (55.45%)	459 (71.38%)	118 (18.35%)	404 (62.83%)	164 (25.55%)	177 (27.53%)	113 (17.6%)	492 (76.64%)	284 (44.2%)	272 (42.3%)	82 (12.8%)
	Yes	236 (67.24%)	235 (66.95%)	56 (15.95%)	254 (72.36%)	91 (25.93%)	129 (36.75%)	64 (18.23%)	307 (87.46%)	106 (30.2%)	179 (51%)	63 (17.9%)
	p-value	0.000	0.149	0.383	0.003	0.939	0.003	0.862	0.000		0.000	
Revision	No	123 (63.73%)	137 (70.98%)	43 (22.28%)	137 (70.98%)	60 (31.09%)	61 (31.61%)	44 (22.8%)	166 (86.01%)	74 (38.3%)	94 (48.7%)	24 (12.4%)
	Yes	469 (58.63%)	557 (69.54%)	131 (16.35%)	521 (65.04%)	195 (24.37%)	245 (30.59%)	133 (16.63%)	633 (79.13%)	316 (39.5%)	357 (44.6%)	121 (15.1%)
	p-value	0.220	0.727	0.058	0.127	0.066	0.795	0.047	0.033		0.499	

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