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ORIGINAL ARTICLE

Ponte osteotomies to treat major thoracic adolescent idiopathic scoliosis curves allow more effective corrective maneuvers

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Abstract
Purpose There is controversy regarding the effect of the Ponte osteotomies in the improvement of coronal correction, its maintenance during follow-up, and the restoration of thoracic kyphosis in adolescent idiopathic scoliosis (AIS).
Methods Seventy-three AIS patients with Lenke type 1–4 curves were included. A prospective description of 43 consecutive patients who underwent apical Ponte osteotomies and sublaminar wires with hybrid instrumentation was retrospectively compared to a historical cohort of 30 patients without "Ponte osteotomies". The surgical details and complications were recorded. We evaluated the radiological measurements and SRS-22 Questionnaire scores over a 2-year follow-up.
Results The Ponte group achieved better postoperative (70 vs 57 %) and final (62 vs 50 %) main curve correction $P < 0.001$, with no significant loss of correction (4.2° vs 2.5°) $P = 0.2$ at the final follow-up (48 vs 106 months). We did not find a difference in thoracic (T5–T12) postoperative (22° vs 24°) and final (25° vs 26°) mean kyphosis angle. However, the "Ponte osteotomies" helped to achieve a normal sagittal profile, increasing preoperative hypokyphotic curves (<10°) from 6° to 17° (control: 9°–12°; $P = 0.01$); and preoperative hyperkyphotic curves (>40°) from 52° to 26° (control: 46°–39°; $P = 0.01$). The length of surgery was similar (4.3 vs 4.6 h), as were the SRS-22 scores. No major complications were found.
Conclusions Ponte osteotomies in major thoracic AIS curves treated by sublaminar wires allowed more effective corrective maneuvers, which improved coronal correction without a significant loss during follow-up. The sagittal profile appears to be determined by other variables; however, "Ponte osteotomies" facilitate the contouring of the desired kyphosis.

Keywords Idiopathic adolescent scoliosis · Ponte osteotomies · Thoracic kyphosis · Scoliosis surgery · Hybrid instrumentation

Introduction

Scoliosis is a three-dimensional deformity that consists of vertebral axial rotation, lateral frontal deviation, and sagittal intervertebral lordosis [1–3]. Traditionally, two main approaches used to correct anterior column overgrowth have been proposed [4]: anterior discectomies, which shorten the anterior column, and posterior releases, which lengthen the posterior column. Posterior releases were initially popularized for the treatment of rigid kyphosis and are currently defined as Ponte osteotomies [5], which have been widely incorporated in the correction of adolescent idiopathic scoliosis (AIS). Ponte osteotomies are used in this surgery to make the spine more flexible, allow posterior thoracic distraction to correct the structural intervertebral lordosis and to improve hypokyphosis.

However, there is conflicting literature regarding the real contribution of Ponte osteotomies in the improvement of coronal correction in AIS surgery [6–9]. Furthermore, because these osteotomies were first designed to correct and decrease rigid (Scheuermann's) kyphosis, we still have to confirm whether they are useful in increasing thoracic

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kyphosis. Finally, there have been no reports regarding the potential pseudoarthrosis or loss of correction during follow-up due to the opened space left by the osteotomies, which can lead to scarce bony contact after the application of the posterior distraction required to restore kyphosis.

The objective was to study if the use of Ponte osteotomies improved coronal correction, maintained it during follow-up, and restored thoracic kyphosis in a prospective cohort of patients operated on with major thoracic AIS curves using apical sublaminar wires and translation corrective maneuvers and to compare the results with a historical cohort in the absence of "Ponte osteotomies".

Materials and methods

We prospectively registered the data of a consecutive series of patients with AIS and major thoracic deformity (Lenke type 1–4) [10], who were surgically treated by a posterior-only approach at a single institution by a single surgeon using apical Ponte osteotomies and mainly corrected using apical concave translation with sublaminar wires. Patients operated with other corrective maneuvers, non-idiopathic deformities, main lumbar curves, or revision surgeries were excluded. A minimum of 2 years follow-up was established. Next, a historical cohort of AIS patients operated by the same single surgeon but without "Ponte osteotomies" was selected and retrospectively compared to the prior series. Both cohorts were homogeneous according to gender, age at surgery, Lenke curve type, preoperative major curve's Cobb angle, preoperative thoracic (T5–T12) kyphosis, rod material (6.35 stainless steel), surgical correction technique, and the number of levels fused.

In all the patients, a hybrid instrumentation was used. The type of construct had the same principles in both groups. To secure the upper foundation, we used either an intrasegmental claw with hooks or an upper transverse hook with an adjacent inferior vertebra pedicle screw. As distal anchors in the thoracolumbar and lumbar segment, bilateral pedicle screws were used. Stainless steel double sublaminar wires were manually bended and inserted in the apex of the concavity (4–6 segments), with the technique described by Asher [11], and used in translational apical correction to a precontoured sagittal rod placed in the concave side of the thoracic curve. To give compression in the convexity, either two transverse hooks or two pedicle screws placed above and below the apex vertebra were used (Fig. 1).

All the patients were corrected with the same maneuvers. To make a derotation effect of the spine, a differential contouring of the rods was used [12]. After instrumentation placement, the concave rod was overbended according to the desired kyphosis to correct the sagittal profile and then inserted first engaging the concave hooks/screws. Sublaminar wires were passed around the rod at this stage. Next, a rod derotation maneuver was performed to adjust the rod to the correct sagittal alignment. Afterward, the apex was translated medially by tightening the sublaminar wires to this first rod, this being the main correction maneuver. Finally, the convex rod was underbended and inserted to push the convexity anteriorly to derotate the spine as described by Cotrel and Dubousset [13].

In the "Ponte" group, the osteotomies were performed along the apex of the deformity; this included all the levels of the deformity with the exception of the upper and lower foundation levels. The levels above and below the apex

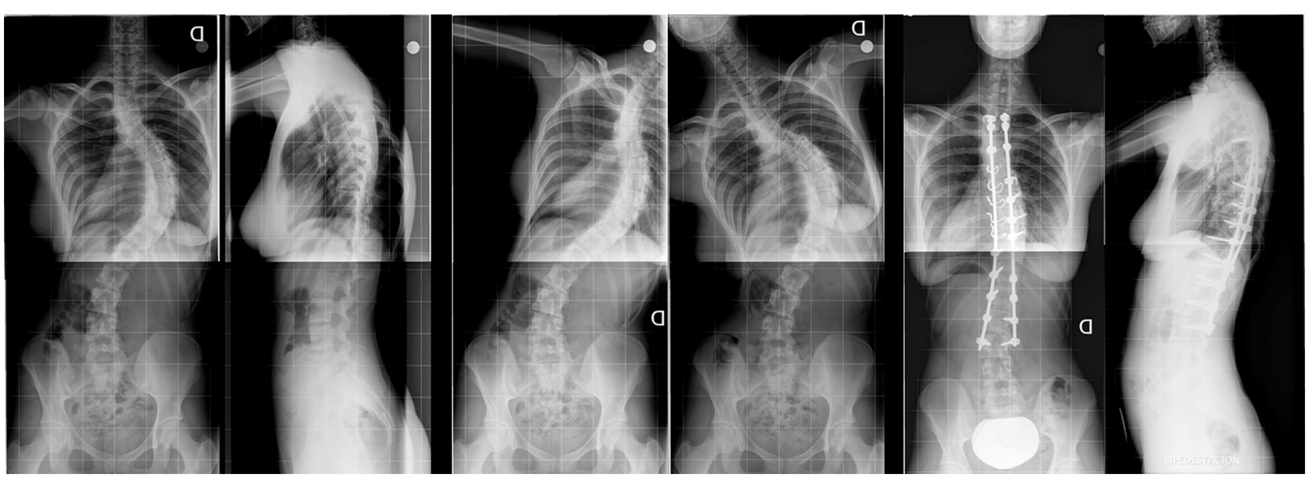

Fig. 1 A 17-year-old girl with idiopathic scoliosis Lenke type 2AN who underwent posterior hybrid instrumentation with additional apical Ponte osteotomies. Proximal thoracic (PT) curve of 47°, bending to 34°. Main thoracic (MT) curve of 79°, bending to 61°, and T5–T12 kyphosis of 32°. After 32 months of follow-up, PT corrected to 10° and MT corrected to 21°. Final T5–T12 kyphosis, 26°. SRS total score improved from 3.6 to 4.3

vertebrae were also carefully osteotomized. A complete excision of the spinous process, the supra and interspinous ligaments, and the ligamentum flavum was performed, in combination with a bilateral extended facetectomy, where the inferior facet of the superior vertebra was removed, as was much of the superior facet of the inferior vertebra. In all patients, the arthrodesis was promoted with posterior decortication and local bone graft. Intraoperative cord monitoring was used in all patients with somatosensory evoked potentials (SSEPs) and transcranial motor evoked potentials (TcMEPs).

All patients were evaluated preoperatively, early postoperatively (within 1 month postoperatively), and at a minimum of 2 years postoperatively. Radiographic analysis was performed on 36-in. long-cassette coronal and lateral radiographs of the spine with the patient standing to determine the Cobb angle measurements. Thoracic kyphosis was measured from the upper endplate of T5 to the lower endplate of T12, and lumbar lordosis was measured from the upper endplate of L1 to the upper endplate of S1. Curve flexibility was determined preoperatively using supine side-bending films. The surgical data and complications were recorded. The postoperative clinical outcomes were evaluated using the SRS-22 Questionnaire.

Overall, 73 AIS patients with Lenke type 1–4 curves were included in the study. Prospectively, 43 consecutive AIS patients with a main thoracic deformity operated by posterior approach and Ponte osteotomies were included between 2008 and 2011. The historical cohort series consisted of 30 patients with the same characteristics but without Ponte osteotomies, who were operated between 2003 and 2006.

Statistical analysis was carried out using the SPSS software (version 11.5, SAS Institute Inc., Cary, NC, USA). The distribution of variables is given as mean and standard deviation. Comparisons between groups were made using two-tailed independent *t* test or Mann–Whitney *U*, the Fisher exact test, and χ^2 statistics as appropriate, with a significance level of 5 % ($p < 0.05$).

Results

Both groups had similar preoperative age, gender distribution, main thoracic curves magnitude and flexibility. The Ponte group achieved better postoperative (70 vs 57 %) and final (62 vs 50 %) main curve correction ($P < 0.001$), with no significant loss of correction (4.2° vs 2.5°) and $P = 0.2$ at the final follow-up (48 vs 106 months) (Table 1). However, only two patients from the control group suffered a final loss of more than 10° (range 10°–14°), while that happened in six patients from the Ponte osteotomy group (range 10°–19°). Immaturity, curve type (Lenke 1), rod material, and type of bone grafting and instrumentation were similar in all of these eight patients.

Preoperative thoracic T5–T12 kyphosis did not differ between groups, both of which had an average of 23°. We could not find a difference in thoracic (T5–T12) postoperative (22° vs 24°) and final (25° vs 26°) mean kyphosis angle between groups (Table 2). We then separated the patients according to the Lenke classification [10] in the three sagittal modifiers (hyperkyphosis >40°; normal kyphosis = 10°–40°; hypokyphosis <10°). These results showed that Ponte osteotomies were conducive to achieving a normal sagittal profile, increasing preoperative hypokyphotic curves from 6° to 17° (control group: 9°–12°; $P = 0.02$) and preoperative hyperkyphotic curves from 52° to 26° (control group: 46° to 39°; $P = 0.01$) (Table 3).

We did not find any complications directly related to the Ponte osteotomies. No neurological complications were encountered during or after the procedures in this series. The length of surgery was similar (4.3 vs 4.6 h) between both groups (Table 4).

Table 1 Comparison of coronal plane parameters

	Control group	Ponte group	*P* value
Major thoracic curve Cobb angle			
Preop	60.4° ± 10°	60° ± 9.9°	0.71
Bending	36.9° ± 11.9°	34.2° ± 15.8°	0.6
Postoperative (% correction)	26.5° ± 8° (57 %)	17.4° ± 7.5° (70.6 %)	0.000*
Final (% correction)	29.4° ± 8.7° (50 %)	22.3° ± 9° (62 %)	0.001*
Degrees of correction	33.9° ± 8°	42.4° ± 10.8°	0.000*
Degrees lost	2.5°	4.2°	0.2
Global balance			
Preoperative	1 ± 0.8 cm	1.4 ± 1.4 cm	0.2
Postoperative	0.7 ± 0.7 cm	0.7 ± 0.8 cm	0.9
Final	0.4 ± 0.5 cm	0.8 ± 0.8 cm	0.02*

* Statistically significant

Table 2 Comparison of sagittal plane parameters

	Control group	Ponte group	*P* value
Preoperative TK	23.5° ± 11.8°	23.7° ± 13.7°	0.9
Postoperative TK	24.9° ± 9.9°	22° ± 6.4°	0.1
Final TK	26.1° ± 9.4°	25.5° ± 6.7°	0.7
Degrees of kyphosis correction	+1° ± 6.1°	−1.4° ± 12.5°	0.3
Initial PJK	4.6° ± 4.3°	5° ± 3.4°	0.6
Final PJK	9.1° ± 5.6°	7.1° ± 7°	0.3
Degrees of PJK difference	4.5° ± 5°	1.4° ± 4.7°	0.05*

TK thoracic kyphosis (T5–T12), *PJK* proximal junctional kyphosis

* Statistically significant

Table 3 Comparison of Lenke's sagittal modifier parameters

	Control group	Ponte group	*P* value
+ (Hyperkyphosis)	3	4	
Preoperative TK	46° ± 3.4°	52.2° ± 5.6°	0.04*
Postoperative TK	39° ± 3°	26.5° ± 2.8°	0.01*
Final TK	38.5° ± 9.1°	30.5° ± 8.5°	0.3
Degrees of final kyphosis correction	−6.5° ± 5°	−21.7° ± 9.1°	0.01*
N (normal kyphosis)	20	27	
Preoperative TK	24.2° ± 7.9°	26° ± 6.1°	0.08
Postoperative TK	25.9° ± 7.6°	23.7° ± 6.6°	0.7
Final TK	27.9° ± 7.5°	25.9° ± 6°	0.4
Degrees of final kyphosis correction	3.4° ± 7.2°	0.1° ± 6.9°	0.008*
− (hypokyphosis)	7	12	
Preoperative TK	9.8° ± 0.3°	6.4° ± 2°	0.07
Postoperative TK	12.6° ± 4.3°	17° ± 3.2°	0.02*
Final TK	15° ± 7°	21.3° ± 5.8°	0.1
Degrees of final kyphosis correction	5.6° ± 7.9°	15.5° ± 7.5°	0.01*

TK thoracic kyphosis (T5–T12)

* Statistically significant

Table 4 Demographics and operative data

	Control group	Ponte group	*P*
Age at surgery	15.2 ± 2.3	14.9 ± 2.1	0.5
Gender	5 M (17 %)	9 M (12 %)	0.7
	25 F (83 %)	34 F (79 %)	
Average follow-up	106.4 ± 30 m	48.2 ± 23 m	0.000*
No. of fused vertebrae	11.4 ± 1.7	11.6 ± 1.7	0.7
Operative time	4.6 ± 0.9 h	4.3 ± 0.7 h	0.2

* Statistically significant

SRS-22 postoperative scores were similar between groups (Table 5), although mental health and function tended to be better in the control group.

Discussion

The three-dimensional conception of scoliosis deformity includes coronal plane deviation, abnormal apical thoracic hypokyphosis in the sagittal plane, and vertebral rotation in the transverse plane [1–3]. Accelerated growth of the anterior portion of the spine resulting in hypokyphosis of the thoracic segment has been theorized as one of the etiologies of AIS [14]. This hypokyphosis has been shown to affect pulmonary function [15, 16]. If properly corrected with surgery, adequate lumbar lordosis can be achieved to prevent future flatback and loss of sagittal balance with aging [17]. It can also avoid junctional misalignments [18] and improve patient perception of deformity [19]. Thus, one of the challenges of scoliosis correction is in restoring a normal sagittal thoracic contour.

Alberto Ponte described a procedure to correct rigid kyphosis such as Scheuermann's kyphosis [5]. This consisted in wide posterior releases at multiple levels with excision of all posterior ligaments in combination with a bilateral extended facetectomy and posterior column shortening followed by posterior rod reduction and compression to close the osteotomy [5]. Shufflebarger et al. [20] applied this method to treat lumbar and thoracolumbar scoliosis and showed that it could improve coronal and sagittal correction. Previous reports have suggested a decrease of approximately 10° of kyphosis decrease per osteotomy level [21] and an overall flexibility increase in cadaveric spines of 69 % [22]. Dorward et al. [23] recently

Table 5 SRS-22 postoperative scores

	Pain	Self-image	Function	Mental health	Satisfaction	Total
Control group	4.4	3.8	4.4	4.1	4.7	4.3
Ponte group	4	3.8	3.9	3.4	4.2	3.9
P value	0.3	0.7	0.1	0.06	0.07	0.08

reported their results in the treatment of both pediatric and adult deformity (kyphosis and scoliosis). Posterior column osteotomies allowed 8.8° of kyphosis reduction per osteotomy in the thoracic spine, increased the lordosis in the lumbar segment, and increased spinal flexibility of coronal stiff deformities to obtain a final coronal correction of 53 %.

Currently, the Ponte osteotomy has become a widespread technique in AIS correction, to increase coronal, rotational, and sagittal flexibility. Posterior column osteotomies (22 %) combined with prone surgical positioning (31 %), provide more than 50 % of the correction prior to rod placement/correction [24]. There is also an effect of self-normalization attributed to the coupling motion which occurs between the coronal and sagittal planes during the prone position and deformity correction [25]. However, results of the use of Ponte osteotomies have not been thoroughly described in the literature and are still controversial. Some studies have reported better coronal and sagittal correction when apical Ponte osteotomies are performed [6, 7], while others have provided contrasting findings demonstrating no advantages [9].

There are also conflicting theories when Ponte osteotomies are used, because the aim in AIS treatment is to lengthen the posterior column and to produce kyphosis by distraction, which is an opposite effect to what the technique was initially conceived. Some studies have found that these osteotomies are not predictive of restoration of normal kyphosis [8, 9]. Our findings are consistent with studies demonstrating that Ponte osteotomies do not necessarily induce an increase in thoracic kyphosis. In the present study, we found that Ponte osteotomies should be taken as a destabilization maneuver to improve the flexibility of the spine. They allow the surgeon to obtain more flexibility that can help model the desired final shape of the spine. When hyperkyphosis was present, we found a significant reduction of nearly 20° in the mean kyphosis. When the patient had a hypokyphosis, we observed a mean increase in thoracic kyphosis of 10°. However, kyphosis appears to be determined by many other aspects of deformity surgery. Rod contouring is essential in deformity correction. An aggressive concave rod over-contouring into marked kyphosis allows surgeons to bring up the deformity in the sagittal plane [12]. In addition, the convex rod should be prebent into a flatter shape at the apex to push the thoracic hump forward with a posteroanterior pressure to improve the derotation effect [12, 13]. The type of rod material is also important [26]. Both the rod and the deformity give away part of their shape during rod placement; thus, some studies have suggested that larger rod diameters and/or increased rod stiffness may improve thoracic kyphosis restoration [19, 27]. The instrumentation used is also crucial. Pedicle screws have been shown to produce more derotation than hooks, bringing the anterior column in place and therefore decreasing kyphosis by anterior lengthening [28]. Sublaminar wires pull posteromedially in translation, which bring back the concavity toward the rod, thereby increasing the kyphosis [29]. Finally, sagittal correction maneuvers also affect thoracic modeling. Thoracic distraction is used in scoliosis to push the thorax forward to create more kyphosis. Posterior thoracic compression is used in Scheuermann's to flatten thoracic kyphosis [30].

Ponte osteotomies also help to maximize coronal correction as demonstrated in our study (12 % of improved correction), which help in the translational maneuver when using sublaminar wires. Other studies have examined their effect on coronal correction (although these studies lacked a control group) and also found them to be useful using pedicle screw constructs, both in adult and pediatric deformity patients [7, 23]. However, other small series analyses could not find any improvement in their results [9]. Anyhow, we should be cautious, as our study shows a trend toward a higher rate of coronal correction loss in the follow-up period when Ponte osteotomies were performed, even though that period was shorter than the control. In these patients, immaturity, curve type, type of bone grafting, and instrumentation were the same as in the control group, and the only difference was the Ponte osteotomies. We speculated that the distraction applied in the sagittal plane to obtain kyphosis opens the osteotomies creating a gap that decreases bony surface contact and increases the risk of pseudarthrosis. However, this effect has not been reported in previous studies, and its importance should be further analyzed with longer follow-up studies.

Although Ponte osteotomies have shown to improve coronal correction and to allow a better sagittal contour restoration, their effects in patient's perception are still limited as shown in our postoperative SRS-22 results. There is still an unsolved debate on this topic. Smith et al. [31] showed that parent satisfaction with postoperative appearance does not correlate with radiographic correction or physical measurements of correction, and some studies have also failed to demonstrate any strong correlation between curve correction and measurable HRQOL [32, 33]. The aim of surgery should always be to obtain a balance spine, and the question is how much correction is necessary to achieve this balance [34].

Ponte osteotomies, if performed carefully by experienced surgeons, show little risk of neurological complications [6, 7, 20, 23, 30]. However, it is essential to use some form of intraoperative cord monitoring to recognize and reverse potential injuries to the spinal cord. Hypokyphosis correction needs to be closely monitored. In addition, we have also found that their performance does not prolong the length of surgery [7].

This study has several limitations. First, its retrospective nature makes it vulnerable to the various biases inherent in such studies. Second, the sample size is limited and, thus, results need to be rigorously evaluated in a large patient population with prospectively controlled comparison groups. Third, because the patients belong to a consecutive series operated on by a single surgeon, the experience gained by the surgeon could be a conflicting factor that can affect the results. However, there is a lack of comparative studies such as the present one in the literature; this study shows statistical powerful differences when comparing groups that are homogeneous and have a long follow-up period. All of the patients were operated using the same techniques and maneuvers by the same surgeon.

In conclusion, our results show that the use of Ponte osteotomies performed in thoracic AIS curves allow a gain in flexibility and more effective corrective maneuvers when using sublaminar wires and translation correction forces. These results produce better coronal correction with no significant loss during follow-up and facilitate the contouring of the desired kyphosis.

Conflict of interest None.

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