

Residual L4 Tilt and Five-Year Self-Image After L3 Fusion for Adolescent-Onset Idiopathic Scoliosis

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Abstract

Purpose.

To characterize L4/L5 alignment after L3 fusion and test whether residual L4 tilt is associated with 5-year self-image.

Methods.

This two-center cohort included adolescent-onset idiopathic scoliosis with Lenke 5/6 lumbar major curves treated by posterior fusion to L3. Absolute L4/L5 tilt, L3/4 disc wedge, thoracolumbar/lumbar (TL/L) Cobb, clavicle angle, and C7-central sacral vertical line offset were assessed at 1 week, 2 years, and 5 years. Robust models evaluated correction transfer, change correlates, and Scoliosis Research Society-22r Self-image.

Results.

Of 117 patients, 81 had complete L4/L5 trajectories. Per 5° greater lowest-instrumented-vertebra correction, initial L4 and L5 leveling increased by 1.99° (95% CI, 1.02–2.95; $P<.001$) and 0.95° (95% CI, 0.14–1.75; $P=.022$), respectively. L4 remained stable from 1 week to 5 years, whereas L5 leveled by 1.17° (95% CI, 0.52–1.82; $P<.001$). L3/4 disc wedge was stable (-0.06° ; $P=.825$), while TL/L Cobb increased by 2.91° ($P<.001$). Five-year L4 tilt correlated with worse Self-image ($\rho=-0.405$; $q=.008$); each 5° greater tilt was associated with 0.22-point lower fully adjusted Self-image (95% CI, -0.42 to -0.02 ; $P=.032$). Age was unrelated to distal change.

Conclusion.

L3 leveling was associated with immediate L4/L5 leveling. Later L5 leveling despite stable L3/4 disc geometry and TL/L correction loss supports segment-specific alignment redistribution, not generalized distal remodeling. Residual L4 tilt remained associated with long-term Self-image.

INTRODUCTION

Selecting the distal fusion level for a structural thoracolumbar/lumbar curve requires balancing durable correction against preservation of mobile lumbar segments. When fusion ends at L3, unfused L4 and L5 must accommodate the coronal geometry of the fused curve, pelvis, and sacrum. Previous work has emphasized distal adding-on, subjacent disc wedging, lowest-instrumented-vertebra (LIV) or LIV + 1 translation, and the L3-versus-L4 choice [1–7].

LIV alignment, translation, and subjacent disc geometry are associated with distal correction and coronal balance [2–5]. A recent 5-year study identified sacral slanting as a determinant but evaluated LIV + 1 rather than L4 and L5 separately [8]. Whether L3 leveling is transmitted differently to these vertebrae, and whether later L5 leveling reflects curve, disc, or global coronal change, remains unclear.

Waistline asymmetry is visible to patients with thoracolumbar/lumbar scoliosis. Photographic waist measures correlate with lower-end-vertebral inclination and apical translation, and persistent postoperative asymmetry is associated with worse Self-image [9–11]. Recent studies have expanded links between radiographic or surface-cosmetic parameters and patient-reported appearance [12–14], but none has tested L4-specific 5-year Self-image after uniform L3-ending fusion while accounting for residual curve magnitude, shoulder balance, and global coronal balance.

We compared L4/L5 trajectories and tested whether residual L4 tilt was associated with 5-year SRS-22r Self-image independently of residual curve, shoulder, and global coronal alignment. Secondary objectives evaluated correction transfer, structural and global correlates of L5 change, and age effects.

MATERIALS AND METHODS

Study Design and Cohort

We hypothesized that operative L3 leveling would accompany early L4/L5 leveling, that later trajectories would differ by segment, and that greater residual L4 tilt would be associated with worse 5-year Self-image. This retrospective two-center cohort used a prospectively maintained database and followed STROBE. Institutional review boards approved the study; details are supplied separately for blinded review. Eligible patients had adolescent-onset idiopathic scoliosis, a Lenke 5/6 lumbar major curve, posterior-only surgery, and LIV=L3.

Of 443 records, 169 had Lenke 5/6 lumbar major curves, 120 had LIV=L3, and 117 had a documented posterior-only approach (Fig. 1). Trajectories required 1-week, 2-year, and 5-year measurements; PROM regression used a common complete sample.

Radiographic and Patient-Reported Outcomes

Standing coronal radiographs were assessed preoperatively and at 1 week, 2 years, and 5 years. L4/L5 tilt and LIV tilt were upper-endplate-to-horizontal angles; the L3/4 disc wedge was between the L3 inferior and L4 superior endplates. Clavicle angle (CA), C7-central sacral vertical line (C7–CSVL) offset, and pelvic obliquity represented shoulder, global coronal, and pelvic alignment. TL/L and main Cobb angles represented structural curve magnitude.

Because sign denoted right-up or left-up orientation, absolute magnitudes represented severity; measured 0° values were retained. Cobb angles were also analyzed as magnitudes. The Japanese SRS-

22r was administered preoperatively and at 2 and 5 years [15]. Five-year Self-image was primary; other domains were exploratory.

Statistical Analysis

Data are reported as mean±standard deviation or median [interquartile range]. Complete trajectories were tested with Friedman and paired Wilcoxon signed-rank tests; the three within-outcome comparisons used Holm correction. Patient-level L5-minus-L4 change tested segment differences. TL/L correction loss $\geq 5^\circ$ and $\geq 10^\circ$ and L3/4 disc-wedge progression $> 5^\circ$ were summarized. Without LIV + 1 translation, the latter was not considered a complete distal-adding-on definition.

Initial leveling was preoperative minus 1-week absolute tilt. HC3-robust models estimated leveling per 5° greater LIV correction, adjusting for baseline segment and LIV tilt, preoperative main Cobb, main-curve correction, age, Lenke type, and center. Separate models tested whether 1-week LIV tilt predicted 5-year L4/L5 tilt after accounting for 1-week alignment.

Exploratory robust models related L5 change to concurrent L4, LIV, L3/4 disc, TL/L and main Cobb, CA, C7–CSVL, and pelvic changes. Models adjusted for 1-week L5 and marker magnitude, age, Lenke type, and center; false-discovery-rate correction covered eight markers. Spearman correlation assessed 5-year radiograph–PROM associations, with a 5000-resample bootstrap confidence interval for L4–Self-image and false-discovery-rate correction across the matrix. Sequential HC3-robust models estimated Self-image difference per 5° L4 tilt, adjusting first for age, baseline Self-image, Lenke type, and center, then CA, residual main Cobb, and C7–CSVL. Site interaction and leave-one-out analyses assessed stability.

Missing-data sensitivity used 50-fold multiple imputation and inverse-probability weighting for 5-year endpoint availability; estimates were pooled by Rubin rules. Age was analyzed continuously, with an age ≤ 24 sensitivity analysis. Python 3.12.13 was used. Two-sided $P < .05$ indicated significance. ChatGPT (OpenAI) assisted statistical-code review, language refinement, and data-based graphics; the authors verified all outputs.

RESULTS

Cohort and Data Availability

The 117 patients had a mean age of 16.1 ± 4.7 years (range, 11–53); 112 (95.7%) were female, 95 (81.2%) had Lenke 5 curves, and 22 (18.8%) had Lenke 6 curves. Only three were aged ≥ 25 years. Complete postoperative L4/L5, LIV, TL/L Cobb, and C7–CSVL trajectories were available in 81 patients, CA in 80, L3/4 disc wedge in 70, and pelvic obliquity in 40. The primary correlation included 78 patients and multivariable model 68 (Table 1).

Table 1
Cohort Characteristics and Analysis Availability

Characteristic	Value
Age at surgery, y	16.1 ± 4.7 (n = 117)
Female sex	112 (95.7%)
Diagnosis: AIS / AdIS	97 / 20
Lenke 5 / Lenke 6	95 / 22
Age ≥ 18 / ≥25 y	23 / 3
Body mass index, kg/m ²	19.5 ± 2.1 (n = 116)
Risser stage	4 [3–5] (n = 107)
Fusion levels	6 [5–7] (n = 84)
Operative time, min	178 ± 71 (n = 117)
Blood loss, g	150 [100–300] (n = 117)
Preoperative main Cobb, °	46.4 ± 9.3 (n = 114)
Preoperative absolute L4 tilt, °	21.0 ± 6.9 (n = 86)
Preoperative absolute L5 tilt, °	12.1 ± 5.1 (n = 86)
Preoperative absolute clavicle angle, °	2.3 ± 2.1 (n = 113)
Preoperative SRS-22r Self-image	2.78 ± 0.53 (n = 98)
Complete L4/LIV trajectory	81 (69.2%)
Complete L5 trajectory used	81 (69.2%)
Complete TL/L Cobb and C7–CSVL trajectories	81 (69.2%)
Complete clavicle-angle trajectory	80 (68.4%)
Complete L3/4 disc-wedge trajectory	70 (59.8%)
Complete pelvic-obliquity trajectory	40 (34.2%)
Primary 5-year L4–Self-image pair	78 (66.7%)
Fully adjusted common sample	68 (58.1%)
Values are mean ± standard deviation, median [interquartile range], or number (%). AIS indicates adolescent idiopathic scoliosis; AdIS, adolescent-onset idiopathic scoliosis treated after adolescence; LIV, lowest instrumented vertebra.	

Endpoint-complete patients were younger (median, 15 vs. 16 years; $P=.046$) and had higher baseline Self-image (2.87 vs. 2.57; $P=.019$); preoperative main Cobb and L4 tilt were similar.

Correction Transfer From L3 to Unfused L4 and L5

Among 85 patients, LIV tilt decreased from $23.23 \pm 6.74^\circ$ preoperatively to $5.50 \pm 4.40^\circ$ at 1 week; L4 decreased from $21.01 \pm 6.95^\circ$ to $8.01 \pm 5.21^\circ$ and L5 from $12.10 \pm 5.14^\circ$ to $7.44 \pm 4.37^\circ$. Each 5° greater LIV correction was associated with 1.99° greater adjusted L4 leveling (95% CI, 1.02–2.95; $P < .001$) and 0.95° greater L5 leveling (95% CI, 0.14–1.75; $P = .022$) (Fig. 3; Online Resource 1, Table S3).

Residual 1-week LIV tilt did not predict 5-year L4 or L5 tilt after adjustment for 1-week alignment ($P = .183$ and $P = .139$). Thus, operative L3 leveling was associated principally with immediate distal alignment rather than subsequent 5-year change.

Distal Alignment and Structural Curve Change

L4 tilt was $8.03 \pm 5.32^\circ$, $8.44 \pm 5.91^\circ$, and $8.26 \pm 5.51^\circ$ at 1 week, 2 years, and 5 years, respectively (1-week-to-5-year change, $+0.23^\circ$; 95% CI, -0.43 to 0.89 ; Holm $P = .741$). L5 decreased from $7.39 \pm 4.45^\circ$ to $6.86 \pm 4.62^\circ$ and $6.22 \pm 4.72^\circ$ (change, -1.17° ; 95% CI, -1.82 to -0.52 ; Holm $P < .001$). Patient-level change differed by -1.40° between L5 and L4 ($P < .001$) (Fig. 2a; Table 2).

Table 2
Postoperative Radiographic Trajectories

Absolute-magnitude measure	n	1 week	2 years	5 years	1 week→5 years mean change (95% CI)	Holm P	Overall P
L4 tilt, °	81	8.03 ± 5.32	8.44 ± 5.91	8.26 ± 5.51	+ 0.23 (-0.43, + 0.89)	.741	.161
L5 tilt, °	81	7.39 ± 4.45	6.86 ± 4.62	6.22 ± 4.72	-1.17 (-1.82, -0.52)	< .001	< .001
TL/L Cobb, °	81	16.32 ± 8.76	17.84 ± 10.41	19.23 ± 11.44	+ 2.91 (+ 1.68, + 4.13)	< .001	.001
L3/4 disc wedge, °	70	4.34 ± 2.73	4.33 ± 3.07	4.28 ± 3.11	-0.06 (-0.70, + 0.58)	.825	.162
Clavicle angle, °	80	2.92 ± 2.02	2.20 ± 1.79	1.61 ± 1.45	-1.31 (-1.86, -0.75)	< .001	< .001
C7–CSVL offset, cm	81	1.61 ± 1.11	1.00 ± 0.96	1.02 ± 1.06	-0.59 (-0.90, -0.28)	< .001	< .001
LIV (L3) tilt, °	81	5.59 ± 4.42	6.25 ± 4.70	5.94 ± 5.01	+ 0.35 (-0.41, + 1.11)	.660	.274
Negative change indicates leveling or reduced imbalance; positive TL/L Cobb change indicates correction loss. Overall P is from the Friedman test; pairwise P is from the Wilcoxon signed-rank test with Holm correction across the three within-measure comparisons. TL/L correction loss from 1 week to 5 years was ≥ 5° in 26/81 (32.1%) and ≥ 10° in 11/81 (13.6%). L3/4 disc-wedge progression > 5° occurred in 5/70 (7.1%); LIV + 1 translation was unavailable, so this was not treated as a complete distal-adding-on definition.							

TL/L Cobb increased from 16.32 ± 8.76° to 19.23 ± 11.44° (change, + 2.91°; 95% CI, 1.68–4.13; Holm P<.001). Correction loss was ≥ 5° in 26/81 (32.1%) and ≥ 10° in 11/81 (13.6%). L3/4 disc wedge remained stable (4.34 ± 2.73° to 4.28 ± 3.11°; change, – 0.06°; P=.825; n = 70), although 5/70 (7.1%) progressed > 5° (Fig. 3c; Online Resource 1, Fig. S1).

L5 change was associated with L4 change (adjusted β = 0.40 per 1°; 95% CI, 0.22–0.58; q<.001); LIV change was borderline (β = 0.21; 95% CI, 0.03–0.39; q=.081). TL/L, main Cobb, L3/4 disc, CA, C7–CSVL, and pelvic changes were unrelated after multiplicity correction (all q≥.505) (Fig. 3d; Online Resource 1, Table S4).

Global Coronal Alignment and Self-Image

CA improved from 2.92 ± 2.02° to 1.61 ± 1.45° (change, – 1.31°; P<.001) (Fig. 2b), and C7–CSVL offset from 1.61 ± 1.11 to 1.02 ± 1.06 cm (change, – 0.59 cm; P<.001); LIV tilt was stable (+ 0.35°; P=.660).

Neither CA nor C7–CSVL correlated with Self-image. Self-image improved from 2.87 ± 0.51 preoperatively to 4.23 ± 0.61 at 5 years ($P < .001$).

Residual L4 Tilt and 5-Year Self-Image

L4 tilt correlated with worse Self-image ($\rho = -0.405$; bootstrap 95% CI, -0.586 to -0.193 ; $P < .001$; $q = .008$) (Fig. 2c). Residual main Cobb also correlated ($\rho = -0.342$; $q = .038$); L5, LIV, L3/4 disc, CA, and C7–CSVL did not.

In 68 patients, each 5° greater L4 tilt was associated with 0.32-point lower base-adjusted Self-image (95% CI, -0.46 to -0.19 ; $P < .001$). This persisted after CA (-0.31 ; $P < .001$), main Cobb (-0.22 ; $P = .035$), and C7–CSVL (-0.22 ; 95% CI, -0.42 to -0.02 ; $P = .032$) adjustment (Fig. 2d; Table 3). Substituting residual TL/L Cobb for main Cobb gave a similar result (-0.23 ; 95% CI, -0.45 to -0.01 ; $P = .039$). There was no center interaction ($P = .557$); leave-one-out estimates were -0.26 to -0.18 . Multiple-imputation/inverse-probability weighting yielded -0.21 (95% CI, -0.39 to -0.03 ; $P = .025$).

Table 3
Adjusted Models of 5-Year SRS-22r Self-Image

Model	n	Difference per 5° greater L4 tilt	95% CI	P	R ²
Base adjustment	68	-0.322	-0.458 to -0.186	< .001	0.393
+ clavicle angle	68	-0.312	-0.450 to -0.175	< .001	0.402
+ residual main Cobb	68	-0.217	-0.419 to -0.016	.035	0.415
+ C7–CSVL offset	68	-0.219	-0.420 to -0.019	.032	0.426
TL/L Cobb substitution sensitivity	68	-0.230	-0.448 to -0.012	.039	0.422
MI + inverse-probability weighting	78	-0.209	-0.392 to -0.026	.025	—
HC3 robust standard errors. Base adjustment included age per 5 years, baseline Self-image, Lenke 6 versus 5, and center. Subsequent models added absolute 5-year clavicle angle, residual main Cobb angle, and absolute C7 plumb-line offset. The four sequential models used the same complete sample (n = 68).					
The TL/L Cobb substitution model replaced residual main Cobb with residual TL/L Cobb while retaining CA and C7–CSVL. The MI + inverse-probability-weighted sensitivity analysis used 50 imputations, retained all 78 endpoint-complete patients, and reweighted for observed baseline predictors of endpoint availability. MI indicates multiple imputation; C7–CSVL, C7-central sacral vertical line.					

Secondary Age Analysis

Age was unrelated to initial or 1-week-to-5-year change for L4 (+ 0.13°, P=.936; -0.11°, P=.679) or L5 (+ 0.29°, P=.648; +0.20°, P=.579) per 5 years (Online Resource 1, Fig. S2 and Table S1).

DISCUSSION

This L3-ending cohort showed that greater L3 leveling accompanied immediate L4/L5 leveling; L4 then remained stable while L5 leveled modestly. TL/L Cobb simultaneously increased and L3/4 disc geometry remained stable, arguing against generalized distal remodeling. Age was unrelated to distal change. Residual L4 tilt remained associated with Self-image after adjustment for residual curve, shoulder and global balance, baseline Self-image, age, curve type, and center.

Previous studies link L3/4 geometry, LIV tilt, and LIV translation with distal correction [2–5]. We quantified correction transfer separately to L4 and L5. LIV correction explained an additional 4.8% of early L4 and 2.5% of L5 leveling beyond baseline geometry and curve correction, but 1-week LIV tilt did not predict 5-year tilt. Thus, operative L3 leveling establishes early distal geometry; these associations neither define a target nor justify forcing LIV tilt to 0°.

Later L5 leveling was only 1.17°, while TL/L Cobb increased 2.91° and 32.1% had ≥ 5° correction loss. This is segment-specific alignment redistribution or vertebral reorientation, not lower-lumbar curve improvement. The 13.6% with ≥ 10° loss compares with 20.3% at 10 years in Fletcher et al., who reported a 3.3° curve increase with relatively stable distal disc geometry [7]. L3/4 disc wedge was stable overall, although 7.1% progressed > 5°. Without LIV + 1 translation, this alone cannot classify adding-on.

Hwang et al. identified sacral slanting as a 5-year determinant of LIV + 1 alignment [8]. Although CA and C7–CSVL improved in our cohort, their changes and pelvic-obliquity change were unrelated to L5 change after multiplicity correction. Only L4 change remained associated; LIV change was borderline. Global rebalancing is plausible but unsupported as the mechanism. L4/5 and L5/S1 disc angles, sacral slanting, and translations are required to localize it.

The clinically stronger observation was the L4–Self-image association, which persisted when residual TL/L replaced main Cobb. SRS-22r ceiling effects limit discrimination [16–18], and the adjusted 0.22-point difference per 5° is modest and not comparable to an approximately 1.0-point within-patient Appearance MCID [19]. A waistline pathway is nevertheless plausible: waist-angle asymmetry correlates with lower-end-vertebral inclination [9], postoperative waist measures with apical translation [10], and persistent severe asymmetry with worse Self-image and L4-tilt differences [11]. Other cosmetic studies support relationships between coronal or surface asymmetry and appearance [12–14]. These data support L4 tilt as a possible patient-visible lower-trunk marker, not a causal mediator or reason to extend fusion. Photography and surface topography are needed to test mediation.

CA and C7–CSVL improved but neither correlated with Self-image nor attenuated the L4 association, consistent with limited shoulder-balance associations with SRS-22 outcomes [20, 21]. The age finding applies only to selected L3-ending constructs because only three patients were aged ≥ 25 years. Other

limitations were retrospective design, incomplete endpoints, unavailable measurement reliability, missing distal disc and translation measures, and only 40 pelvic trajectories. Multiple-imputation/inverse-probability-weighted results were consistent. Strengths were two centers, uniform LIV, retained true 0° values, within-patient segment comparison, and 5-year follow-up.

In conclusion, L3 leveling was associated with immediate L4/L5 leveling; L4 remained stable and L5 showed modest late leveling. Concurrent TL/L correction loss and stable L3/4 disc geometry support segment-specific alignment redistribution rather than generalized remodeling. Residual L4 tilt remained associated with 5-year Self-image and may mark patient-visible lower-trunk asymmetry.

Declarations

DATA AVAILABILITY

Deidentified data may be available from the corresponding author on reasonable request, subject to institutional approval.

Author Contribution

T.O.,H.O and H.H.; Methodology, N.T., K.O., and G.G.; Validation,H.O., K.O., N.T., and T.O.; Formal Analysis, T.O. ,H.O .,S.I .,D.K.and U.M.; Investigation, J.T.,H.H.; Writing – Original Draft, T.O.; Writing – Review & Editing,H.H.,J.T., N.T. and T.O.

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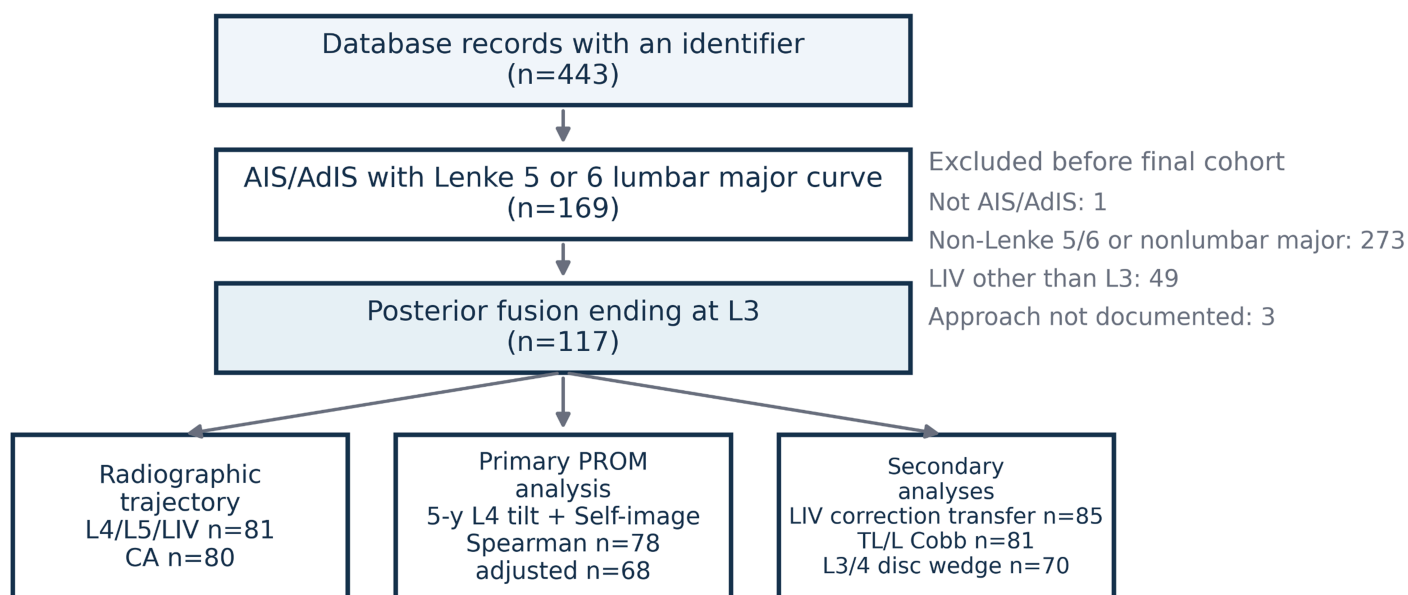
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Figures



Primary estimand

Association between residual L4 tilt magnitude and 5-year SRS-22r Self-image, accounting for baseline Self-image, age, Lenke type, center, residual main Cobb, CA, and C7-CSVL.

Tilt was analyzed as absolute magnitude; confirmed true 0° measurements were retained.

Figure 1

Cohort selection and analysis framework. AIS indicates adolescent idiopathic scoliosis; AdIS, adolescent-onset idiopathic scoliosis treated after adolescence; CA, clavicle angle; C7-CSVL, C7-central sacral vertical line; LIV, lowest instrumented vertebra; PROM, patient-reported outcome measure; TL/L, thoracolumbar/lumbar.

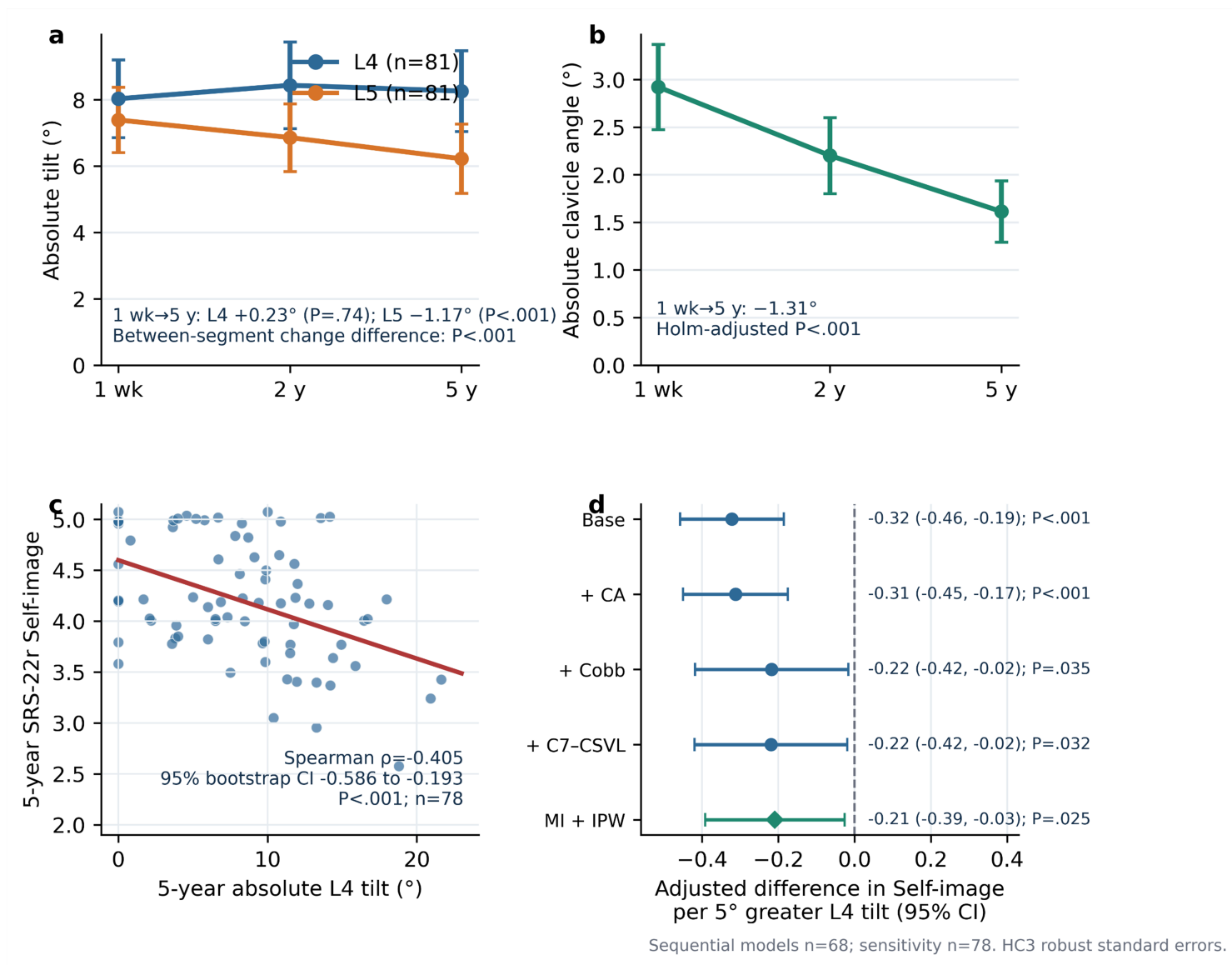


Figure 2

Main results. (a) Mean absolute L4 and L5 tilt with 95% confidence intervals. (b) Mean absolute clavicle angle. (c) Five-year L4 tilt and SRS-22r Self-image; points are vertically jittered for visibility. (d) Adjusted Self-image difference per 5° greater L4 tilt across sequential models and multiple-imputation/inverse-probability-weighted sensitivity analysis.

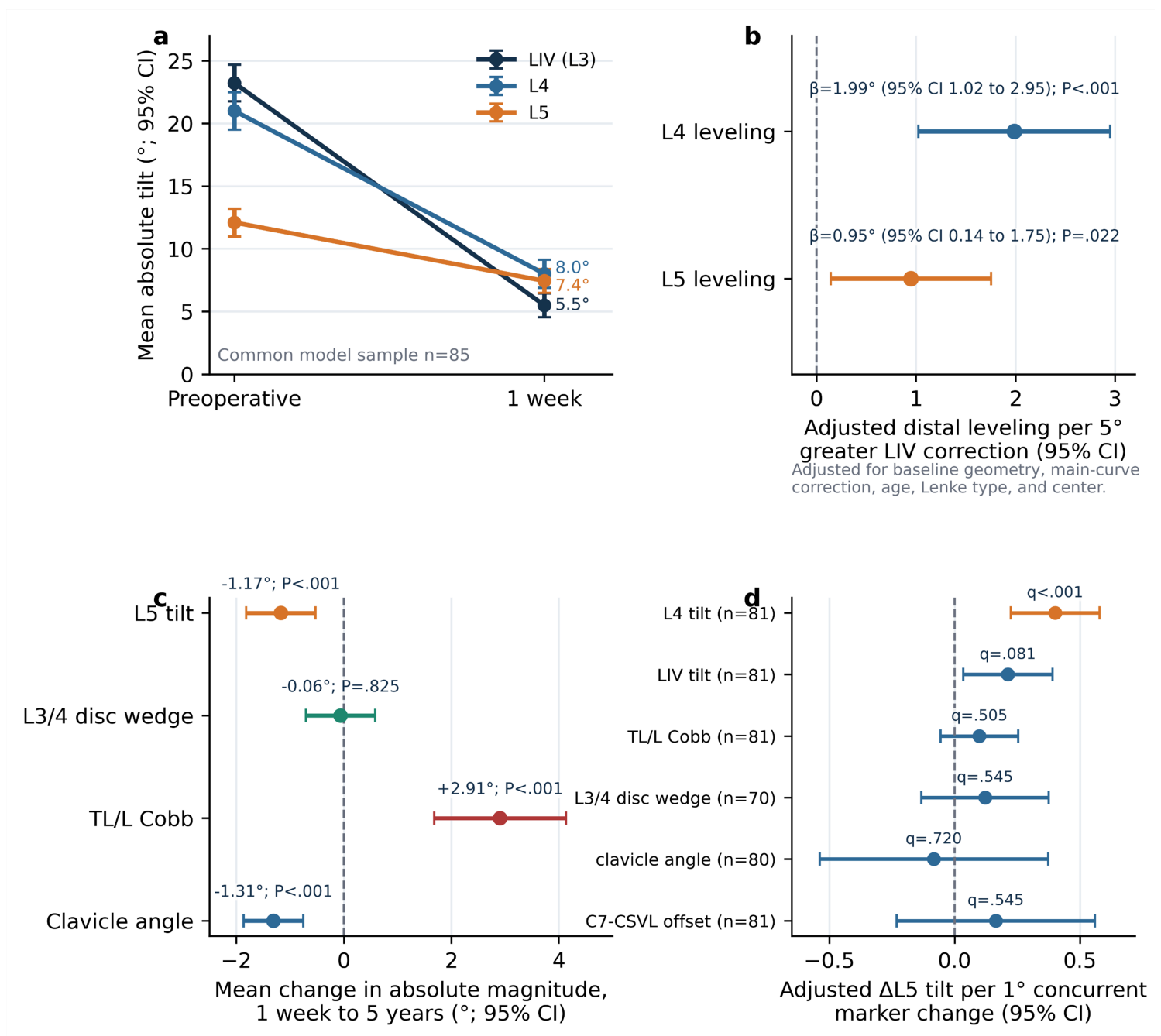


Figure 3

Correction transfer and context of late L5 leveling. (a) Mean absolute LIV, L4, and L5 tilt before surgery and at 1 week among the 85 patients included in early correction models; error bars show 95% confidence intervals. (b) Adjusted difference in early L4/L5 leveling per 5° greater LIV correction. Models adjusted for preoperative segment and LIV tilt, preoperative main Cobb angle, main-curve correction, age, Lenke type, and center. Positive estimates indicate greater distal leveling. (c) Mean 1-week-to-5-year changes in L5 tilt, L3/4 disc wedge, TL/L Cobb, and clavicle angle. Negative change indicates leveling; positive TL/L change indicates correction loss. (d) Adjusted association of concurrent marker change with L5 change; positive estimates indicate concordance. Models used HC3 robust standard errors, adjusted for 1-week L5/marker, age, Lenke type, and center; FDR covered eight markers (six shown).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [OnlineResource1.pdf](#)