Simultaneous translation on two rods is an effective method for correction of hypokyphosis in AIS: radiographic results of 24 hypokyphotic thoracic scoliosis with 2 years minimum follow-up

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Abstract Recent publications confirm that moderate correction of thoracic hypokyphosis can be achieved by posterior instrumentation with hooks or pedicle screws. Twenty-four prospective and consecutive thoracic adolescent scoliosis patients with hypokyphosis ($<20^\circ$) were operated on by posterior spinal fusion (PSF) with a specific method of reduction: Simultaneous translation on two rods (ST2R), performed by the same surgeon using stable anchorages such as screws or self-stabilizing claws. Radiographic parameters were measured preoperatively, at 1 month, 1 year and at 2 years minimum follow-up. In the coronal plane, the average main curve was significantly reduced from 51° to 17° and maintained at last follow-up, corresponding to an average correction of 67%. In the sagittal plane, the average kyphosis angle was significantly improved from 9° to 30° postoperatively and to 32° at last follow-up, corresponding to a mean gain of 23° . The 24 patients reported normal kyphosis at last follow-up ($\geq 20^\circ$). Reduction of scoliosis by ST2R is an effective method that gives coronal correction equivalent to all screw constructs and allows restoration of normal thoracic kyphosis.

Keywords Hypokyphotic adolescent idiopathic scoliosis · Posterior spinal fusion · Simultaneous translation on two rods · Thoracic pedicle screw · Polyaxial claw

Introduction

Idiopathic scoliosis is a deformity in the three planes of the spine. Surgical treatment for scoliosis aims to reduce the coronal deformity by decreasing the magnitudes of the main and counter curves, to restore a normal sagittal profile and to correct the vertebral rotation. It should furthermore preserve lumbar spine mobility, prevent neurologic risk and provide a balanced spine. Posterior spinal fusion and reduction with vertebral anchors linked by rigid rods is still the standard surgical method.

In the coronal plane, the use of lumbar pedicle screws has been shown to allow a better reduction of the deformation than the use of lumbar pedicle hooks [1, 2]. Moreover, several comparative studies have shown better results using thoracic pedicle screws instead of hooks [3–7]. That's why pedicle screws are used increasingly for the instrumentation of scoliosis in regard to coronal correction.

In the sagittal plane, results are differing in studies concerning scoliosis populations with thoracic hypokyphosis. Some authors have found an increase of kyphosis with hook, screw or hybrid constructs [8–12] while others have found no change or decrease of kyphosis with the same type of constructs particularly in recent studies [6, 7, 13–16]. Most of the authors found an important number of cases remaining in hypokyphosis after surgery and a post-operative angle of kyphosis close to the inferior value. It appears that there is no ideal instrumentation in regards to sagittal plane correction.

On the other hand, various rod insertion techniques have been tested to achieve the reduction in the coronal, sagittal, and transverse planes. No difference has been shown between different techniques such as rotation of the rod, sequential approximation, in situ bending or translation [17]. Recent specific techniques have tried to reduce

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vertebral rotation but seem detrimental to kyphosis [18]. In a previous study [19], we compared the correction of thoracic hypokyphosis in a limited number of cases of adolescent idiopathic scoliosis treated with similar instrumentation but with two different methods of reduction. We concluded that reduction by simultaneous translation on two rods (ST2R) achieved a better correction of thoracic hypokyphosis than sequential approximation by cantilever reduction.

Publications generally report the results of global cohorts of adolescent idiopathic scoliosis (AIS) without selection on preoperative kyphosis angle. We propose to focus our work on patients with AIS and preoperative hypokyphosis ($T4-T12 < 20^\circ$).

The purpose of the present study is to present the results of sagittal and coronal correction of a cohort of patients with AIS and hypokyphosis using instrumentation with stable anchorages like pedicle screws or claws and with reduction by a specific technique (ST2R).

Materials and methods

Patients: demographic data and curve classification

Inclusion criteria were patients with a diagnosis of thoracic AIS (Lenke type 1–4), thoracic hypokyphosis ($T4-T12$ Cobb angle $< 20^\circ$) and at least 2 years of follow-up. Twenty-four consecutive patients (22 women and 2 men) with a mean age of 14.6 years (range 12.5–16.5 years) were included. They were all surgically treated between July 2000 and October 2007.

Demographic data and curve classification are reported in Table 1. According to the classification of AIS by Lenke et al. [20], the curves distribution was as follows: 19 main thoracic (type 1), four double thoracic (type 2) and one triple major (type 4). All 24 patients have a preoperative hypokyphosis $< 20^\circ$. Twelve patients had a severe hypokyphosis $\leq 10^\circ$ and 12 patients presented a mild hypokyphosis between 10° and 20° . The mean follow-up was 49 months (range 24–89 months).

Radiographic measurements

Standard anteroposterior (AP) and lateral digital radiographs of the spine in standing position and AP radiographs in supine lateral bending positions were made before surgery. AP and lateral postoperative radiographs in standing position were done after surgery at 1 month, 1 year and at the last follow-up intervals. All radiographic measurements were made manually by the senior author.

On the coronal radiographs, we measured the Cobb angles and the translation of the apex vertebra between the

Table 1 Demographic and operative data

	Hypokyphotic series (<i>n</i> = 24)	Range
Follow-up (months)	49.2	(24–89)
Age at surgery (years)	14.6	(12.5–16.5)
Male/female	2/22	
Risser sign	3.1	(0–5)
Lenke AIS curve type		
Type 1	19 (79.2%)	
Type 2	4 (16.7%)	
Type 3	0	
Type 4	1 (4.1%)	
Lenke AIS lumbar spine modifier		
A	10 (41.7%)	
B	6 (25.0%)	
C	8 (33.3%)	
Hypokyphosis ($T4-T12$ Cobb angle)		
Severe ($\leq 10^\circ$)	12	
Mild ($> 10^\circ$ and $\leq 20^\circ$)	12	
Number of levels instrumented	10.5 ± 1.0	(9–12)
Time of surgery (min)	196.5 ± 32.3	(130–270)

center of the vertebral body and the central sacral line (CSL) of the main curve and of the instrumented proximal and distal counter curves.

Curves flexibility was evaluated with preoperative supine side bending radiographs.

On the lateral radiographs, we measured the thoracic kyphosis from the superior endplate of T4 to the inferior endplate of T12, the lumbar lordosis from the superior endplate of L1 to the inferior endplate of L5 and, the proximal junction sagittal Cobb angle from the superior endplate of the upper instrumented vertebra to the cephalad endplate two vertebrae proximal [21]. Proximal junctional kyphosis (PJK) was defined as an association of a post-operative proximal junction sagittal Cobb angle superior or equal to $+10^\circ$ and a proximal junction sagittal Cobb angle at least 10° greater than the preoperative measurement. The quality of the digital radiographs allowed us to properly visualize the proximal thoracic vertebrae.

Surgical procedure

All operative procedures were performed by the senior surgeon (JLC) using lumbar and thoracic pedicle screws. The surgeon has used thoracic pedicle screws since 1993 after extensive previous experience with lumbar pedicle screws. Pedicle screws were inserted using a “free hand” technique developed by the author, without an image intensifier. The technique was described in a previous publication [19]. In all cases, AP and lateral X-rays were

taken after placement of all anchors and prior to insertion of the rods.

The instrumentation used (PASS[®] instrumentation, MEDICREA[®], France) was adapted with the translation technique and consists of stable anchorages such as pedicular screws or claws. The surgeon used mainly thoracic pedicle screws. He used claws at the upper end of the construct. Sometimes, he used also claws when the pedicle was too narrow to put a screw or difficult to find, usually in the concavity of the curve. Generally, the claw was a pedicle-transverse polyaxial claw composed of a main pedicle hook and an opposing transverse counter hook. These two hooks are connected by a threaded rod and locked with a nut and constitute a self-stabilizing polyaxial anchor. Both screws and claws include a threaded extension, which allows top loading and side connection to the rods with connecting clamps. The two 6.0 mm titanium (TA6V) rods were bent first according to the sagittal profile and linked at distance to the anchorages without any reduction maneuver due to the threaded polyaxial extensions. The rods were then properly oriented in the sagittal plane, and two nuts, usually the proximal one at each rod, were tightened on the threaded extensions to lock the rotation of the rods. Reduction of the deformity was obtained by gradual tightening of all nuts on both rods, allowing the vertebrae to gradually approach the rods, and thus performing the translation maneuver (Fig. 1). No distraction was used.

The spinal cord was monitored during the surgery by Neurogenic Mixed Evoked Potentials.

Thoracoplasty was performed in all cases to improve morphologic correction. On this group of patients either three or four prominent ribs of the rib hump were subperiosteally resected [22] and used as bone graft for the arthrodesis.

Statistical analysis

Statistical analysis was performed using the xlstat. Distributions of variables are given as mean, standard deviations and ranges. Statistical comparisons were performed using a two-tailed paired-samples *t* test with a level of significance of 5% ($P < 0.05$).

Results

The average number of levels instrumented was ten, with an average of nine screws and four claws. The average operative time was 196.4 min (range 130–270 min).

Table 2 illustrates preoperative and postoperative coronal plane measurements. The average Cobb angle of the major curve was corrected from 51° preoperatively to 17° at last follow-up ($P < 0.001$) obtaining an average correction of 67% with a preoperative bending reducibility of 52%. On average on the 24 patients, there was no loss of correction. However, concerning the nine patients who had loss of correction, we found an average loss of 3° (range 1–7°). Average major curves translation decreased from 36 mm preoperatively to 17 mm at last follow-up.

Instrumented minor curves average Cobb angle decreased from 43° preoperatively to 19° at last follow-up ($P = 0.001$) achieving an average correction of 53% with a preoperative bending reducibility of 51%. Average instrumented minor curves translation decreased from 24 mm preoperatively to 10 mm at last follow-up.

Table 3 illustrates sagittal plane radiographic results for thoracic kyphosis and lumbar lordosis. The average thoracic kyphosis significantly increased from 9° preoperatively to 30° at immediate postoperative follow-up, and to

Fig. 1 Simultaneous translation on two rods (ST2R), anteroposterior and sagittal views. **a** The two rods, bent according to the sagittal profile, are placed on the anchorages without any reduction maneuver thanks to the threaded polyaxial extensions. The rods are properly

oriented in the sagittal plane and the two proximal nuts are tightened on the anchorage extensions to lock their rotation. **b, c** The progressive and simultaneous tightening of all the remaining nuts on both rods performs the translation maneuver

Table 2 Coronal measurements

	Major curves (<i>n</i> = 24)	Instrumented minor curves (<i>n</i> = 7)
Cobb angle (°) (mean ± SD)		
Preoperative	51 ± 9 (40–90)	43 ± 6 (36–54)
Bending reducibility (%)	52 ± 17 (19–80)	51 ± 30 (16–88)
Immediate postoperative	17 ± 6 (8–27)	18 ± 6 (7–27)
At last follow-up	17 ± 5 (8–26)	19 ± 7 (10–30)
Correction at last follow-up (%)	67 ± 9 (48–82)	53 ± 19 (29–76)
<i>P</i> value*—last follow-up/preoperative	<0.001 [†]	<0.002 [†]
Translations (mm)		
Preoperative	36 ± 18 (0–80)	24 ± 14 (0–40)
Immediate postoperative	14 ± 11 (0–30)	10 ± 9 (0–25)
At last follow-up	17 ± 11 (0–40)	14 ± 10 (0–25)

* Two-tailed paired-samples *t* test

[†] Statistically significant if *P* < 0.05

Table 3 Sagittal measurements

	Mean ± SD	Range
Thoracic kyphosis (°)		
Preoperative	9 ± 9	(–14 to 19)
Immediate postoperative	30 ± 7	(18–45)
At last follow-up	32 ± 6	(20–42)
<i>P</i> value*—last follow-up/preoperative	<0.001 [†]	
Gain at immediate postoperative	21 ± 9	(3–39)
Gain at last follow-up	23 ± 7	(11–41)
Lumbar lordosis (°)		
Preoperative	47 ± 11	(26–68)
Immediate postoperative	49 ± 10	(33–66)
At last follow-up	52 ± 10	(32–72)
<i>P</i> value*—last follow-up/preoperative	0.04 [†]	
Gain at immediate postoperative	1 ± 6	(–11 to 13)
Gain at last follow-up	4 ± 10	(–16 to 22)
Proximal junctional measurements (°)		
Preoperative	3 ± 4	(0–16)
At last follow-up	0 ± 1	(0–4)
Gain at last follow-up	–2 ± 4	(–16 to 4)

* Two-tailed paired-samples *t* test

[†] Statistically significant if *P* < 0.05

32° at final follow-up (*P* < 0.001) (Fig. 2). Lumbar lordosis slightly increased from 47° preoperatively to 52° at last follow-up (*P* = 0.04).

The association of the two parameters specified by Glattes et al. [21] to define abnormal PJK, was not observed in our cohort. Two patients presented a preoperative proximal junctional angle ≥10° (10° and 16°). This angle decreased to 3° and 0°, respectively, at last follow-up.

There was one case of reoperation in our series for adding on. There was no short or long-term neurologic or vascular complication resulting from the placement of pedicle screws or reduction of the deformity. No implant

failures occurred such as screw or rod fractures. Finally, no perioperative complications (such as screw pull-out) were observed.

Discussion

The study reports the result of posterior spinal fusion to correct AIS with reduction by a translation technique and focus on sagittal plane. The translation technique was first used by Eduardo Luque in 1972 and progressively perfected for scoliosis in poliomyelitis using lamina wire linked on two rods [23]. He introduced translation as a new method of reduction, which was also used in ISOLA instrumentation, providing interesting results [24]. The objective of the translation maneuver is to pull back the vertebra toward the rods. It requires stable anchorages to be effective and the reduction obtained is a compromise between the stiffness of the spine and the rigidity of the rods.

In the present study, we used stable anchorages allowing the use of translation technique. It consisted mainly of lumbar and thoracic pedicle screws and sometimes of claws in the concavity of the curve when the pedicle was too narrow to put a screw or too difficult to find. We also used claws at the proximal extremity of the construct in order to preserve the integrity of the superior facet joint, the destabilization of which could be responsible for PJK [25]. Anchorages were placed mainly at the proximal and the distal extremities of the construct and at the apex of the curve to benefit from the translation effect.

Each anchorage was made up of a polyaxial threaded extension that enabled the connection to the rods before any reduction maneuver was performed. This polyaxiality was essential for the simultaneous connection of all anchorages on the rods. Then, the progressive tightening of all the nuts on the threaded extensions progressively pulled back the vertebrae toward the rods, enabling the ST2R. The

Fig. 2 A 13.5-year-old girl with hypokyphotic Lenke 1C type AIS. **a, b** Preoperative standing sagittal and anteroposterior radiographs. **c, d** Immediate postoperative radiographs. **e, f** 30-month postoperative radiographs

reduction forces were distributed over both rods simultaneously, improving the overall corrective capacity and avoiding the possibility of the screws being pulled out.

We hypothesize that the improvement of the correction would be due to the technique. Contrary to other techniques that used one rod to reduce and one rod to stabilize, the ST2R used the two rods to reduce the scoliosis. Thus, both the rods, rather than only one, participated in the

reduction of the curve. Although our 6 mm titanium rods are more flexible than stainless steel or Chrome-Cobalt rods of the same diameter (Standards ISO 5832), the translation on two rods could explain our results obtained in the coronal and sagittal planes.

In the sagittal plane, recent publications concerning scoliosis instrumented with screws have reported kyphosis results. A moderate gain was observed by Suk et al. [26] in

a large study of 203 patients with a mean gain of 5° for thoracic kyphosis at 5 years follow-up ($18^\circ \pm 11$ to $23^\circ \pm 8$). In another study, results were presented in the sagittal plane based on the magnitude of pre-operative kyphosis and found a gain of 19° for hypokyphotic scoliosis instrumented with screws [5]. In another article concerning 42 patients with single thoracic adolescent idiopathic scoliosis, a gain of 13° in the hypokyphotic spine was reported [12]. The number of patients remaining in hypokyphosis after surgery was not given.

A decrease of kyphosis between pre and postoperative has been observed by several authors: 10° for Lowenstein et al. [15], and 9° for Kim et al. [7]. The overall decrease observed seems to prove that instrumentation has a lordogenic effect.

Further, these disappointing results are not the prerogative of screw constructs. In a recent study, Sucato et al. [16], compared anterior spinal fusion (ASF) and PSF and noted a weak decrease of kyphosis in the two PSF series either with hook constructs or with hybrid constructs, at 6–8 week follow-up. Meanwhile, Lowenstein et al. [15] reported a 4° kyphosis decrease in a hybrid series. However, De Jonge et al. [11] observed a gain of 12° for the hypokyphosis cases in a large series of hook constructs yet 37% of the patients still had a kyphosis below 20° at last follow-up reaching 62% with a preoperative hypokyphosis below 10° .

These conflicting results demonstrate that restoration of kyphosis is difficult. The reduction technique used may be the reason for these disappointing results. Lee et al. [27] compared two corrective techniques using screw instrumentations: simple rod derotation and direct vertebral rotation. In the sagittal plane, the authors observed no difference between the two techniques in terms of kyphosis gain, which remained moderate (5° vs. 7°).

With the Isola technique, Asher et al. [24], on the global series of AIS, observed a decrease of the kyphosis from 34° to 29° but reported a gain of 10° for the 23 hypokyphosis cases. The mean value of postoperative kyphosis was 20° , which is the same limit of the normal value. In a comparative study of two methods of reduction [19], we showed that ST2R is more effective to cure the hypokyphosis than cantilever reduction.

The results of our study, in terms of kyphosis, showed that ST2R reduction allows a gain of 23° in hypokyphotic cases. Our results demonstrated the technique's effectiveness for sagittal correction in AIS. To the best of our knowledge, this important gain has never been reported in spine literature. It is greater than those reported in hypokyphotic populations with all-screw constructs by Suk et al.: 13° [12] and with hook constructs by De Jonge et al.: 12° [11]. In these studies, the flexibility, the preoperative main thoracic curve magnitude, and the preoperative

thoracic kyphosis (8°) were similar to those of the present study.

We observed a significant increase of the lordosis in our cases with a gain of 5° at last follow-up. We think that this gain would be in direct correlation with the increase of kyphosis and due to the sagittal balance restoration.

No PJK [21] was observed in our cohort with a mean follow-up of 4 years. Our results differ from those reported by Kim et al. [28], who found a PJK incidence of 26% after 5 years in a population of 193 patients and 27% after 2 years in a population of 410 patients [29]. This difference can be explained by the fact that we focused our study on patients presenting hypokyphosis. Kim et al. [28] reported a lower rate of PJK for patients with hypokyphotic subpopulations: 10% out of 40 and 14% out of 71 [29]. While the small number of patients included in the study may limit our observations of PJK, it is proposed that the recovery of a normal postoperative kyphosis decreases the risk to appear a PJK.

There is a lack of long-term follow-up on adolescent patients focused on the restoration of the thoracic kyphosis, and its effects on the overall clinical outcome are not established. However, we hypothesized that non-restoration of a normal thoracic kyphosis may lead to a sagittal imbalance. Emami et al. [30] documented that sagittally decompensated patients had significantly more pain than patients who were well balanced. Moreover, a loss of sagittal balance is correlated with high pseudarthrosis rate and fixation failure [31].

The follow-up in adult life showed that junctional hyperkyphosis may become an element of decompensation for operated scoliosis. It appears either at the (proximal or distal) extremities of the instrumentation, or within the constructs on a pseudarthrosis. Kim et al. [29] reported that patients with a postoperative decrease of T5-T12 kyphosis of more than 5° demonstrated a higher incidence of PJK than those with a loss of 5° or less. Thus, it seems that a residual hypokyphosis could lead to junctional hyperkyphosis compensation. To our opinion, the restoration of the kyphosis appears as necessary as that of the scoliosis in the coronal plane, and this will probably contribute to decrease the rate of late decompensation in kyphosis.

In the coronal plane, we obtained a correction of the angulation of 67%, equivalent to those previously reported in the literature using lumbar and thoracic pedicle screws [6, 7, 26, 29]. Moreover, the translation of the apex vertebra of the instrumented curves decreased in the same proportions as the decrease of the Cobb angle. However, our construct is considered as a hybrid construct.

Authors stated that all-screw constructs result in a negligible loss of correction at follow-up compared with that observed with hybrid constructs and especially with hook constructs [6, 7, 32, 33]. It is speculated that this loss of

reduction is due, in great part, to the instability of the anchorages. In our cases with hybrid constructs, we observed a loss of correction which is similar to that reported in the literature for the all-screw constructs. It seems to demonstrate that all of our anchorages are stable.

Our study showed good results with an effective technique of coronal and sagittal correction in a single institution series of AIS patient. We obtain a gain of 23° for the kyphosis in hypokyphotic thoracic scoliosis with ST2R reduction.

The horizontal correction could not be studied in this series of patients, through lack of data. In fact, the thoracoplasty and the use of pedicle screws did not allowed us performing clinical evaluation or X-rays measurements of post-operative vertebral rotation [34].

Because all operative procedures were performed by the senior surgeon and measurements done by a single observer, the results need to be confirmed by further multicenter investigations.

Moreover, this study does not contain clinical results and further trials are needed to confirm a correlation between clinical outcomes (pulmonary function, functional status, patient satisfaction) and hypokyphosis correction.

Conclusion

The restoration of normal kyphosis in hypokyphotic AIS is a difficult challenge as showed by recent studies. ST2R is an effective reduction technique for the correction of sagittal hypokyphosis in AIS. The mean gain of kyphosis was 23° and all patients recovered a normal kyphosis.

Conflict of interest The device(s)/drug(s) is/are FDA-approved by corresponding national agency for this indication. Funds were received in support of this work. One or more of the author(s) has/have received or will receive benefits for personal or professional use for a commercial party related directly or indirectly to the subject of this manuscript: e.g., royalties, stocks, stock options, decision making position.

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