Rethinking Sagittal Alignment: The Value of Evaluating of Spinal Shape in Conjunction with T4-L1PA Measurement to Prevent Proximal Junctional Failure

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INTRODUCTION: The T4-L1 Axis (T4-L1PA) has gained attention for its ability to predict mechanical complication rates in long fusions to the sacrum. However, its potential to address severe proximal junctional kyphosis (PJK) and its applicability to lower thoracic-pelvis fusions where it has not been validated, remains uncertain. Using a virtual model simulating the theoretical post-operative alignment before PJK, this study aimed to (1) validate T4-L1PA guidelines in patients with long fusions, with a focus on severe PJK and proximal extension, and (2) investigate T4-L1PA's applicability in thoracolumbar fusions.

METHODS: This study is a Retrospective review of a multicenter adult spinal deformity database with with pan-lumbar fusion to the ilium, upper instrumented vertebrae (UIV) between T1-T12, and a minimum of 2-year follow-up. Surgically treated ASD patients enrolled into a prospective study were evaluated for postoperative PJF and categorized based on adherence to the previously published L1PA and T4-L1PA guidelines: L1PA = 0.5 × PI -19 ± 2° and T4-L1PA between -3° and 1°. Proximal failure (PJF) was defined as (1) revision surgery requiring proximal extension, or (2) severe radiographic PJK (proximal junctional angle >28° and ΔPJA >22°). Failure rates were stratified by UIV position (upper thoracic: T2-4; lower thoracic: T9-11) and cross-tabulated into nine combinations of L1PA and T4-L1PA as defined in the literature. Findings were graphically illustrated by constructing a median shape of each category.

RESULTS: Among 672 patients (64 ± 9 yo; 78% F; BMI: 28.2 ± 5.7 kg/m²), postop PJF rate at minimum 2 years was 17% (7.9% required proximal extension, and 9.7% met severe PJK criteria. Early postoperative alignment improvements were significant (all p < 0.001), with mean PI-LL mismatch decreasing from 21.3° to 1.3°. Postoperative L1PA exceeded PI-adjusted normative values (6.8 ± 6.2°) by 2.5 ± 5° (p < 0.001). Compared to patients with TL UIVs, the cohort with UT UIVs had a greater proportion of L1PA below recommended guidelines (36.1% vs. 27.6%, p = 0.037) and had T4L1PA below recommended guidelines (20.9% vs. 5.5%, p < 0.001) Patients with UT UIV with postop L1PA smaller (overcorrected) than the guideline had a significantly greater rate of failures than those with L1PA matching or larger (undercorrected) than the guideline (25.3% vs 12.7% & 10.7%, p<0.025). Conversely, failure rates were similar across all three T4-L1PA groups (p=0.075). Stratification into nine combinations of L1PA and T4-L1PA (Figure 1, Table 1) revealed that patients with L1PA greater than the guideline and a T4-L1PA between -3 and 1 had the smallest PJF incidence (5%), while those with L1PA smaller than the guideline and T4-L1 PA < -3 had the greatest PJF incidence (44%). Patients with TL UIV demonstrated similar PJF rates across all T4L1PA groups (16.1% vs 23.8% vs 15.4% p=0.148), and all L1PA groups (23.8%, 19.1%, 13.8%, p=0.132) (Figure 2).

DISCUSSION AND CONCLUSION: Rethinking spinal alignment as a shape comprised of a combination of pelvic angles represents an advancement in sagittal alignment understanding. Our findings validate the utility of T4-L1PA in long fusions. However, adjustments of L1PA boundaries to a more anterior (less correction) spine may further reduce PJF rates. For LT UIV, T4-L1PA validation showed no significant benefits, emphasizing the need for additional measures to delineate alignment differences accurately.

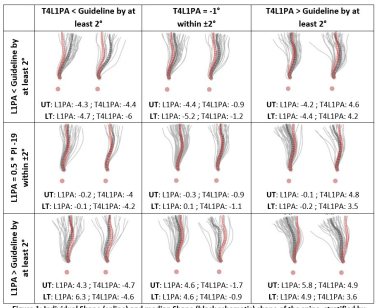

Figure 1: Individual Shape (spline) and median Shape (black schematic) shape of the spine, stratified by guidelines for L1PA (lines) and T4-L1PA (columns). Median shape according to these guidelines is represented for each of the nine combinations (red schematic)

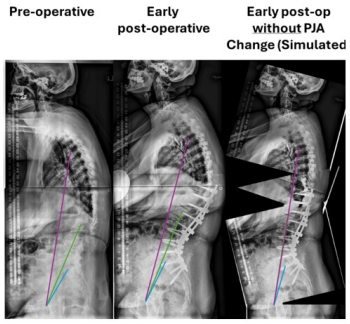

Figure 2: Example of the early post-operative alignment, with and without effect of Proximal Junctional Angle change (right)

Table 1: Rate of proximal failure by L1PA and T4-L1PA categories without the effect of PJA change on immediate post-operative follow-up. Smaller indicates "Overcorrection" per guidelines, and greater indicates "Undercorrection".

		T4L1PA <-3	T4L1PA -3 TO 1	T4L1PA > 1	TOTAL
UPPER TH.	L1PA SMALLER	44.4%	21.2%	18.8%	25.3%
	MATCH PI ADJUSTED	16.7%	16.0%	7.7%	12.7%
	L1PA GREATER	16.7%	5.0%	10.9%	10.7%
	TOTAL	27.1%	15.4%	12.5%	16.5%
LOWER TH.	L1PA SMALLER	14.8%	33.3%	21.4%	23.8%
	MATCH PI ADJUSTED	16.7%	21.3%	18.6%	19.1%
	L1PA GREATER	16.7%	19.1%	8.2%	13.8%
	TOTAL	16.1%	23.8%	15.4%	18.5%