

How to optimize axial correction without altering thoracic sagittal alignment in hybrid constructs with sublaminar bands: description of the « frame » technique

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White paper

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INTRODUCTION

Thoracic adolescent idiopathic scoliosis (AIS) is a progressive three-dimensional deformity, responsible for rib cage axial asymmetry and sagittal curves flattening. The goal of surgery is to achieve a 3D correction and to prevent progression of the unfused spine, while improving the overall cosmetic aspect of the trunk (1). Since recent studies have showed that self-image was the only domain that differed at long-term between untreated AIS and healthy controls, reducing the clinical rib hump should remain the treatment's major objective (2,3,4). Thoracic pedicle screws associated with direct vertebral (DVD) or "en bloc" derotation techniques have gained popularity after the mid 1990's (5,6). However, this gain in axial correction has been obtained at the expense of postoperative sagittal alignment, frequently altered in all-screw constructs (7,8,9,10). As a matter of fact, all techniques emphasizing apical axial correction tend to place the anterior and convex higher vertebral wall in a more ventral position, thus increasing the length of the anterior column and therefore flattening the spine (11). While some authors advocate the use of larger diameter rods, higher screw density on the concave side or multiple facetectomies to optimize the correction of the thoracic hypokyphosis, Mazda et al. and Ilharreborde et al. have emphasized since 2009 the efficacy and safety of the posteromedial translation technique, using sublaminar bands, even in large stiff curves, with no need for previous thoracoscopic anterior release (12-19). The conclusions of the promoters of the technique have later been confirmed by several independent studies (20,21,22,23). However, Pizones et al. recently questioned the ability of the sublaminar band to correct the axial plane, after noticing intraoperatively that the tightening of concave sublaminar wires during the correction maneuver tended to create an opposite effect than that desired, making the vertebra rotate clockwise instead of counterclockwise, and thus increasing RVA and the rib hump (24). This observation of great importance had been encountered by the authors in their preliminary experience with severe curves, but has been addressed by a technical improvement emphasizing axial correction. The goal of this paper is therefore to describe the "frame" reduction technique and report the 3D quantitative analysis of postoperative corrections in a recent consecutive series of thoracic AIS patients.

MATERIALS AND METHODS

Patients

Following institutional review board approval, a consecutive series of AIS patients, operated for progressive Lenke 1 or 2 curves between January 2016 and March 2017, were retrospectively

analyzed. The apex and both end vertebrae (upper and lower) of the main thoracic curve were determined by an independent senior spine surgeon. Demographic and surgical data was collected. A minimum 6-month follow-up was required. All patients were evaluated preoperatively, in the early postoperative period (within 1 month), and at latest follow-up. None of the patients had prior spinal surgery.

Surgical procedure

All patients underwent posterior spinal fusion using hybrid constructs, combining pedicle screws (below the inflection point, from T11 to L4) (ISS (Implanet, Bordeaux, France) or Legacy (Medtronic, Minneapolis, USA)), concave thoracic sublaminar bands (above the inflection point, from T5 to T11) (Jazz systems (Implanet, Bordeaux, France) and proximal hooks with 5.5 mm CoCr diameter rods, as previously reported (25,26). No selective thoracic fusion was performed and no patient underwent prior anterior release before posterior fusion. The same perioperative blood saving strategy was used, associating intraoperative cell saver and tranexamic acid. Posteromedial translation was the main technique used for thoracic correction, using the progressive tension transmitted by the polyester bands to bring the thoracic spine to precontoured rods. Autograft was the only material used for fusion and spinal cord monitoring was systematically applied.

Implants location and reduction maneuver using the « frame » technique

After pedicle screw insertion below the inflection points (minimum 4 screws, 2 per side), sublaminar bands were placed at every level of the main thoracic curve (upper end vertebra to lower end vertebra) on the concave side. One additional convex sublaminar band was placed at the apex for construct stabilization. The upper fixation relied on a bivertebral claw in all cases, using angled supralaminar hooks on the UIV and either bands (Jazz claw, Implanet, Bordeaux, France) or pedicle hooks (Instinct autostable claw, ZimmerBiomet, Warsaw, USA) on the UIV-1, depending on surgeon's preference (Figures 1,2). Two additional sublaminar bands were often placed on the UIV-3 in order to reduce the pull-out forces on the proximal anchor (Figure 1).

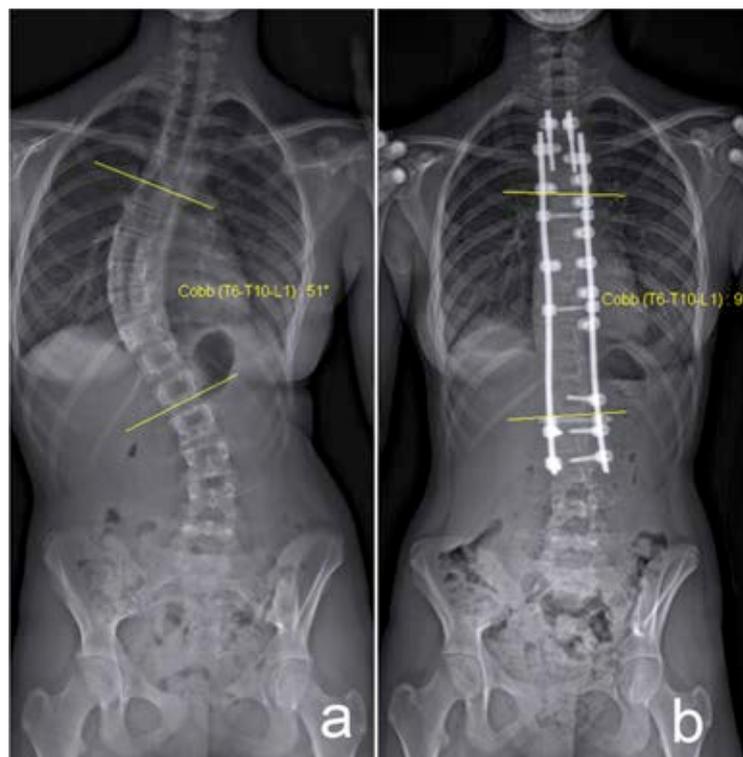


Figure 1 : Preoperative (a) and postoperative (b) frontal radiographs of a 51° Lenke 1A curve, who underwent a T3L3 fusion using Jazz claw for the upper fixation.

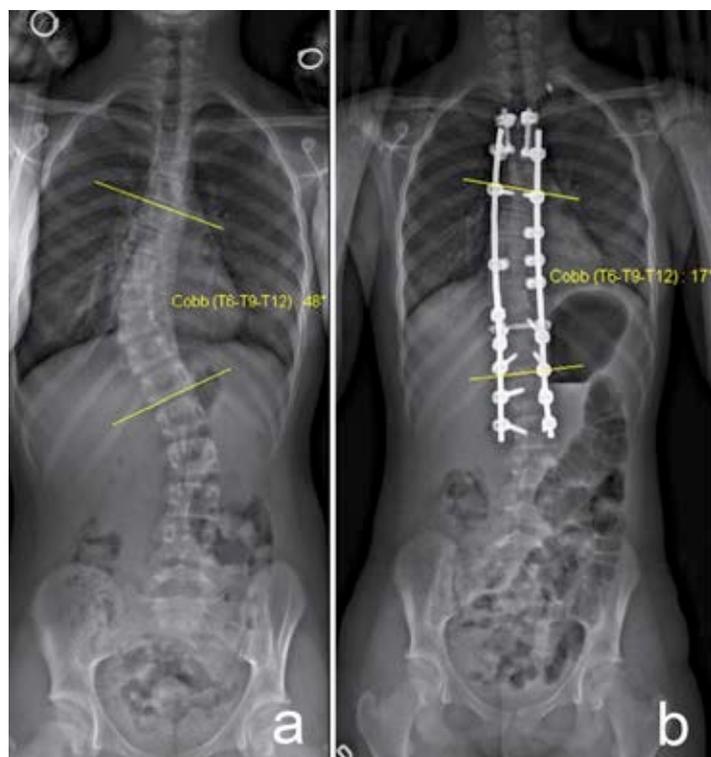


Figure 2 : Preoperative (a) and postoperative (b) AP radiographs of a 48° Lenke 1A curve, who underwent a T3L2 fusion using Instinct autostable claw for the upper fixation. The 64.5% frontal correction of the main curve was obtained using only 3 concave sublaminar bands. One additional convex sublaminar band was used at the apex for construct stabilization.

Once all implants were placed (no fluoroscopy or any imaging guidance required), 2 CoCr rods were bent in the sagittal plane according to preoperative planing. Attention was paid to respect the preoperative inflection point, give a lumbar lordosis adapted to pelvic incidence, and restore as much as possible the thoracic kyphosis without modifying the 3D preoperative location of the UIV. The 2 rods were bent in the same manner and no overbending was used on the concave side.

At that stage, both rods were connected before insertion by 1 or 2 fixed transverse connectors (25, 30 or 35 mm length depending on patient's anatomy), in order to obtain a frame (Figure 3).



Figure 3 : Insertion of two 30mm length fixed transverse connectors in order to obtain a rigid « frame ».

One connector was systematically placed at the apex in order to rigidify the construct and avoid rod flattening during the correction. The first step of the correction was the frame insertion in the pedicle screws. Lumbar correction was first performed using derotation and convex contraction. The second step was the connection of the frame with the upper anchors on both sides, with the set screws left open in order to allow spinal lengthening (Figure 4).



Figure 4 : Bilateral connection of the frame with the upper anchors after initial lumbar correction.

Sublaminar bands were then connected to their respective rods (3 to 7 bands on the concave side, and 1 or 2 on the convex rod). The thoracic deformity was then progressively reduced by the tension transmitted by the concave polyester bands to bring the vertebrae to the precontoured

frame. The spine was first translated medially and posteriorly, but when the convex rod came in contact with the rotated right lamina of the apex, the location of the vertebral center of rotation was modified. The latter shifted posteriorly and therefore emphasized the counterclockwise axial correction during the last stage of correction (Figure 5).



Figure 5 : Top view of the apical vertebra, showing the contact between the convex rod and the rotated right lamina during correction, resulting in a posterior shift of the vertebral center of rotation.

After applying the maximal tension on each band, contraction and/or distraction were applied on the proximal claws to achieve shoulders and T1 frontal balance and all set screws were locked.

Radiological measurements

All patients underwent low-dose stereoradiographs using the EOS system (EOS imaging, Paris, France) preoperatively and at latest follow-up, as previously described (27). 3D reconstructions were performed using SterEOS software (EOS imaging, Paris, France) by an independent Imaging reconstruction service (EOS 3DServices, Montreal, Canada). Inter and intraobserver reliabilities of both methods have been previously reported (27,28). All 3D measurements were calculated using to the patient's plane, using the central hip vertical axis (CHVA) as a reference, and were therefore not influenced by the patient's position in the cabin.

The following 3D coronal radiographic parameters were recorded: Cobb angles of the main curve and T1 tilt (measured between the horizontal reference line and the upper endplate of T1). Sagittal 3D parameters included: T1T12 and T4T12 thoracic kyphosis (TK), L1S1 lumbar

lordosis (LL), and pelvic parameters. Sagittal and frontal global balances were evaluated by the projections in the respective planes of the distance between the center of T1 vertebral body and the CHVA. In addition, the axial rotations of the apical vertebra (RVA), the upper instrumented vertebra (UIV), the UIV+1, the lower instrumented vertebra (LIV) and the LIV L1 were calculated. Considering the measurement bias in the axial plane, a residual axial rotation $>10^\circ$ was considered significant, especially if it affected 2 consecutive vertebrae (LIV and LIV+1 or UIV and UIV+1) (27).

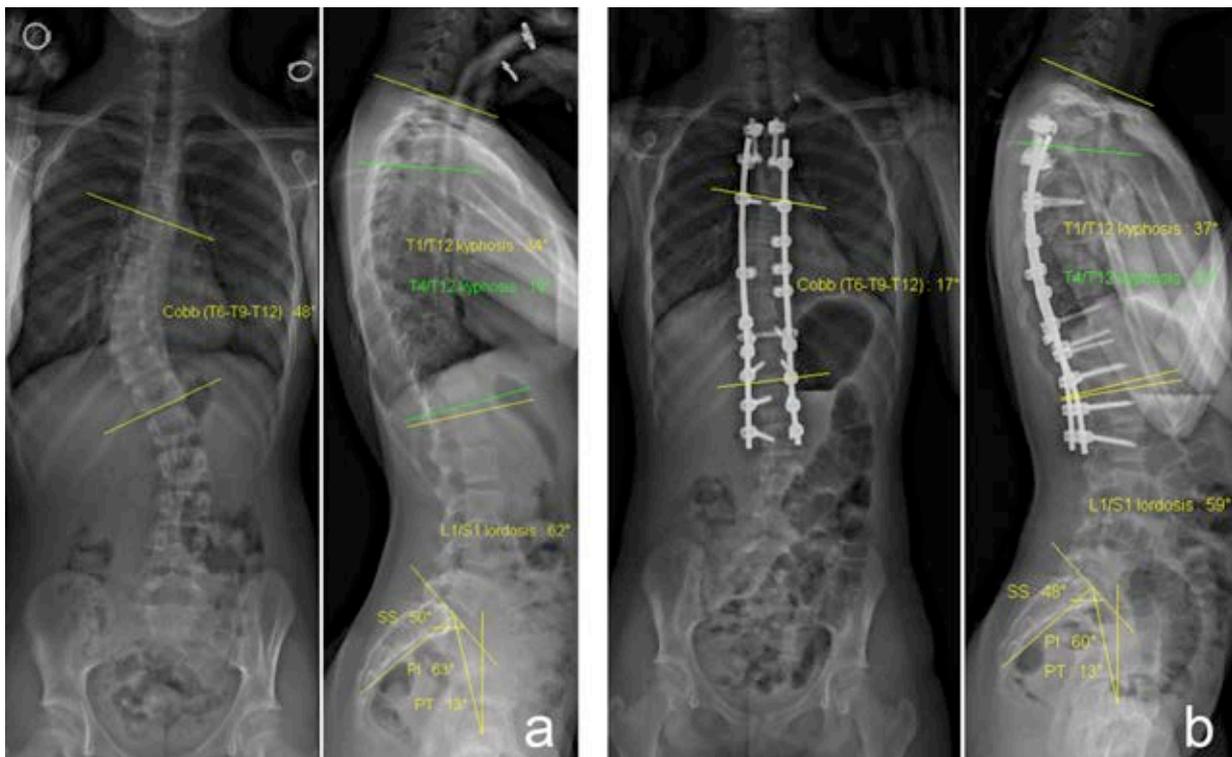


Figure 6 : Preoperative (a) and postoperative (b) anteroposterior and lateral radiographs of a 48° Lenke 1AN patient. Frontal correction rate reached 64.5% with only 3 concave sublaminar bands. The frame allowed to obtain 43% of axial correction at the apex, while the sagittal alignment was maintained.

Statistical analysis

Statistical analysis was performed using SPSS version 12.0 (SPSS Inc, Chicago, IL, USA).

Continuous variables were expressed as means and standard deviations. Paired-samples Student's *t*-tests were used to compare preoperative and postoperative radiological parameters. Pearson test was used to analyze the correlation between the gain in thoracic kyphosis and the axial correction of the apical vertebra (RVA). All statistical tests were 2-tailed, and a *P* value <0.05 was considered to be significant.

RESULTS

Demographic and operative data

Among the 64 eligible Lenke 1 and 2 AIS patients operated during the study period, 4 were excluded because the personalized 3D reconstructions were not feasible. The reason was the existence of lumbosacral transitional anomaly (lumbarized S1 or sacralized L5) altering vertebrae numbering on SterEOS software. Mean age of the 60 patients kept for analysis was 15.4 years (± 2). There were 6 boys and 54 girls, with a mean follow-up of 10.3 months (± 4). Lenke 1 curves were the most frequent (44 cases, 73.3%), while Lenke 2 curves were identified in 16 patients (26.6%). The number of fused vertebrae averaged 12.9 (± 1), and all fusions extended to L2 or below (no selective thoracic fusion). The UIV was T2 in 20 cases (33.3%) and T3 in 40 patients (66.6%). The mean number of sublaminar bands used for correction at thoracic levels was 6 (± 1.5).

Frontal correction

Preoperative and postoperative 3D measurements are reported in Table 1.

Table 1 : Preoperative and postoperative 3D measurements (mean \pm standard deviation)

	Preoperative	Postoperative	p
Main Cobb angle (°)	56 \pm 11	20 \pm 7	<0.001
RVA (°)	19 \pm 6	11 \pm 5	<0.001
T1T12 sagittal Cobb (°)	28 \pm 12	35 \pm 11	<0.001
T4T12 sagittal Cobb (°)	20 \pm 11	21 \pm 8	0.719
L1S1 sagittal Cobb (°)	57 \pm 9	54 \pm 10	0.002
T1 frontal tilt (°)	5 \pm 4	6 \pm 5	<0.001
Pelvic incidence (°)	52 \pm 11	52 \pm 11	0.447
Sacral slope (°)	44 \pm 7	43 \pm 9	0.281
Pelvic tilt (°)	9 \pm 8	9 \pm 8	0.426

RVA : axial rotation of the apical vertebra

Frontal correction rate averaged 64% (± 11 , from 40% to 84%), and 75% of the patients had a residual Cobb angle $<25^\circ$ postoperatively. The surgical correction tended to raise the left

shoulder in 95% of the patients (57/60), but a residual T1 tilt $>10^\circ$ (to the right) in the early postoperative period was only noted in 10 cases (16.6%). The distance from the center of the apical vertebra to the reference axis (CHVA) in the frontal plane was reduced from 4.7 cm (± 2) to 1.1 cm (± 1), traducing the efficient medial translation of the spine during correction ($p < 0.001$).

Sagittal correction

The T1T12 kyphosis significantly increased after surgery ($p < 0.001$), but the instrumented T4T12 kyphosis remained stable ($p = 0.719$). However, the high proportion of normokyphotic patients preoperatively (76.6% with T4T12 sagittal Cobb between 10° and 40°) require further analysis. Among the 46 normokyphotic patients preoperatively, 12 (26%) had an unintentional reduction of T4T12 kyphosis $>5^\circ$, while 74% remained with a stable sagittal alignment or gained kyphosis. Mean increase in the 12 most challenging hypokyphotic patients (i.e T4T12 sagittal Cobb $<10^\circ$) was 8.5° (± 4), and only 3 patients (5% of the global cohort) remained hypokyphotic at latest follow-up. Most importantly, the reduction maneuver did not significantly affect the 3D location of the UIV ($p = 0.171$), despite a slight but not clinically significant increase of the T1-UIV distance (3mm, $p < 0.001$) being reported (Table 2).

Table 2 : Preoperative and postoperative 3D parameters of global balance, measured in regards to the Central Hip Vertical Axis (CHVA)

	Preoperative	Postoperative	p
Frontal T1 distance (cm)	1.3 \pm 1	1.4 \pm 1	0.846
Sagittal T1 distance (cm)	3.4 \pm 2	3.4 \pm 2	0.737
Frontal UIV distance (cm)	1.2 \pm 1	1.5 \pm 1	0.181
Sagittal UIV distance (cm)	3.9 \pm 2	4.2 \pm 2	0.171
Frontal LIV distance (cm)	1.2 \pm 1	1.0 \pm 1	0.075
Sagittal LIV distance (cm)	1.3 \pm 1	1.5 \pm 1	0.387
Frontal T1-UIV distance (cm)	0.4 \pm 0.3	0.4 \pm 0.3	0.999
Sagittal T1-UIV distance (cm)	0.6 \pm 0.5	0.9 \pm 0.5	<0.001

UIV : upper instrumented vertebra
LIV : lower instrumented vertebra

Axial correction

The apical rotation was significantly reduced after surgery ($p < 0.001$), and the RVA correction rate averaged 42.2% (gain ranged from 0° to 25°), without any direct derotation maneuver (Figure 6). No correlation was found between the axial and sagittal correction of the apex ($R^2 = 0.005$). The LIV axial rotation significantly decreased from $6^\circ (\pm 4)$ to $4^\circ (\pm 3)$ ($p = 0.015$). A residual axial rotation of the LIV $> 10^\circ$ was reported in 2 cases (3.3%), and these 2 patients also had a residual axial rotation of the LIV+1 $> 10^\circ$. One of them developed a radiological adding-on at 6 month postoperative, without revision surgery to date.

Complications

No instrumentation failure, no pseudarthrosis and no significant loss of correction was reported in the cohort during the follow-up period. Three (5%) early surgical site infections (within 4 weeks) were reported, all due to *Propionibacterium acnes*. Implant retention strategy was applied, and outcomes were favourable after 1 surgical debridement followed by 12 weeks of antibiotherapy (2 weeks IV and 10 weeks oral). According to Yagi et al. criteria, 1 radiological proximal junctional kyphosis (PJK) occurred (6.6%) (29). The patient was asymptomatic and no revision was performed. One patient developed an aorto-mesenteric clamp syndrome at 6 days postoperative, which spontaneously resolved after 10 days of nasogastric decompression and intravenous hyperalimentation. This patient had a 72° Lenke 1A- curve with severe hypokyphosis (1° of T4T12 sagittal Cobb). Her curve was corrected to 25° postoperatively (65% correction) and the T4T12 thoracic kyphosis gained 12° after surgery.

DISCUSSION

Results of this series confirm the ability of sublaminar bands to correct the deformity in 3D, without altering sagittal balance. The main advantage of the current study is that only 3D measurements were used for analysis. Indeed, Newton et al. have demonstrated that most of the 2D sagittal Cobb measurements were biased, and clearly underestimated the real thoracic spine flattening (30).

Limitations of all-screw constructs

The development and rapid expansion of pedicle screws in AIS has increased construct stability, improving early postoperative care and fusion rates, but has also allowed the application of

greater reduction forces with direct vertebral rotation techniques (5,6). However, the spine community should acknowledge that the increased complexity of AIS surgical correction procedures has been associated not only with better initial outcomes, but also with more postoperative complications (31). For example, PJK was rarely described after CD instrumentation using hooks and hybrid constructs, whereas it is now considered a topic of much interest and still not fully understood (32). One potential explanation is that while lumbar lordosis is usually preserved after the correction, thoracic pedicle screws associated with derotation have a tendency to flatten the thoracic spine, resulting in a posterior shift of the UIV (11). Since most AIS patients are sagittally balanced preoperatively (in opposition to adult spine deformity with anterior imbalance), the early consequence is a junctional kyphosis above the instrumented levels in order to replace the center of gravity where it stood before surgery. This phenomenon can be appreciated by the UIV-T1 3D measure. Hence, maintaining or restoring thoracic sagittal alignment without significantly modifying the preoperative location of the UIV should be considered a major goal in AIS surgery. Nonetheless, axial plane correction should not be neglected, since it is associated to the rib hump reduction, still a key factor in patient satisfaction with post-surgical outcome.

Modern hybrid constructs

The concept of posteromedial translation reduction technique has been introduced by Asher et al. (Isola system) in the early 1990's with satisfactory clinical and radiological outcomes at 10-year follow-up (33). The system integrated hooks, wires and screws, and the largest corrections in the 11-year series of 185 patients reached 63% in the frontal plane and 39% for angle trunk inclination (related to axial correction of the apical vertebra). The principal problems identified at the time were the need for stronger transverse connectors, stable end-instrumented vertebrae foundations, and convex thoracic anchorage (33).

All these weaknesses have been efficiently addressed by modern hybrid constructs combining pedicle screws, sublaminar bands and proximal stable claws. As a matter of fact, Jazz claws are made of angled supralaminar hooks connected with a dedicated sublaminar bands, allowing connection with 2 rods (the main thoracic one, laterally, and the shorter one connecting UIV and UIV-1, medially) (Figure 1). Once the UIV-1 band has been tensioned, contraction is applied on the supralaminar hook placed on the UIV and both set screws are locked. The bivertebral claw therefore acts like a stable implant, with strong resistance to pull-out forces during correction. Sublaminar bands also make convex thoracic anchorage easier, because the connection between

the rod and the polyester band can be placed anywhere around the instrumented vertebra (above, below, medial or lateral). Its location is not dictated and limited by the anatomy, in opposition to convex screw or pedicle hook. Finally, optimizing transverse connections is also part of the frame technique concept.

Advantages of the « frame » technique

The frame reduction technique relies on 2 stiff rods (ideally CoCr) precontoured in a similar manner, according to a personalized preoperative planning, and the connection of these 2 rods with a stiff and fixed transverse connector placed at the apex before tensioning the bands. The frame therefore represents a rigid construct, resistant to the posteromedial loads applied during correction, and therefore limiting rod deformation (concave flattening). Results of the current study found a mean 63% frontal correction rate, equivalent to the best results reported by Asher et al., and reached 84% in some severe 72° curve (33). However, the main objective was not to obtain the greatest frontal correction rate, but to respect spinal harmony, restoring frontal balance (T1-CHVA distance), leaving residual LIV tilt and rotation <10°, and all without altering the preoperative UIV location in order to avoid PJK.

This series also confirm that hybrid constructs with the frame technique do not have the same tendency as pedicle screws to flatten the thoracic spine, and can efficiently maintain sagittal alignment, or even restore it in hypokyphotic patients (mean gain 8.5° in this subgroup).

The last advantage of the frame is that after the initial posterior and medial translation of the spine obtained during the first stage of correction, the convex rod came in contact with the convex lamina, thus shifting the center of rotation of the vertebra to the contact point. Hence, the axial correction was enhanced at the end of correction maneuvers, and the unexpected increased RVA reported by Pizones et al. with sublaminar wires was avoided (Figure 5) (24). This indirect counterclockwise rotation (mean 42.2%) corresponds to a detorsion of the spine and is directly correlated to rib hump reduction, even though this parameter was not evaluated in the current study. However, the authors still consider that convex rib dystrophy plays a major role in the gibbosity, and recommend thoracoplasty if patients express preoperatively a strong concern regarding their self-image.

CONCLUSION

While many surgeons currently advocate the use of thoracic pedicle screws for optimal care in AIS, sometimes associated with multiple Ponte osteotomies, sublaminar bands should be considered, especially in hypokyphotic patients, in order to reduce complication rates and in particular the risk of intraoperative concave screw failure due to pull-out forces (34,35). The frame technique is the most efficient way of using polyester bands, optimizing axial correction while respecting sagittal alignment, and should become the gold standard in modern hybrid constructs.

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