

Patient-specific rod planning is often too optimistic in hypokyphotic adolescent idiopathic scoliosis patients

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Abstract

Purpose

To evaluate whether the discrepancy between planned and postoperative T4T12 thoracic kyphosis (TK) using patient-specific rods (PSR) differed between hypokyphotic and normokyphotic adolescent idiopathic scoliosis (AIS) patients.

Methods

Consecutive AIS patients undergoing posterior spinal fusion (PSF) with PSR for thoracic structural curves were retrospectively analyzed from prospectively collected data. Patients were classified as hypokyphotic (T4T12 TK < 20°) or normokyphotic (20–40°). Preoperative, planned, and postoperative radiographic parameters were compared. TK plan execution was considered excellent when the absolute postoperative-to-planned difference was < 5°, acceptable between 5° and 15°, and insufficient when > 15°.

Results

Two hundred and ten patients were included, including 92 hypokyphotic (43.8%) and 118 normokyphotic. Preoperative T4T12 TK was 11°±7 versus 29°±6, respectively ($p < 0.001$), while planned TK was 31°±5 versus 34°±4 ($p < 0.001$). Postoperatively, TK increased to 21°±7 in hypokyphotic patients and remained stable (30°±6) in normokyphotic ones. The difference with the TK target was significantly greater in the hypokyphotic group (10°±5 vs 4°±7, $p < 0.001$). TK plan execution was excellent or acceptable in 85% of the overall cohort, but insufficient in 20% of hypokyphotic patients.

Conclusion

PSR effectively restored sagittal spinal shape in AIS, but TK predictions were frequently too optimistic in hypokyphotic patients. Planning should therefore better take into account patients' preoperative specific sagittal alignment, as well as surgeon-specific correction techniques.

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a three-dimensional (3D) spinal deformity affecting approximately 2–3% of the pediatric population [1, 2]. Sagittal flattening is often observed, and restoring a harmonious spinal shape with physiological thoracic kyphosis (TK) is essential to avoid junctional complications and provide satisfactory long-term outcomes [3]. The first step of spinal reconstruction involves fusion level selection, which is pivotal in spinal alignment restoration, followed by sagittal segmental analysis aimed at identifying surgical targets. The biggest challenge remains intraoperative plan execution, complicated by a lack of accurate radiological control [4].

Until recently, the only option to achieve the desired rod contour intraoperatively was to manually bend straight rods, with a large variability being demonstrated among surgeons when addressing similar deformities [5]. Pre-bent patient-specific rods (PSR) and their associated software represent an innovative solution, aiming to enhance surgical plan execution [6]. In this ecosystem, the expected correction can now be planned, simulated, and its consequences on adjacent unfused segments observed thanks to the dedicated pediatric predictive model [7]. Promising results were recently reported with PSR, achieving greater TK gains and larger proportions of postoperatively normokyphotic patients, but studies are often limited by small sample sizes and/or a lack of hypokyphotic subgroup analyses [7–11]. In addition, the inevitable concave rod flattening during stiff curve corrections, and residual axial periapical rotation (responsible for differential rod contours) remain difficult to predict. Therefore, the purpose of this study was to assess whether the difference between planned and postoperative TK using PSR differed between hypokyphotic and normokyphotic AIS patients.

MATERIALS AND METHODS

Population

After IRB approval (CEER-2023-692), all consecutive AIS patients (< 19 years old) treated by posterior spinal fusion using PSR between May 2022 and May 2024 for thoracic structural curves (Lenke 1–4) were included, with a minimum 2-year follow-up. Data was collected prospectively but retrospectively analyzed. Patients with prior spine surgery, hyperkyphosis (T4T12-TK > 40°) or loss to follow-up were excluded.

Patient-specific rod planning

Preoperative radiographs (standing, supine and bending films) were uploaded online (UNiD Hub, Medtronic, Minneapolis, MN, USA) at least 6 weeks prior to surgery. The upper and lower instrumented vertebrae (UIV and LIV, respectively) were defined, and the expected frontal correction was overestimated at 100%, with 10mm of extra-length safety margins added at both cranial and caudal ends. A preliminary surgical plan with PSR contouring was then elaborated according to the surgeon's preferences and the recent literature (Table 1). The inflection point was placed between T11 and L1 and the regional T10L2 thoracolumbar (TL) junction angle was set around 0°. Lumbar lordosis (LL) value and shape were determined based on pelvic incidence (PI) (PI-LL < 9°), L1 pelvic angle (L1PA = 0.5PI-20°), and the distal L4S1-LL was set at 2/3 of the L1S1-LL, with a minimum value of 30° [12, 13]. When needed, adjustments were made targeting a physiological TK between 20° and 40°, T4L1 pelvic angle (T4L1PA) mismatch between – 4° and + 4°, and a sagittal vertical axis (SVA) close

to 0mm [14]. The final plan was validated by the treating physician at least 3 weeks before surgery, and PSR were sent for production. No differential rod bending, specifically concave overbending, was used in the current series.

Surgical technique

All patients were operated under neuromonitoring, using PSR 5.5mm Cobalt-Chrome (CoCr) rods (UNiD, Medtronic, Minneapolis, USA) and high-density hybrid constructs, combining lumbar pedicle screws (Solera, Medtronic, Minneapolis, USA), polyaxial screws and periapical sublaminar bands (Jazz, Implanet, Bordeaux, France) in the thoracic concavity, and uniplanar screws on the convex side, as previously described [15]. Bilateral facetectomies were performed at every instrumented level, and up to 5 posterior column osteotomies were added, if necessary, using a bone scalpel (Olea, Implanet, Bordeaux, France). No prior anterior releases were performed. The primary reduction techniques were cantilever from the LIV, posteromedial translation, and subsequent direct vertebral derotation, followed by additional contraction/distraction maneuvers to adjust LIV/UIV residual tilt.

Radiological analysis

All patients underwent low-dose full-spine biplanar radiographs (EOS Edge, EOS imaging, Paris, France) preoperatively, postoperatively, and at latest follow-up. Postoperative analyses were performed independently by PSR engineers, and spinal and pelvic measurements were reported. Patients were considered hypokyphotic (HypoTK) preoperatively if T4T12-TK was $< 20^\circ$ (group 1), and normokyphotic (NormoTK) if between 20 and 40° (group 2), as previously reported [9, 16]. The proximal junctional angle (PJA) was calculated between the UIV lower endplate and the UIV + 2 upper endplate. The differences between postoperative and planned measures (delta post-plan) were calculated, and TK execution was considered excellent if delta was $< 5^\circ$, acceptable if between 5 and 15° , and insufficient if $> 15^\circ$.

Complications

All clinical and radiological complications (intraoperatively or during follow-up) were recorded. Proximal junctional kyphosis (PJK) was defined as the association of a postoperative PJA $\geq 15^\circ$ and an increase of $\geq 10^\circ$ compared to preoperative. The PJA cut-off of 15° slightly differed from Glattes's recommendation (10°) but was chosen to better reflect the T1-slope target ($> 15^\circ$), as most fusions ended above T4 [17].

Statistical analysis

Differences in radiographic measurements between the preoperative, planned, and postoperative values were assessed using either RM-ANOVA followed by pairwise paired t-tests or Friedman followed by Nemenyi tests, based on data normality (Shapiro-Wilk test). TK subgroups were compared using either a Student t-test or a Mann-Whitney U test. Qualitative variables were compared using either a Chi-square or Fisher's exact test. Paired categorical data with multiple response categories were compared using a Stuart-Maxwell test. Analyses were conducted with SPSS (IBM, New York, USA; v 31). Statistical significance was set at $p < 0.05$.

RESULTS

Patients and surgical parameters

A total of 210 patients were included (168 female and 42 male), with a mean age of 15.2 ± 1.7 years (Table 2). The mean preoperative TK was $21^\circ \pm 11$, and 92 patients (43.8%) were HypoTK (group 1). Demographic and surgical parameters did not differ between groups. The average number of levels fused was 13.8 ± 0.9 , with a mean implant density of 1.7 ± 0.2 . The most frequent Lenke type was 1 (N=125, 59.5%), and 35 patients (17%) had a negative (-) Lenke sagittal modifier, while 175 (83%) were N. The most frequent UIV and LIV were T3 (N=108, 51%) and L3 (N=122, 58%), respectively. Mean follow-up was 2.8 ± 0.2 years.

Radiological analysis

a. Preoperative alignment

Both groups were comparable in terms of coronal curve severity (main Cobb $57^\circ \pm 14$ vs $58^\circ \pm 14$, $p=0.62$) (Table 3). As expected, mean TK was significantly lower in group 1 ($11^\circ \pm 7$ vs $29^\circ \pm 6$, $p<0.001$), despite comparable PI ($p=0.68$). Sagittal thoracic flattening also significantly impacted lumbar alignment, with a lower LL ($p<0.001$) and more lordotic TL junction ($p<0.001$) in group 1. Hypokyphotic patients more frequently had a TL inflection point above T11 (n=58, 63%), while it was located between T11 and L1 in 69% ($p<0.001$) in group 2. The cervicothoracic junction was similarly affected, with a significantly lower T1-slope in group 1 ($9^\circ \pm 8$ vs $18^\circ \pm 7$, $p<0.001$). Mean T4L1PA was also significantly higher in group 1, but with a small and clinically insignificant difference ($-5^\circ \pm 4$ vs $-3^\circ \pm 3$, $p=0.009$). No differences were found regarding SVA and pelvic parameters (Table 3).

b) Rod planning

The planned rod contours were similar in both groups, with the only significant differences seen in TK targets, with 3 more degrees on average in group 2 for both T1T12 ($p=0.009$) and T4T12 TK ($p<0.001$) (Table 3). However, the expected planned TK gain was significantly greater in group 1 ($+20^\circ \pm 6$ vs $+5^\circ \pm 6$, $p<0.001$).

c) Postoperative alignment

No significant difference was found between groups regarding the postoperative main Cobb angle ($p=0.81$), but as expected, the average 64% correction rate was drastically lower than the 100% planned. Mean TK significantly improved in the overall series, and only 6 patients (3%) were hypokyphotic at follow-up according to Lenke's criteria (i.e. $<10^\circ$). However, the gain in group 1 ($+10^\circ \pm 7$) remained 10° lower than anticipated ($p<0.001$), with a twice larger delta with the target than in group 2 ($10^\circ \pm 5$ vs $4^\circ \pm 7$, $p<0.001$). In the latter, there was no loss of TK during deformity correction, and sagittal alignment was maintained. The plan execution for TK restoration was therefore considered excellent or acceptable in 85% of the cohort but insufficient (delta with plan $>15^\circ$) in 20% in group 1 (Table 4). Group 2 had a significantly higher proportion of excellent results ($p=0.005$).

In group 1, the other consequences of spinal flattening were also corrected, with significant increases in both T1-slope and L1S1-LL ($p<0.001$ and $p<0.001$, respectively). PSR helped restore a harmonious spinal shape, with a more physiological inflection point position (between T11 and L1) in 89% of the patients (Table 5). A greater proportion with proximal postoperative inflection points were observed in group 1, due to insufficient TK restoration, while not reaching significance (14% vs 6%, $p=0.13$) (Figure 1). Mean T4L1PA mismatch remained in the lower range of physiological values in both groups but was significantly more negative than expected in most patients (74% and 75%, respectively) (Table 3). No significant loss of correction was observed during follow-up.

Complications

No infection, neurological complication or unplanned revision were reported. The overall incidence of radiological PJK was 16% ($n=34$), without differences between groups (14 and 20, respectively; $p=0.85$). Patients remained asymptomatic and no further surgery was required.

DISCUSSION

Results of this study, corresponding to the largest series of AIS operated with PSR to date, showed that pre-bent rods were efficient to restore a harmonious spinal shape, and greatly helped improve TK in patients with thoracic scoliosis. However, the targeted TK was often too optimistic in hypokyphotic patients, and planning should better reflect preoperative alignment and surgeon-specific correction techniques and experience.

Sagittal alignment restoration in AIS

AIS represents a diverse group of spinal curvatures with alterations in the coronal, axial, and sagittal planes, requiring 3D reconstruction during surgery. While the coronal plane affects shoulder balance, waistline asymmetry, and risk of adding-on, axial correction is essentially cosmetic for rib hump reduction. The importance of restoring or maintaining an adequate sagittal alignment is now widely understood, as it drives functional outcomes. This can be challenging in stiff and lordotic curves, in which TK is flattened and the spinal shape harmony impaired [3, 7]. The need for more correction often leads surgeons to use higher implant densities, but the lordosing effect of pedicle screws has also been emphasized, with better TK restoration often reported with hybrid constructs [15]. Besides implant selection, the main surgical parameters affecting sagittal correction include rod selection and contouring, and reduction technique, as pointed out by Newton et al. [4]. The latest is in constant progression over a surgeon's career, and rod manual contouring is a major part of that learning curve. However, the main limitation to date is the lack of reliable intraoperative control of the overall sagittal alignment in long constructs.

Benefits of PSR in AIS surgery

Pre-bent PSR and their associated software represent a disruptive innovation, aiming to improve surgical plan execution, accuracy and consistency, reducing some limitations from surgeon-related factors [10]. The correction can now be planned and anticipated, with the consequences on adjacent levels simulated using pediatric predictive models. Recent comparative studies with traditional manually-bent rods have emphasized the added value of PSR, with a significantly lower proportion of T4L1PA and PI-LL mismatch [18, 19]. These findings were confirmed in our series, with a mean postoperative PI-LL mismatch of $-9^\circ \pm 10$, and only 10 cases (5%) with a mismatch exceeding $+9^\circ$. Similarly, an acceptable T4L1PA mismatch averaging -4° was found postoperatively in both groups. Furthermore, PSR restored a harmonious spinal shape, with a physiological inflection point in 88.5% of the cases after surgery (vs 49% preoperatively, $p < 0.001$).

The main variable in this new technology is the method elected for surgical planning, which can greatly impact rod contouring. While some may choose to fully rely on the AI-driven model, others prefer to be more directive and provide engineers with essential prerequisites. In the current series, the AI-driven model was obtained first and further adjusted to match the conditions listed in Table 1, representing a hybrid solution based on trust and communication. Interestingly, the impact of the planning method, which is generally consistent in each department and should not vary between curve types, has never been investigated.

PSR in hypokyphotic patients

Hypokyphotic patients clearly represent the most challenging AIS subgroup and are underrepresented in most published PSR series [7, 9, 20, 21]. These patients are usually stiffer in the sagittal plane, sometimes lordotic, and with significant alterations of the overall spinal shape, as shown in this study, requiring a distinct planning strategy. Thoracic alignment restoration should be as physiological as possible, shifting the inflection point caudally towards the TL junction, with subsequent spontaneous increases in T1-slope and L4S1-LL (unfused segments). Unpredictability lies in the amount of expected intraoperative TK gain, as there is to date little information regarding spinal sagittal flexibility assessment. Indeed, the predictive model consistently suggested a too-optimistic simulation, assuming a flexible spine. The planned rod contours were therefore very similar between groups (only 3° difference in TK target, Table 3), representing a mean expected gain of 20° in hypokyphotic patients. In our hands, only 10° were achieved on average (ranging from -3° to 31°) (Figs. 2 and 3). While this is in the lower range of recent PSR literature (from 14° to 22.4°), their sample sizes were often quite small (between 7 and 17 cases), and postoperative measures were not independent [7, 9, 10, 21].

Although 97% of the operated patients were considered normokyphotic at follow-up according to Lenke's criteria (10 to 40°), TK predictions were often too optimistic, with 93% of the total cohort being undercorrected relative to the preoperative plan. In group 2, the mean 4° difference with the target was

consistent with the findings of Ngo et al. (4.9°), Marya et al. (around 5°), and Jabbouri et al. (3.7°) [8, 9, 21] (Fig. 3). However, the plan-to-postoperative mismatch in TK was considered unacceptable (> 15°) in 20% of group 1, with 10° of undercorrection on average. The hypokyphotic group therefore represents a distinct entity, especially difficult to correct, in which the predictions appear less reliable. More realistic target values are therefore required, which could be surgeon-specific based on data obtained from advanced postoperative analytics.

Limitations

This series presents some limitations. First, it was monocentric with a single surgeon. Nevertheless, this ensured the consistency of surgical technique and planning over the study period. Second, no control group with traditional manually-bent rods was included, so the real benefit of PSR in radiological outcomes cannot be demonstrated. Third, the observed concave rod flattening occurring during correction was not measured and increasing the rod diameter to 6mm or adding differential contouring (10° overbending on concave rod) might improve the reliability of the plan execution. The additional in-situ coronal and sagittal maneuvers performed at the end of correction to optimize UIV and LIV residual tilts, and shoulder and global balance, were also not reported. Finally, the cost-benefit analysis of this emerging technology was not evaluated, as its impact on functional outcomes still needs to be further assessed.

In conclusion, patient-specific rod planning is efficient and promising to optimize AIS surgery, but the predictions are often too optimistic, especially in hypokyphotic patients, and should be better adjusted to surgeon-specific technique and personal experience.

Declarations

Competing Interests

Brice Ilharreborde is a consultant at and receives royalties from Implanet and Medtronic and receives royalties from Highridge Medical. Emmanuelle Ferrero is a consultant at Implanet and Medtronic. Remaining authors have no relevant financial or non-financial interests to disclose.

Author Contribution

Conceptualization: Brice Ilharreborde, Methodology: Brice Ilharreborde, Anne-Laure Simon, Emmanuelle Ferrero, and Aren Joe Bizdikian, Formal analysis and investigation: Aren Joe Bizdikian and Brice Ilharreborde; Writing - original draft preparation: Aren Joe Bizdikian; Writing - review and editing: Brice Ilharreborde, Emmanuelle Ferrero, and Anne-Laure Simon; Funding acquisition: N/A; Resources: Brice Ilharreborde; Supervision: Brice Ilharreborde, Emmanuelle Ferrero, and Anne-Laure Simon

Data Availability

The data are available upon request and with the permission of Université Paris Cité's ethics committee.

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Tables

Table 1: Correction targets for patient-specific rod contouring

Parameter	Planned values
1) Inflection point location	Between T11 and L1
2) L1PA	0.5*PI-20
3) PI-LL	<9°
4) L4S1 LL	~2/3 of L1S1 LL and >30°
5) T10L2 sagittal Cobb	~0°
6) T4L1 PA	Between -4° and +4°
7) T4T12 TK	Between 20° and 40°
8) T1 slope	>15°
9) SVA	~0mm

L1PA: L1 pelvic angle; PI: pelvic incidence; PI-LL: pelvic incidence - lumbar lordosis mismatch; LL: lumbar lordosis; T4L1 PA: Mismatch between T4 and L1 pelvic angle; TK: thoracic kyphosis; SVA: sagittal vertical axis.

Table 2: Patients demographics and surgical parameters

	HypoTK (Group 1, n=92)	NormoTK (Group 2, n=118)	p-value
Age (years)	15.3 ± 1.8	15.1 ± 1.6	0.85
Sex (n)			0.08
Female	68 (74%)	100 (85%)	
Male	24 (26%)	18 (15%)	
Lenke type			0.23
1	49 (53%)	76 (64%)	
2	5 (5%)	9 (8%)	
3	30 (33%)	25 (21%)	
4	8 (9%)	8 (7%)	
UIV (n)			0.42
T2	48 (52%)	53 (45%)	
T3	44 (48%)	64 (54%)	
T4	0 (0%)	1 (1%)	
LIV (n)			0.1
L2	16 (17%)	13 (11%)	
L3	46 (50%)	76 (64%)	
L4	30 (33%)	29 (25%)	
Fusion levels (n)	13.8 ± 0.9	13.8 ± 0.8	0.75
Implant density	1.8 ± 0.1	1.7 ± 0.2	0.9

UIV: upper instrumented vertebra; LIV: lower instrumented vertebra; HypoTK: hypokyphotic group; NormoTK: normokyphotic group

Table 3: Analysis of the different preoperative, planned and postoperative radiological measurements

		Preoperative			Planned			Postoperative			Overall	Pairwise comp	
		HypoTK (Group 1)	NormoTK (Group 2)	p-value	HypoTK (Group 1)	NormoTK (Group 2)	p-value	HypoTK (Group 1)	NormoTK (Group 2)	p-value	p-value	Pre-Post	Pre-Plan
Coronal	Proximal Thoracic Cobb (°)	30±12	29±12	0.98	0°	0°	-	18±8	18±7	0.92	-	<0.01	-
	Main Thoracic Cobb (°)	57±14	58±14	0.62	0°	0°	-	20±9	21±8	0.81	-	<0.01	-
	Lumbar Cobb (°)	35±13	37±12	0.38	0°	0°	-	15±6	15±7	0.85	-	<0.01	-
Sagittal Spinal	T1 slope (°)	9±8	18±7	<0.001	22±6	22±6	0.71	18±11	26±9	<0.001	<0.001	<0.001	<0.001
	PJA (°)	5±7	3±7	0.10	5±7	3±7	0.20	13±10	15±10	0.17	<0.001	<0.01	0.26
	T1T12 TK (°)	19±10	36±8	<0.001	39±7	42±7	0.009	37±13	49±11	<0.001	<0.001	<0.001	<0.001
	T4T12 TK (°)	11±7	29±6	<0.001	31±5	34±4	<0.001	21±7	30±6	<0.001	<0.001	<0.001	<0.001
	T10L2 Lordosis (°)	7±10	2±11	<0.001	0±3	0±3	0.14	8±6	7±7	0.33	<0.001	<0.001	<0.001
	L1S1 LL (°)	52±12	59±11	<0.001	59±9	60±10	0.40	60±13	61±11	0.69	<0.001	<0.001	<0.001
	L1L4 LL (°)	19±12	21±9	0.15	23±9	22±7	0.67	26±10	27±8	0.53	<0.001	<0.001	<0.001
	L4S1 LL (°)	33±8	38±7	<0.001	36±7	38±7	0.17	34±9	34±9	0.91	<0.001	0.16	<0.001
	PI-LL (°)	-0.1±10	-8±10	<0.001	-7±8	-9±7	0.11	-7±11	-10±9	0.004	<0.001	<0.001	<0.001
	SVA (mm)	7±23	12±25	0.15	3±12	0±11	0.06	19±24	19±21	0.87	<0.001	<0.001	<0.001
	T4L1 PA mismatch (°)	-5±4	-3±3	0.009	-2±1	-2±2	0.78	-4±3	-4±2	0.79	<0.001	<0.001	<0.001
Sagittal Pelvic	SS (°)	43±10	42±9	0.32	41±8	41±9	0.87	43±10	42±9	0.10	<0.001	0.21	<0.001
	PT (°)	9±8	9±8	0.81	11±9	10±7	0.60	9±8	8±8	0.50	<0.001	0.4	<0.001
	PI (°)	52±14	51±13	0.68	52±14	51±13	0.68	52±14	51±13	0.68	-	-	-

Bold values indicate significant differences.

PJA: Proximal Junctional angle; TK: thoracic kyphosis; LL: lumbar lordosis; PI-LL: pelvic incidence - lumbar lordosis mismatch; SVA: sagittal vertical axis; T4L1 PA: Mismatch between T4 pelvic angle and L1 pelvic angle; SS: sacral slope; PT: pelvic tilt; PI: pelvic incidence; HypoTK: hypokyphotic group; NormoTK: normokyphotic group

Table 4: Analysis of the plan execution for T4T12 TK

	All (n=210)	HypoTK (Group 1, n=92)	NormoTK (Group 2, n=118)
Excellent	78 (37%)	23 (25%)	55 (47%)
Acceptable	101 (48%)	51 (55%)	50 (42%)
Insufficient	31 (15%)	18 (20%)	13 (11%)

Chi square p=0.005. Bold values indicate significant residuals.

TK: Thoracic kyphosis; HypoTK: hypokyphotic group; NormoTK: normokyphotic group

Table 5: Patients' distribution according to the thoracolumbar inflection point

	Inflection point	HypoTK (Group 1, n=92)	NormoTK (Group 2, n=118)	p-value
Preoperative	Above T11	58 (63%)	16 (14%)	<0.001
	Between T11 and L1	22 (24%)	81 (69%)	
	Below L1	12 (13%)	21 (18%)	
Planned	Above T11	0 (0%)	0 (0%)	1
	Between T11 and L1	92 (100%)	118 (100%)	
	Below L1	0 (0%)	0 (0%)	
Postoperative	Above T11	13 (14%)	7 (6%)	0.13
	Between T11 and L1	77 (84%)	109 (92%)	
	Below L1	2 (2%)	2 (2%)	

Bold values indicate significant residuals.

HypoTK: hypokyphotic group; NormoTK: normokyphotic group.

Figures

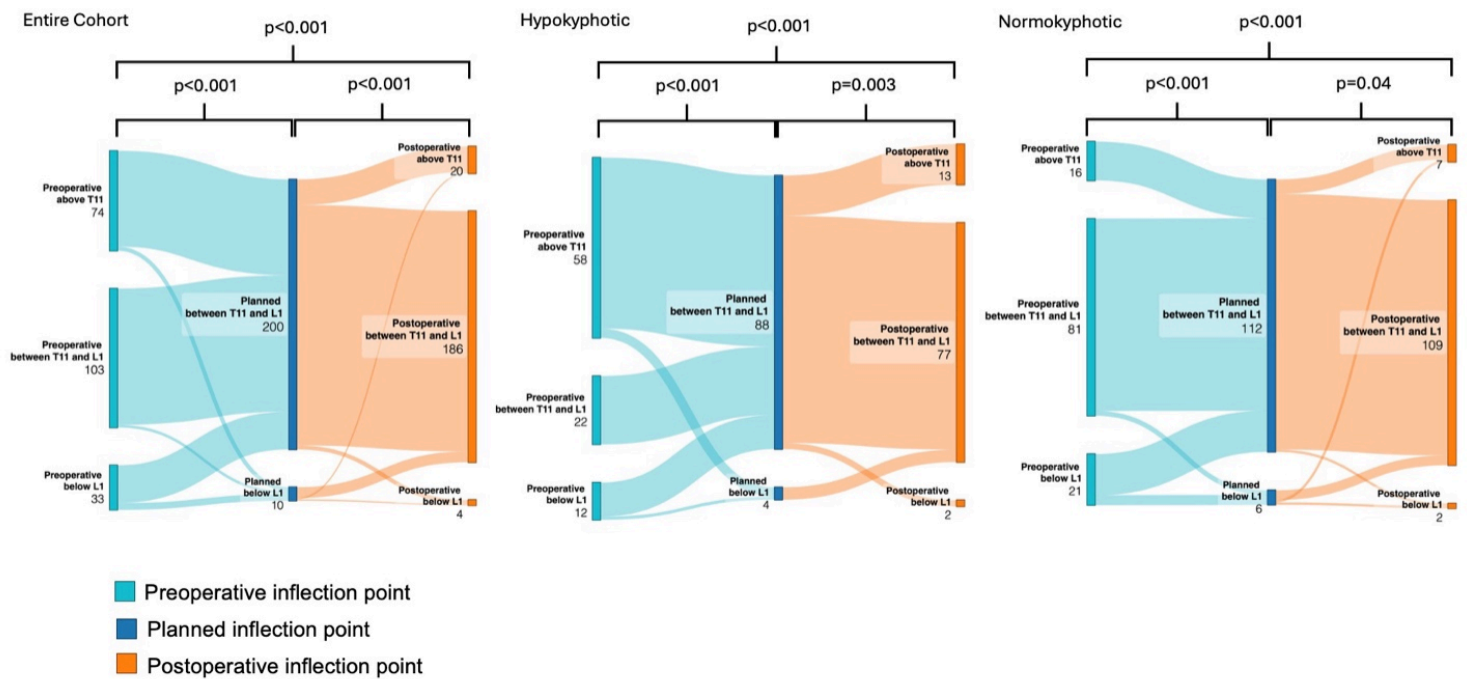


Figure 1

Sankey plots illustrating the change in thoracolumbar inflection point between the preoperative, planning, and postoperative timepoints in the entire cohort.

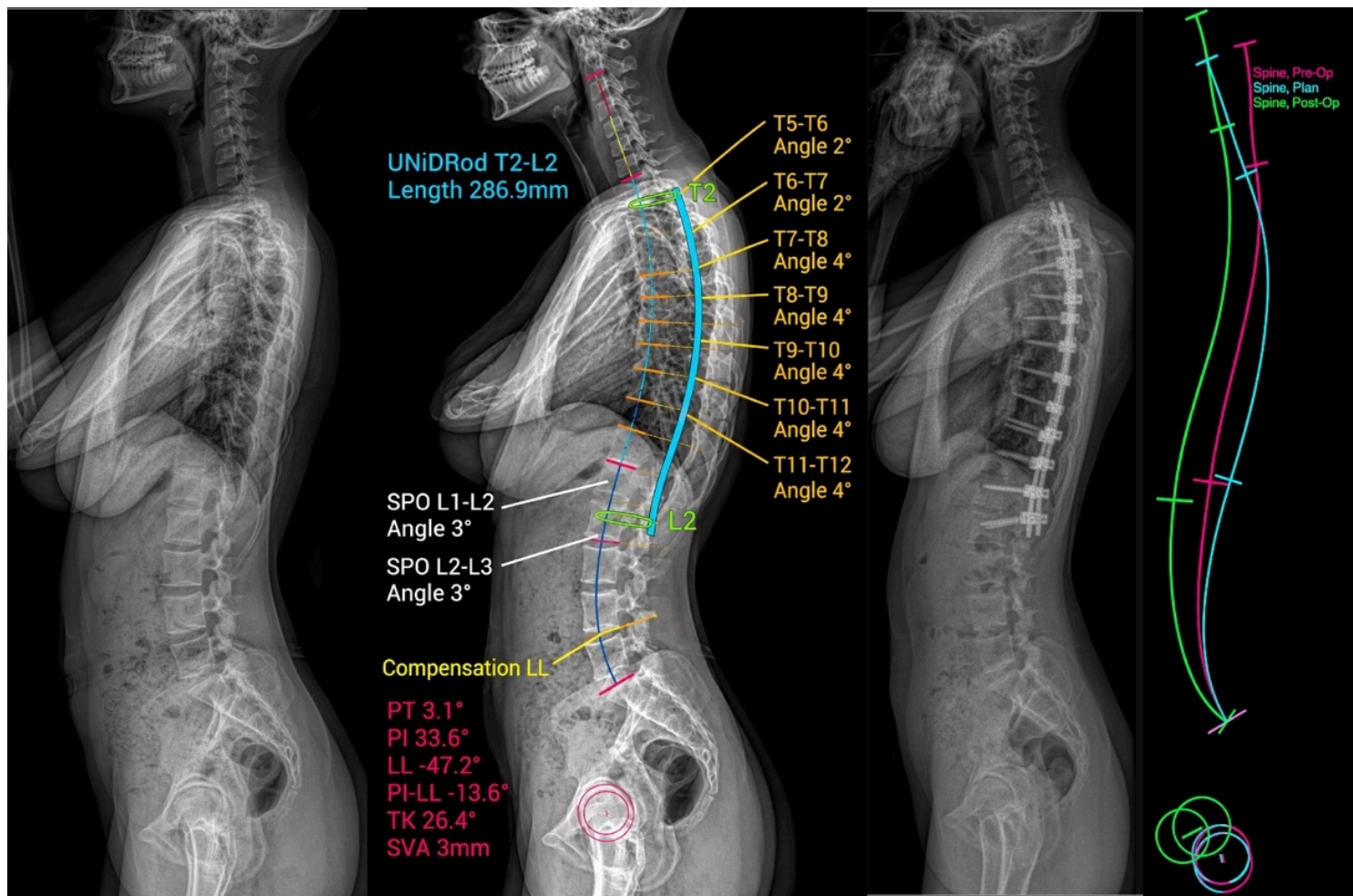


Figure 2

Hypokyphotic AIS patient (preoperative T4T12-TK 2°) (a), planned at 26° (b), but who only gained 15° (T4T12-TK 17° postoperative) (c). with preoperative hypokyphosis maintaining an insufficient sagittal correction with hypokyphosis postoperatively. This undercorrection can be seen on the spline-based representation of the sagittal profiles (d).

TK: Thoracic kyphosis

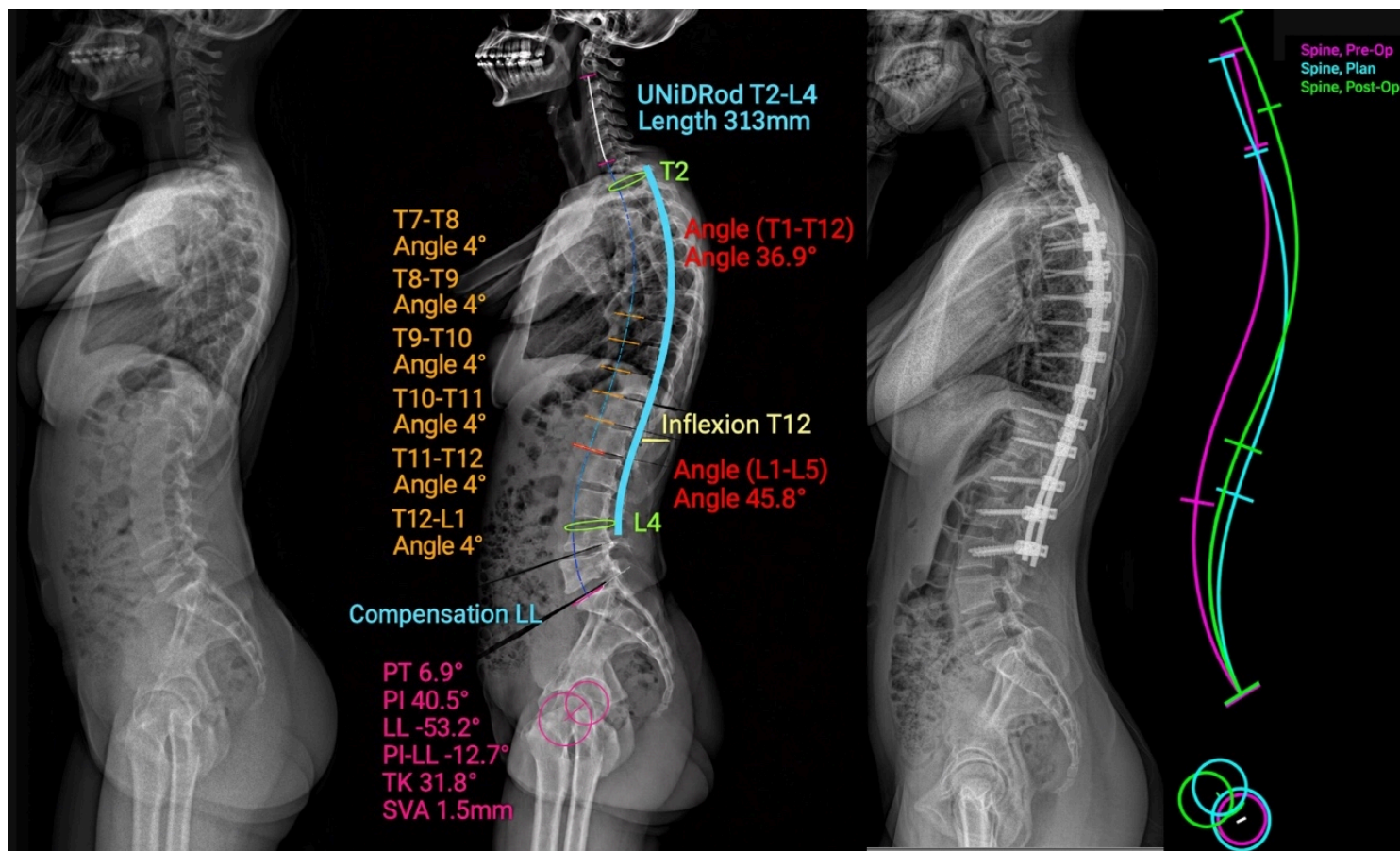


Figure 3

Hypokyphotic AIS patient (T4T12-TK 12°) (a), planned at 32° (b), with excellent sagittal alignment restoration (31°, +19°) (c). The pline-based representation (d) also shows an improved spinal harmony, with a caudal shift of the inflexion point (from T8 to T12, as planned), and a -3° postoperative T4L1PA mismatch (versus -9° before surgery).

TK: Thoracic Kyphosis; T4L1PA: mismatch between the T4 and L1 pelvic angles

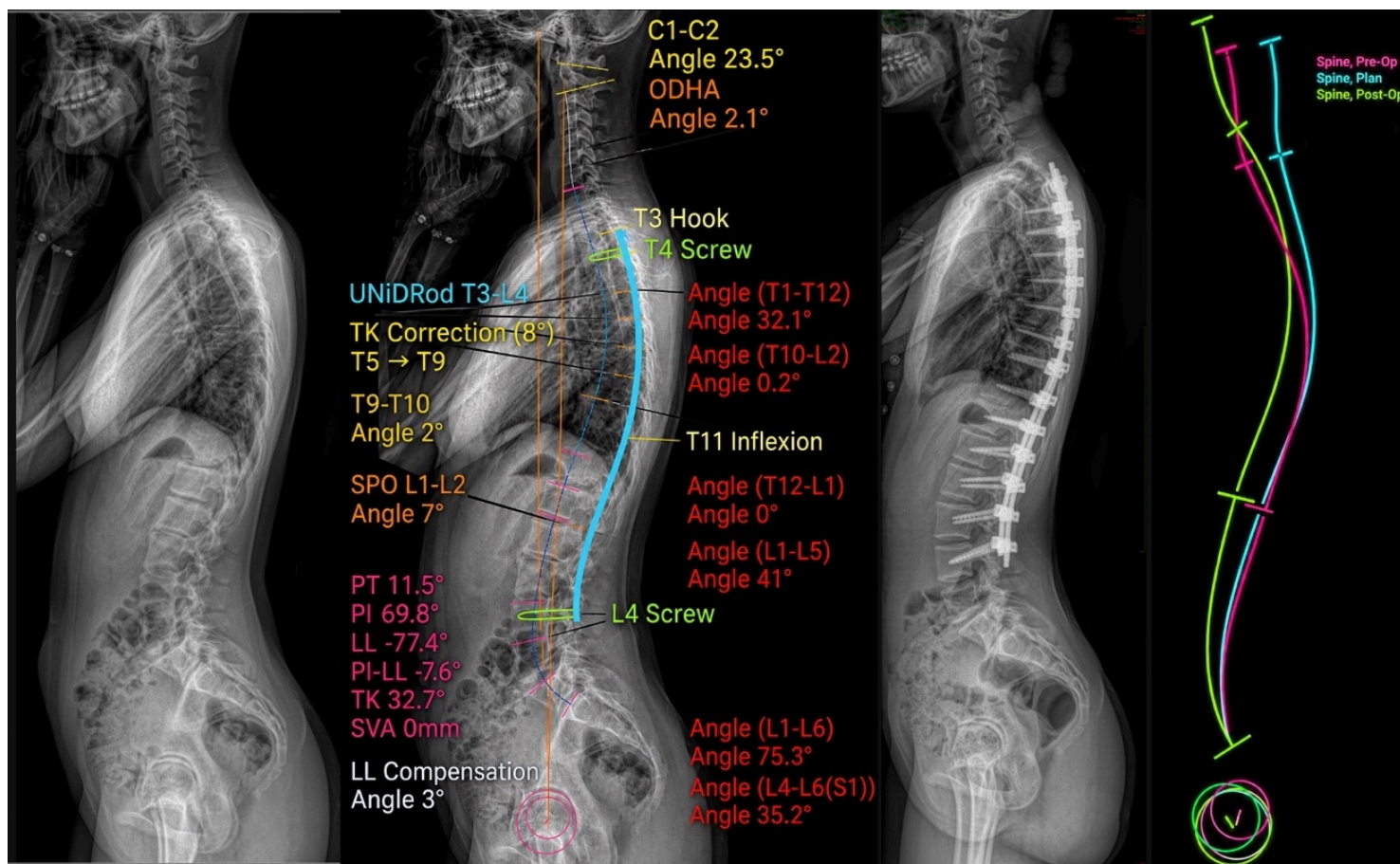


Figure 4

Normokyphotic AIS patient (preoperative T4T12-TK 38°) (a), in whom the planning (T4T12-TK 33°) (b) was respected (32° postoperative) (c) and the sagittal alignment maintained despite high-density implants constructs (d).

TK: Thoracic kyphosis