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Correction of Adolescent Idiopathic Scoliosis in hypokyphotic patients using Jazz sublaminar bands: preliminary results of a multicentric study using 3D reconstruction

Brice Ilharreborde[1], Jean-Luc Jouve[2], Jérôme Sales de Gauzy[3] and Keyvan Mazda[1]

White paper

1. Department of Pediatric Orthopaedics, Robert Debré Hospital, AP-HP, Paris Diderot University, France

2. Department of Pediatric Orthopaedics, La Timone children Hospital, AP-HM, Aix-Marseille University, France

3. Department of Pediatric Orthopaedics, Purpan University Hospital, Toulouse, France

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a progressive three-dimensional deformity, often responsible for flattening of sagittal curves. Epidemiological studies estimate that AIS affects 1%-3% of the population (1, 2). The goal of AIS surgery is to achieve a 3D correction of the deformity and to prevent curvature progression of the unfused spine, while improving the overall cosmetic aspect of the trunk (3-5). Correction has been reported with numerous systems, but the most popular technique currently relies on pedicle screws, with a recent emphasis on the axial correction of the deformity using direct vertebral derotation techniques (6). In early reports, these pedicle screws were part of hybrid constructs, combined with hooks, wiring or cables at thoracic levels. In 1995, Suk *et al*. (7) introduced the concept of all-screw constructs, and reported greater frontal correction. Although all-screw constructs are still widely used, these have some limitations, such as a tendancy to flatten the thoracic spine in Lenke 1 AIS (8-11). Furthermore, all-screw constructs have been associated with higher spinal implant costs (27.6% annually in United State). On the other hand, some surgeons now prefer hybrid constructs with sublaminar bands not only for the low complication rate, but also because posteromedial translation mediated by periapical sublaminar bands provides better sagittal correction than all-screw instrumentation, while the coronal correction is equivalent (11, 12). The sublaminar bands technique has first been described by Mazda *et al*. (13). Polyester sublaminar bands combine the initial primary stability of pedicle screws with the straightforwardness and correcting potential of Luque wiring, but with a greater bone contact surface when compared with wires, which allow a higher strength in attraction without risk of laminar fracture. Moreover, it is possible to perform a retensioning and a progressive correction because of the simplicity of the implant and tensioning of the strips, making conventional deformity correction maneuvers easier, including translation, compression/distraction and *in situ* bending (14).

The rate of correction of the major curve in the coronal plane has long been considered as the most important parameter for evaluation of treatment outcomes. However, the sagittal alignment and its change after surgery has gained more and more attention, especially when evidence suggests that correction of the coronal plane and the transverse plane using segmental pedicle screws comes at the cost of thoracic kyphosis (TK) sacrifice (15, 16). Thoracic hypokyphosis is a well-acknowledged characteristic of sagittal alignment of AIS patients in previous studies (17, 18). Even though there is insufficient evidence showing that it affects the quality of life of patients with AIS in the short term, a further decrease of TK after surgery is associated with increased risk of adjacent-segment disease (9, 15, 19, 20).

Analysis of the current existing literature regarding the consequences of AIS surgery on thoracic sagittal alignment is difficult due to multiple biases. First, most of the series include different Lenke types curves, while the sagittal flattening of the spine mostly occur in Lenke 1 and Lenke 2 curves (single structural thoracic and double structural thoracic, respectively). Second, the analysis of the postoperative results, even in this subgroup of thoracic structural curves (Lenke 1 and 2), is also biased by the repartition of the 3 Lenke's sagittal modifiers (-, N or +). As a matter of fact, hyperkyphotic patients (sagittal modifier +) tend to increase the mean postoperative thoracic kyphosis of the series, therefore leading to an overestimation of the surgical gain, while the number of the most challenging patients (sagittal modifier -) is very often limited or not even reported. Last, radiological outcomes are usually assessed in 2D, and the value of such measurements in severe AIS is questionable.

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 thoracic sagittal misalignment, several studies have recently emphasized 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 (21-29).

Since the EOS low-dose system is now accessible in routine clinical use, the purpose of the present multicenter study was to analyze the 3D radiological outcomes of a consecutive subgroup of hypokyphotic thoracic AIS patients, operated with Jazz sublaminar bands.

MATERIALS AND METHODS

Patients

Following institutional review board approval, a consecutive series of 43 hypokyphotic patients, operated for progressive Lenke 1 or 2 AIS in 3 University teaching hospitals between June 2011 and May 2014, were retrospectively analyzed. Thoracic hypokyphosis was defined by a preoperative 2D sagittal T4T12 Cobb angle <15°. A minimum 2-year 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

Fusion levels, implants number and localization at thoracic levels were selected according to the same criteria in all 3 centers. The only difference between departments regarding the operative strategy was the type of rod material used for correction (CoCr in center 1 and Ti in centers 2 and 3). All patients underwent posterior spinal fusion using hybrid constructs, combining lumbar pedicle screws (ISS (Implanet, Bordeaux, France) or Legacy (Medtronic, Minneapolis, USA)), concave thoracic sublaminar bands (Jazz systems (Implanet, Bordeaux, France) and proximal hooks with 5.5 mm diameter rods (**Figure 1**). 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. Spinal cord monitoring was systematically used.

Radiological measurements

All patients underwent low-dose stereoradiographs using the EOS system (EOS imaging, Paris, France) preoperatively and postoperatively (within 1 month), as previously described (30). Spinal measurements were first performed in 2D (Kodak Carestream, Rochester, NY, USA) by an experienced independent spinal surgeon, and then 3D reconstructions were performed using SterEOS software (EOS imaging, Paris, France) by an independent Imaging reconstruction service (EOS 3DServices, Montreal, Canada). The following coronal radiographic parameters were recorded: Cobb angles of the main curve and contra-curves and T1 tilt (measured between the horizontal reference line and the upper endplate of T1). Sagittal parameters includes: T1T12 and T4T12 thoracic kyphosis (TK), L1S1 lumbar lordosis (LL), and pelvic parameters. 2D and 3D parameters were compared, and only hypokyphotic patients (i.e sagittal T4T12 Cobb <15°) on preoperative 3D reconstructions were kept for analysis. In addition, the posterior shift of the apical vertebra (PSAV), corresponding to the translation of the center of the apical vertebra of the main curve in the sagittal plane, in reference to the central hip vertical axis, was calculated from 3D reconstructions (**Figure 2**).

Statistical analysis

Paired-samples Student's *t* tests were used to analyze differences between 2D and 3D radiological measurements, and to evaluate the outcomes of surgery. Pearson correlation test was used to analyze the postoperative gain in T4T12 kyphosis on PSAV. All statistical tests were 2-tailed, and a *P* value <0.05 was considered to be significant. All statistical analyses were conducted using SPSS version 12.0 (SPSS Inc, Chicago, IL, USA).

RESULTS

Demographic and operative data

Among the 43 consecutive Lenke 1 and 2 hypokyphotic AIS patients identified on 2D measurements, 8 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 35 patients kept for analysis was 16 years (±2). There were 11 boys and 24 girls, with a mean follow-up of 34 months (±8). Lenke 1 curves were the most frequent (30 cases, 85%), while Lenke 2 curves were identified in 5 patients (15%). The number of fused vertebrae averaged 12.5 (±1), and all fusions extended to L1 or below. The upper instrumented level (UIV) was T1 in 1 case (2.9%), T2 in 12 cases (34.2%), T3 in 20 patients (57.1%) and T4 in 2 cases (5.8%). The mean number of sublaminar bands used for correction at thoracic levels was 6 (±1.5).

Radiological measurements

Preoperative radiological values are reported in **Table 1**. The Cobb angle of the proximal thoracic curve appeared to be overestimated in 2D (average 5°, p=0.003). The only significant difference between 2D and 3D measurements regarding preoperative sagittal alignment was the L1S1 lordosis, which was underestimated in 2D (mean 5°, p<0.001). The same finding was reported after surgical correction (**Table 2**). However, both T1T12 and T4T12 sagittal Cobb angles appeared to be overestimated on 2D postoperatively (3°, p=0.002 and 4°, p<0.001, respectively). Hence, only 3D measurements were kept for the quantitative analysis of the postoperative correction (**Table 3**). T4T12 thoracic kyphosis significantly increased after the procedure (average 7°±8, p<0.001), but 11 patients (31.4%) still remained hypokyphotic according to Lenke's classification (i.e T4T12<10°) (**Figure 3**). Seven out of the 8 patients who presented a thoracic lordosis (i.e T4T12<0°) preoperatively were corrected after surgery (mean gain 16°±4). A posterior shift of the apical vertebra was reported in 23 patients (65.7%). In this subgroup, mean PSAV was 2cm (±1). Good correlation was found between the PSAV and the postoperative change in T4T12 kyphosis (r=0.62, **Figure 4**). Significant spontaneous increases in T4T12 and T1T12 sagittal Cobb angles were observed during follow-up (p=0.002 and p<0.001, respectively), with a subsequent increase in the lumbar lordosis (p=0.006) (**Table 3**). Similarly, the apex of the main thoracic curve significantly shifted posteriorly, while a significantly loss of correction was also observed in the frontal plane (average 4° in both main and proximal thoracic curves) (**Table 4**).

DISCUSSION

Whatever the technique, primary goals of the surgical strategy remain the same: obtain a stable correction of the deformity and avoid further degenerative disorders during adulthood.

In spinal deformity surgery, recent literature has highlighted the importance of sagittal plane analysis and the potential impact of spino-pelvic alignment on pain and disability later in life (31-33). As suggested by Kim *et al.* (4) and Winter *et al.* (5), restoring physiologic TK should reduce the risk of progressive junctional kyphosis at the extremities of the fused spine. In 2013, Clément *et al.* (34) found a significant correlation between thoracic kyphosis and proximal lordosis in AIS suggesting that sagittal improvement might better ensure long-term results and decrease the rate of long-term decompensation by proximal kyphosis. Nonetheless, restoring the sagittal balance of the spine is still one of the most challenging goals in scoliosis surgery. Some authors previously reported that pedicle screw constructs provided a better correction of the sagittal kyphosis associated with coronal deformity (7). However, numerous studies have shown the efficacy of hybrid constructs in providing a greater post-operative thoracic kyphosis control with a similar result at the coronal level in scoliosis surgery compared to all-screw constructs. Lowenstein *et al.* (8) observed a trend toward better correction of the main thoracic curve in all-screw *versus* hybrid hook-screw instrumentation in adolescent idiopathic scoliosis (AIS), but this trend was not significant. Vora *et al*. (11) observed a lordosing effect in the thoracic spine with posterior pedicle screw instrumentations. Based on a retrospective study of patients with Lenke type 1 AIS, treated with all-pedicle screw instrumentation, Quan and Gibson recently concluded that the greater the coronal plane correction achieved with pedicle screw constructs, the greater was the loss of thoracic kyphosis (35). In contrast, Clément *et al.* (36) documented a mean gain of 14° of thoracic kyphosis with pedicle screw instrumentation in hypokyphotic patients with posteromedial translation used as main correction technique. Furthermore in previous studies we have also confirmed that hybrid constructs (37-38) including sublaminar bands improved both sagittal and coronal correction compared to hook hybrid constructs.

However, this study presents some limitations. Indeed, patients were operated in 3 distinct centers by 4 different senior surgeons. Ti rods were used in 2 institutions, while the third one chose to perform the posteromedial translation with CoCr rods. However, no significant difference was found between the 2 types of rods, and this cohort represents one of the largest series of hypokyphotic patients, who are very often underrepresented in AIS literature. In addition, the measurements were performed in 3D using a reproducible software, and the reference plane was given by the position of the patient hips for optimal accuracy and reliability. Finally, the spontaneous improvement of the thoracic sagittal alignment in an instrumented zone needs to be further explored. Whether it is primitive or secondary to a physiological adaptation of the uninstrumented lumbar spine remain unclear. Longer follow-up is necessary to make sure that fusion will be obtained without further loss of correction.

CONCLUSION

Results of this 3D study revealed an effective correction of hypokyphosis in AIS patients (average 8°). The posteromedial translation technique using sublaminar bands and either Ti or CoCr 5.5mm diameter rods is an efficacious and reliable treatment for hypokyphotic AIS, both in the frontal and sagittal planes. 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 in hypokyphotic patients in order to reduce complication rates and in particular the risk of intraoperative concave screw failure due to pull-out forces (39). The low density of implants (average 6 Jazz per patient) required to obtain an efficient and long-lasting correction should also be taken into account in the global cost of AIS surgery.

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Figure 1: Hybrid construct used for spinal fusion, combining lumbar pedicle screws and sublaminar bands at thoracic levels.

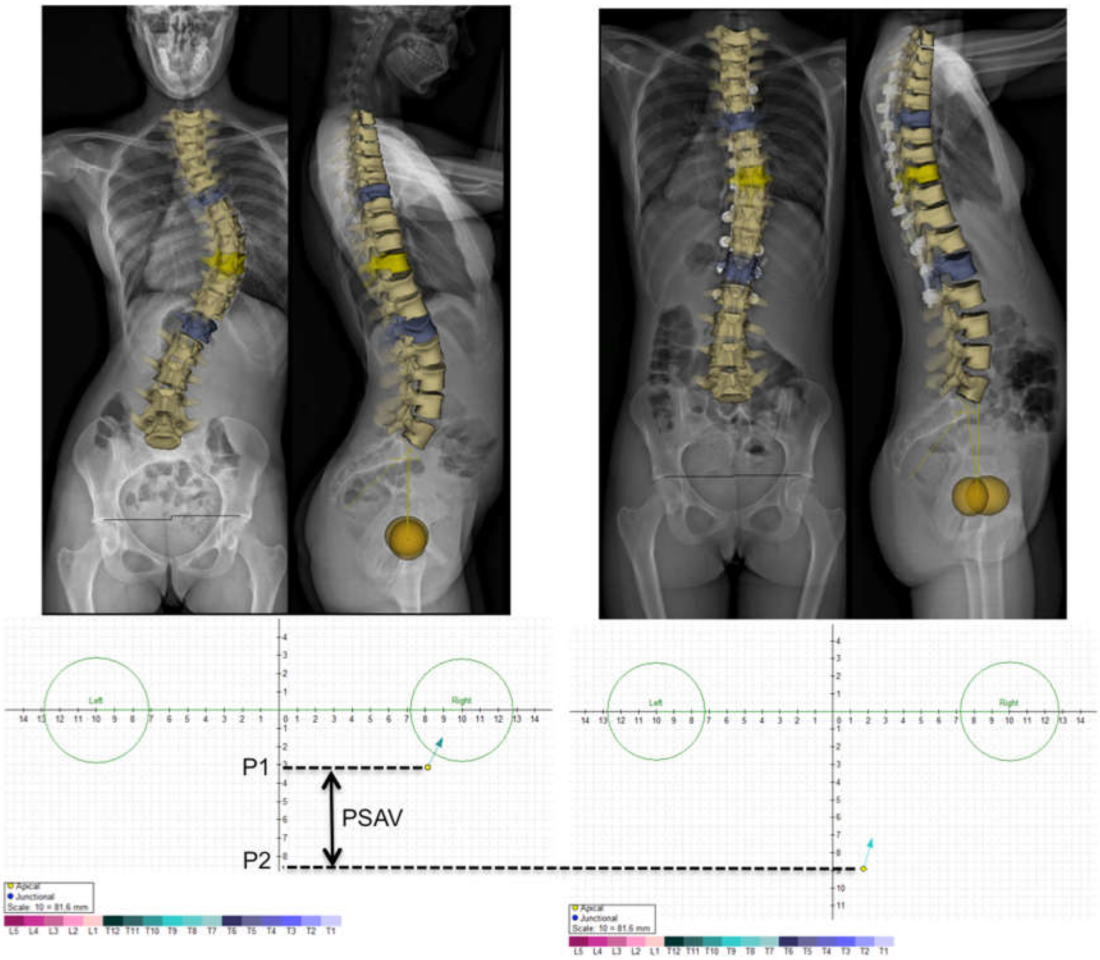

Figure 2: Determination of the posterior shift of the apical vertebra (PSAV) from 3D reconstructions (PSAV = P2-P1).

<u>Figure 3</u>: 3D reconstruction showing the restoration of the thoracic sagittal alignment and the subsequent effect on cervical spine.

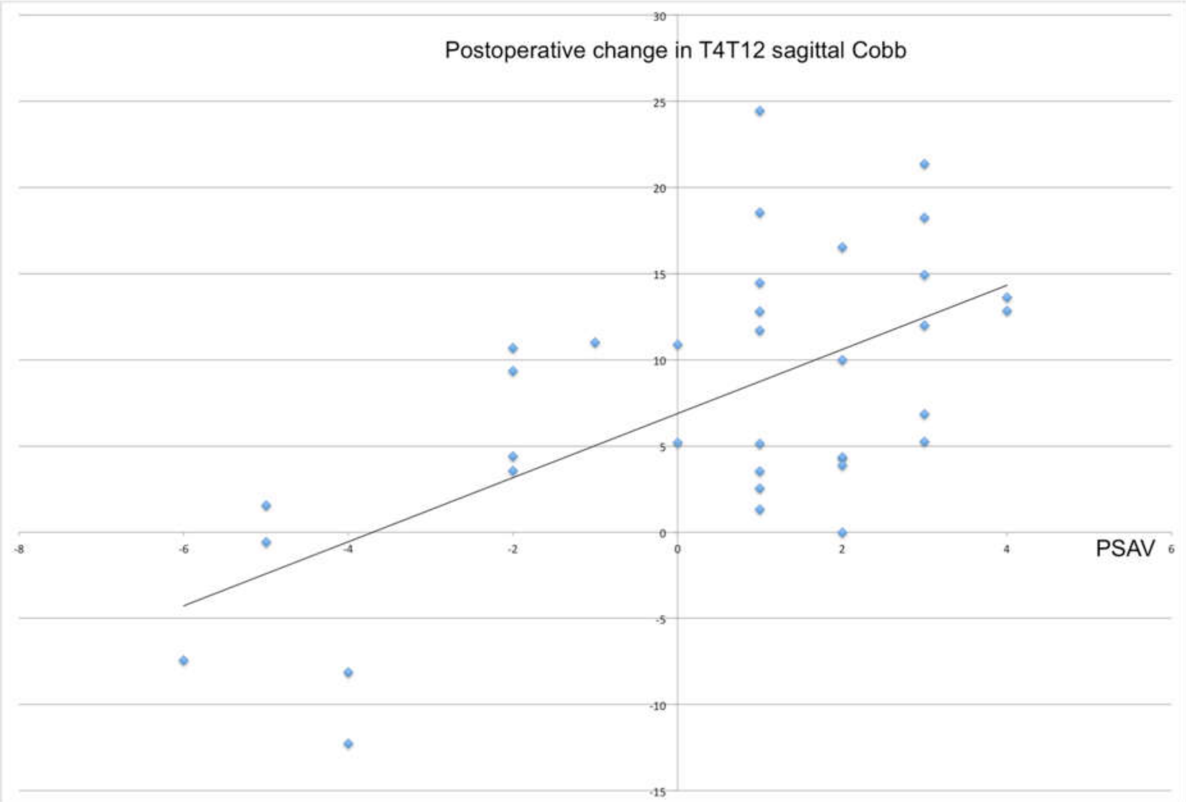

Figure 4: Correlation between the PSAV and the postoperative change in T4T12 kyphosis

Table 1: Preoperative comparison between 2D and 3D measurements

	2D measurements		**3D measurements**		**p**
	mean	**SD**	**mean**	**SD**	
main Curve (°)	56	11	53	10	0.090
proximal contra curve (°)	30	8	25	9	**0.003**
distal contra curve (°)	33	12	33	9	0.469
T1 Tilt (°)	3	5	2	7	0.288
L1S1 lordosis (°)	40	14	46	11	**0.001**
T4T12 kyphosis (°)	5	8	6	9	0.432
T1T12 kyphosis (°)	11	10	13	9	0.154
T1 slope (°)	8	6	8	8	0.077
pelvic incidence (°)	51	14	50	10	0.610
sacral slope (°)	41	9	41	8	0.961
pelvic tilt (°)	11	7	10	7	0.051

Table 2: Postoperative comparison between 2D and 3D measurements.

	2D measurements		**3D measurements**		**P**
	mean	**SD**	**mean**	**SD**	
main Curve (°)	17	6	16	7	**0.021**
proximal contra curve (°)	18	6	15	7	0.195
distal contra curve (°)	8	6	9	6	0.806
T1 Tilt (°)	4	5	5	5	0.396
L1S1 lordosis (°)	41	13	44	11	**0.003**
T4T12 kyphosis (°)	17	7	13	8	**0.001**
T1T12 kyphosis (°)	24	7	21	8	**0.002**
T1 slope (°)	14	8	15	7	0.850
pelvic incidence (°)	50	12	50	11	0.827
sacral slope (°)	38	9	39	7	0.159
pelvic tilt (°)	15	12	12	8	**0.021**

Table 3: Comparison between preoperative and postoperative 3D parameters.

	preoperative measurements		postoperative measurements		P
	mean	SD	mean	SD	
main Curve (°)	53	10	16	7	**<0.001**
proximal contra curve (°)	25	9	15	7	**<0.001**
distal contra curve (°)	33	9	9	6	**<0.001**
T1 Tilt (°)	2	7	5	5	**<0.001**
L1S1 lordosis (°)	46	11	44	11	0.469
T4T12 kyphosis (°)	6	9	13	8	**<0.001**
T1T12 kyphosis (°)	13	9	21	8	**<0.001**
T1 slope (°)	8	8	15	7	**<0.001**
CHVA apex sag (cm)	1.4	2	1.8	3	0.182
CHVA apex coronal	5	2	0.8	1	**<0.001**
pelvic incidence (°)	50	10	50	11	0.484
sacral slope (°)	41	8	39	7	**0.016**
pelvic tilt (°)	10	7	12	8	**0.020**

Table 4: Comparison between postoperative and final follow-up 3D parameters.

	postoperative measurements		follow-up measurements		p
	mean	SD	mean	SD	
main Curve (°)	16	7	20	7	**0.002**
proximal contra curve (°)	15	7	19	8	**0.034**
distal contra curve (°)	9	6	9	7	0.478
T1 Tilt (°)	5	5	5	6	0.461
L1S1 lordosis (°)	44	11	51	11	**0.006**
T4T12 kyphosis (°)	13	8	18	8	**0.002**
T1T12 kyphosis (°)	21	8	27	9	**<0.001**
T1 slope (°)	15	7	18	7	**0.010**
CHVA apex sag (mm)	1.8	3	3	2	**0.010**
CHVA apex coronal	0.8	1	1.4	1	**0.025**
pelvic incidence (°)	50	11	50	11	0.472
sacral slope (°)	39	7	41	8	0.054
pelvic tilt (°)	12	8	9	8	0.059