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Do Ponte Osteotomies Enhance Correction in Adolescent Idiopathic Scoliosis? An Analysis of 191 Lenke 1A and 1B Curves

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Abstract

Study Design: Retrospective review of a prospectively collected multicenter database of patients with adolescent idiopathic scoliosis (AIS).
Objective: To determine if Ponte osteotomies improve correction in Lenke 1A and 1B AIS curves treated with pedicle screws.
Summary of Background Data: There is little data studying the risks and benefits of Ponte osteotomies in AIS.
Methods: We identified patients with Lenke 1A and 1B curve types treated with pedicle screw constructs and a 2-year follow-up. They were grouped based on whether they did (PO) or did not (NoPO) have Ponte osteotomies. Demographic, surgical, and radiographic data collected preoperatively and at 2 years were statistically analyzed using unpaired Student *t* test and Fisher exact test.
Results: One hundred ninety-one patients met the inclusion criteria (mean age of 14.7 ± 2.2 years), and among those, 125 patients (65.4%) had Ponte osteotomies (average of 4.3 ± 1.5 Pontes per patient). The patients treated with Ponte osteotomies had similar clinical and radiographic parameters (major Cobb: PO = 51.5°, NoPO = 50.8°, p = .6) to the patients who did not have Ponte osteotomies except that they had stiffer and more lordotic curves (Flexibility Index: PO = 47.3%, NoPO = 54.5%, p = .04; T5−T12 kyphosis: PO = 18.7°, NoPO = 23.2°, p = .02). At 2 years, the patients treated with Ponte osteotomies had significantly better thoracic Cobb angle correction (Correction Index: PO = 67.1%, NoPO = 61.8%, p = .01) and an increase in T5−T12 kyphosis (PO = +3.0°, NoPO = −0.4°, p = .045). The Ponte group demonstrated greater rib prominence correction (PO = 53.2%, NoPO = 38.4%, p = .02). There were no neurologic events in this cohort.
Conclusions: Although the use of Ponte osteotomies was not randomized, these data suggest that greater deformity correction in all 3 planes may be possible when Ponte osteotomies are performed for the stiffer and more lordotic Lenke 1A and 1B curves. The clinical significance of these overall small statistical differences remains to be determined.

Institutional review board approval for the study was obtained locally from each contributing institution's review board, and consent was obtained from each patient prior to data collection.

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Introduction

Smith-Petersen and colleagues [1] introduced the posterior column osteotomy to treat flexion deformity in patients with autofused spines from rheumatoid arthritis or ankylosing spondylitis. Later, Ponte and colleagues [2] described a similar technique involving the removal of the facet joints, ligamentum flavum, and posterior ligamentous complex in the nonfused spine for the treatment of Scheuermann kyphosis. Since then, Ponte osteotomies have been widely utilized in the treatment of spine deformity, particularly with respect to the sagittal plane [3-12]. With respect to primarily sagittal plane deformities such as Scheuermann kyphosis, reports suggest that the sagittal correction gained with the Ponte/Smith-Petersen osteotomy is about 10° per level [13-16], or about 1° of correction per millimeter of tissue removed.

There is a paucity of literature on the potential benefits of Ponte osteotomies in patients with adolescent idiopathic scoliosis (AIS) [9,17-21]. Shufflebarger and colleagues [21] reported on the efficacy of the Ponte osteotomy in treating patients with lumbar and thoracolumbar scoliosis; however, their study lacked a control group of patients who did not have Ponte osteotomies. Their results demonstrated excellent correction with few complications. Shah and colleagues [22] reported on 87 AIS patients with Lenke 1-4 curves treated with pedicle screws and Ponte osteotomies. They reported excellent correction in the coronal and sagittal plane, but did not have a ''no Ponte'' control group. Halanski and colleagues [19] found different results in a small cohort of patients with thoracic scoliosis. Comparing Ponte with inferior facetectomy only, they found no difference in coronal or sagittal correction but a higher blood loss and operative time. This study compares the clinical and radiographic outcome of patients with Lenke 1A and 1B curves treated with pedicle screw constructs with and without Ponte osteotomies.

Materials and Methods

Institutional review board approval for the study was obtained locally from each contributing institution's review board, and consent was obtained from each patient prior to data collection. A prospectively collected multicenter database was queried to identify consecutive patients with Lenke 1 AIS treated with pedicle screws (>80% anchors) with a minimum 2-year follow-up. Exclusion criteria included Lenke 1C curves, thoracoplasty, or anterior release. The patients were grouped based on whether or not they underwent a Ponte osteotomy. The No Ponte group underwent facetectomies with removal of the inferior facets.

Clinical and radiographic measurements were obtained preoperatively and at 24 months. Demographic (age, gender), surgical (upper and lower instrumented vertebra levels, estimated blood loss, cell saver transfused, surgical time, hospital length of stay, and neurologic complications), radiographic (thoracic and lumbar coronal Cobb angle, coronal and sagittal balance, kyphosis, and lordosis), and inclinometer (thoracic and lumbar) data were compared between the patients who underwent Ponte osteotomies (PO) and the patients who did not undergo Ponte osteotomies (NoPO) using unpaired Student *t* test and Fisher exact test. Flexibility index was calculated by the formula: 1−(Cobb angle on bend/Cobb angle). Correction index was similarly calculated by the formula: 1−(postoperative Cobb/preoperative Cobb).

Results

Patient demographics and baseline measurements

A total of 191 patients met the inclusion criteria, with a mean age of 14.7 ± 2.2 years (Table 1). The majority of the patients were female (80.6%) and had Lenke 1A curves (73.8%). The average thoracic Cobb angle of the patients was 51.3 ± 8.4°, with a flexibility index of 48.5 ± 21.2% and a rib prominence of 15.0 ± 4.5. The lumbar Cobb angle averaged 29.9 ± 7.1°, with a proximal thoracic curve of 25.3 ± 6.8°. T5−T12 kyphosis averaged 20.3 ± 12.9°.

Table 1
Patient demographics.

Patients (N)	191
Males, n (%)	37 (19.4)
Females, n (%)	154 (80.6)
Age at surgery (years), M ± SD	14.7 ± 2.2
Lumbar modifier, n (%)	
A	141 (73.8)
B	50 (26.2)
Coronal Cobb angle (°), M ± SD	
Upper thoracic	25.3 ± 6.8
Thoracic	51.3 ± 8.4
Lumbar	29.9 ± 7.1
Percentage flexibility (%), M ± SD	
Upper thoracic	36.5 ± 21.6
Thoracic	48.5 ± 21.2
Lumbar	74.2 ± 20.3
Coronal balance (C7−CSVL) (cm), M ± SD	0.6 ± 2.1
Sagittal balance (C7−sacrum) (cm), M ± SD	−0.8 ± 3.5
Kyphosis (T5−T12) (°), M ± SD	20.3 ± 12.9
Lordosis (T12−sacrum) (°), M ± SD	−57.8 ± 11.8
Rotational prominence (°), M ± SD	
Thoracic	15.0 ± 4.5
Lumbar	6.4 ± 4.5

CSVL, central sacral vertical line; M, mean; SD, standard deviation.

Table 2
Preoperative comparison between patients treated with (PO) and without (NoPO) Ponte osteotomies.

	PO (n = 125)	NoPO (n = 66)	p value
Age at surgery (years), M ± SD	14.8 ± 2.3	14.6 ± 2.1	.41
Females, n (%)	98 (78.4)	56 (84.8)	.34
Lumbar modifier, n (%)			
A	91 (72.8)	50 (75.8)	.73
B	34 (27.2)	16 (24.2)	.73
Preoperative coronal Cobb angle (°), M ± SD			
Upper thoracic	25.3 ± 6.9	25.2 ± 6.8	.90
Thoracic	51.5 ± 8.6	50.8 ± 8.1	.60
Lumbar	30.0 ± 7.3	29.9 ± 6.8	.95
Percentage flexibility (%), M ± SD			
Upper thoracic	35.7 ± 21.0	38.2 ± 23.2	.48
Thoracic	47.3 ± 22.1	54.5 ± 22.8	**.04**
Lumbar	74.4 ± 20.4	73.8 ± 20.5	.85
Kyphosis (T5–T12) (°), M ± SD	18.7 ± 13.0	23.2 ± 12.3	**.02**
Lordosis (T12–sacrum) (°), M ± SD	−57.3 ± 12.0	−58.8 ±11.5	.40
Thoracic rotational prominence (°), M ± SD	15.4 ± 4.2	14.3 ± 5.0	.13
Lumbar rotational prominence (°), M ± SD	6.1 ± 4.5	6.8 ± 4.4	.39
Coronal balance (C7–CSVL) (cm), M ± SD	0.8 ± 2.4	0.3 ± 1.9	.25
Sagittal balance (C7–sacrum) (cm), M ± SD	−0.6 ± 4.0	−0.9 ± 3.3	.70

CSVL, central sacral vertical line; M, mean; SD, standard deviation.
Boldface indicates statistical significance.

Radiographic and clinical measurements in patients treated with and without Ponte osteotomies

Ponte osteotomies were performed in 125/191 patients (65.4%) (Tables 2 and 3). In the patients who had Ponte osteotomies (PO), the mean number of osteotomies performed during each spinal fusion was 4.3 ± 1.5, and the percentage of Ponte osteotomies performed per disc level fused was 45% ± 17%. The patients who did not have Ponte osteotomies (NoPO) underwent facetectomies with removal of the inferior facet only. The patients in the PO group had similar demographic, radiographic, and inclinometer parameters to the patients in the NoPO group except they had stiffer thoracic curves (flexibility index PO: 47.3 ± 22.1%, NoPO: 54.5 ± 22.8%, p = .04) and less preoperative thoracic kyphosis (T5–T12) (PO: 18.7 ± 13.0°, NoPO: 23.2 ± 12.3°, p = .02). At 2 years after

Table 3
Postoperative radiographic comparison between patients treated with (PO) and without (NoPO) Ponte osteotomies.

	PO (n = 125)	NoPO (n = 66)	p value
2-year coronal Cobb angle (°), M ± SD			
Upper thoracic	13.9 ± 6.4	15.1 ± 5.9	.23
Thoracic	16.8 ± 6.3	19.4 ± 7.0	**.01**
Lumbar	11.3 ± 6.2	11.5 ± 7.1	.83
Percentage correction Cobb (%), M ± SD			
Upper thoracic	45.3 ± 20.8	39.3 ± 21.4	.06
Thoracic	67.1 ± 11.8	61.8 ± 12.6	**.01**
Lumbar	61.7 ± 23.3	62.1 ± 20.4	.90
Kyphosis (T5–T12) (°), M ± SD			
2 years postoperation	21.8 ± 7.9	22.8 ± 9.4	.33
Change	3.0 ± 11.6	−0.4 ± 9.9	**.045**
Lordosis (T12–sacrum) (°), M ± SD			
2 years postoperation	−59.1 ± 11.9	−58.4 ± 13.9	.74
Change	−1.6 ± 11.2	−1.0 ± 12.4	.76
Thoracic rotational prominence (°), M ± SD			
2 years postoperation	6.9 ± 3.7	7.7 ± 4.7	.16
Percentage correction (%)	53.2 ± 31.8	38.4 ± 50.9	**.02**
Lumbar rotational prominence (°), M ± SD			
2 years postoperation	3.2 ± 3.3	2.8 ± 2.5	.47
Percentage correction (%)	38.9 ± 81.1	46.3 ± 60.3	.57
Coronal balance 2 years postoperation (%), M ± SD	−0.4 ± 1.2	−0.1 ± 1.3	.49
Sagittal balance 2 years postoperation (cm), M ± SD	−0.9 ± 2.8	−1.0 ± 3.1	.77

M, mean; SD, standard deviation.
Boldface indicates statistical significance.

surgery, the patients treated with Ponte osteotomies had smaller thoracic Cobb angles (PO: 16.8 ± 6.3°, NoPO: 19.4 ± 7.0°, p = .01) and greater correction index (PO: 67.1 ± 11.8%, NoPO: 61.8 ± 12.6%, p = .01).

In addition, restoration of T5–T12 kyphosis was better in the patients who had a Ponte osteotomy, whereas it remained stable in those without (PO: 3.0 ± 11.6°, NoPO: minus 0.4 ± 9.9°, p = .045). With respect to rib prominence, the Ponte group started with a higher preoperative thoracic inclinometer measurement (PO: 15.4 ± 4.2°, NoPO: 14.3 ± 5.0°, p = .13), and at 2 years this was less than the No Ponte group (PO: 6.9 ± 3.7°, NoPO: 7.7 ± 4.7°, p = .16), although this did not reach statistical significance. However, the rib prominence percentage correction was significantly greater in the Ponte osteotomy group (PO: 53.2 ± 31.8%, NoPO: 38.4 ± 50.9%, p = .02).

Other radiographic and clinical measurements at 2-year follow-up were similar between the two groups, including upper thoracic Cobb angle (p = .23), lumbar Cobb angle (p = .83), coronal (p = .49) and sagittal balance (p = .77), lumbar lordosis (T12 to sacrum) (p = .74), and lumbar rotational prominence (p = .47).

Intraoperative factors

The patients with Ponte osteotomies had an average of 0.5 more levels fused (PO: 9.6 ± 1.5, NoPO: 9.1 ± 1.5, p = .02), an increased total estimated blood loss compared with the patients who did not have Ponte osteotomies (PO: 970.1 ± 566.5 mL, NoPO: 778.9 ± 726.1 mL, p = .046), and a trend toward increased cell saver transfused (PO: 282.2 ± 249.9 mL, NoPO: 203.1 ± 293.0 mL, p = .06) (Table 4). It is not clear to us why the PO group had slightly longer fusions, but this may in part be explained by the surgeons' fusing stiffer curves slightly longer. When adjusted for the extra 0.5 levels fused in the Ponte osteotomy group, the EBL was no longer statistically significant (PO: 101.2 ± 55.3 mL/level fused, NoPO: 84.2 ± 71.3 mL/level fused, p = .07), and the cell saver transfused remained a trend (PO: 29.5 ± 25.5 mL/level fused, NoPO: 21.1 ± 30.2 mL/level fused, p = .06). In addition, when we expressed blood loss as a percentage of total blood volume (calculated as patient weight in kilograms times 70), there was no difference between the groups (PO: 12.9 ± 7.4%, NoPO: 11.2 ± 12.3%).

Surgical time (PO: 277.4 ± 98.9 min, NoPO: 295.9 ± 136.4 min, p = .29) and hospital length of stay (PO: 5.3 ± 1.2 days, NoPO: 5.3 ± 1.2 days, p = .92) were not found to be statistically significant between the two groups. None of the patients in this cohort sustained a neurologic injury.

Scoliosis Research Society (SRS) 22 scores

The SRS-22 scores for patients before surgery were similar between the two groups (SRS total PO: 3.9 ± 0.5, NoPO: 4.0 ± 0.4, p = .14; SRS Self-Image PO: 3.4 ± 0.7, NoPO: 3.7 ± 0.7, p = .76). After surgery, the scores were also not statistically different (SRS total PO: 4.5 ± 0.4, NoPO: 4.5 ± 0.4, p = .48; SRS Self-Image PO: 4.5 ± 0.5, NoPO: 4.5 ± 0.6, p = .96). Hence, the increased correction observed in those patients who had undergone Ponte osteotomies was not detected by the SRS-22.

Discussion

In this study, we compared the effect of Ponte osteotomies on spine deformity correction in patients with AIS Lenke 1A and 1B curves treated with pedicle screws. Operating time and hospital stay were similar between the groups, and no neurologic injuries occurred in this cohort.

There have been numerous reports on the corrective results of Ponte osteotomies in the sagittal plane [3-12], with a few studies documenting the correction gained in the coronal plane [9,17-21], and only cadaveric studies reporting on the axial plane [20]. The results in patients with AIS demonstrate some variability. Some reports have shown excellent correction with minimal adverse effects [17,22], as opposed to that of Halanski and colleagues [19], who did not find improved correction but only a higher blood loss and longer operative time. Our study did find improved correction in all three planes but no increase in operative time or blood loss (when adjusted for weight). This difference may be explained by the relatively small sample size of their cohort and the fact that they included all Lenke 1 and 2 curves. The surgical goals for Lenke 1C curves may not always be maximal correction, and this is the reason we chose to exclude this curve type. In addition, their study was limited by short follow-up (only 6 weeks to 4 months) and significant baseline differences in Cobb angles and curve flexibility. Other studies on wide posterior

Table 4
Comparison of intraoperative data between patients treated with (PO) and without (NoPO) Ponte osteotomies.

	PO (n = 125)	NoPO (n = 66)	p value
Estimated blood loss (mL), M ± SD	970.1 ± 566.5	778.9 ± 726.1	**.046**
Cell saver transfused (mL), M ± SD	282.2 ± 249.9	203.1 ± 293.0	.06
Surgical time (minutes), M ± SD	277.4 ± 98.9	295.9 ± 136.4	.29
Hospital length of stay (days), M ± SD	5.3 ± 1.2	5.3 ± 1.2	.92
Levels fused (n), M ± SD	9.6 ± 1.5	9.1 ± 1.5	**.02**

M, mean; NoPO, no Ponte osteotomy; PO, Ponte osteotomy; SD, standard deviation.
Boldface indicates statistical significance.

release support our findings in the coronal plane [17,18]. Specifically, Pizones and colleagues [18] showed that patients with AIS treated with posterior hybrid constructs had better coronal correction of the main curve 2 years after surgery with wide posterior release (61.8%) compared with those who underwent a standard posterior release (51.6%).

In our cohort, the overall percentage correction of the main thoracic curve was 65%; this was similar to other published reports with all pedicle screw constructs [23-25]. Min and colleagues [23] demonstrated a 63% correction in 48 consecutive patients with a minimum 10-year follow-up.

Restoration of kyphosis in patients with AIS presents unique challenges [26]. Ponte osteotomies have been utilized to help correct this hypokyphosis, although Ponte and colleagues [2] initially described the Ponte osteotomy as a procedure to correct hyperkyphosis in Scheuermann kyphosis [13,26-28]. With respect to correction of hypokyphosis, Halanski and colleagues [19] did demonstrate a greater increase in postoperative kyphosis with Ponte osteotomies, although this did not reach statistical significance. This finding was similar to our results in that kyphosis restoration was greater in the Ponte group. Our significantly larger sample size did result in statistical significance.

In 2011, Wiemann and colleagues [20] published a human cadaveric study showing that complete facetectomies (Ponte or Smith-Petersen) decreased the torque required to rotate spinal elements in the axial plane by approximately one-fifth. Our study demonstrated the clinical translation of this finding. Although there was no difference in preoperative or 2-year postoperative absolute measurements between the patients treated with Ponte osteotomies and those who did not have Ponte osteotomies with respect to thoracic inclinometer readings, there was a statistically significantly greater percentage correction of the thoracic inclinometer measurements at 2 years. However, the improvement in the axial plane may be explained by the coupling effect of the enhanced coronal correction observed in patients who had Pontes performed. The greater axial correction is likely a combination of both the enhanced coronal correction and the biomechanical advantage of derotation provided by Pontes. Pre- and postoperative CT scans would have allowed for more detailed assessment of apical rotation but were not routinely obtained.

Criteria for when to perform a Ponte osteotomy vary among surgeons and need to be tailored to each patient's individual goals. In broad terms, one can consider performing Ponte osteotomies when the flexibility index is $<50\%$ and/or thoracic kyphosis is $<20°$.

Our study did not find an increase in weight-adjusted estimated blood loss in the patients who received Ponte osteotomies, in contrast to other studies [13,14,19]. Halanski and colleagues [19] reported longer operating times in patients treated with Ponte osteotomies. The current study did not find an increase in surgical time in the patients treated with Ponte osteotomies (mean surgical time 277.4 minutes). In the current study, there was no statistically significant increase in hospital length of stay in the patients who underwent Ponte osteotomies. Finally, there were no neurologic complications in the current study. Neurologic complications have been reported to be slightly higher in patients treated with Ponte osteotomies, ranging from 0% to 7% [9,13,14].

Limitations of our study include nonrandomization of Ponte osteotomies and a multicenter data set. The nonrandomization allows surgeon-specific factors to potentially confound the results. This may be one reason we did not observe longer surgical times in patients who underwent Ponte osteotomies. However, a randomized study would be greatly limited by surgeon resistance to randomization and the cost of undertaking such a study. We further attempted to control for this factor by attempting to identify for each surgeon's patients before and after they began routinely performing Ponte osteotomies. Unfortunately, the data set did not reliably include this information. All of the surgeons who participated contributed patients to both the Ponte and No Ponte groups. This may decrease surgeon-specific confounding factors. However, we could not control for surgeon learning curve and technical evolution.

In addition, standard PA and lateral radiographs do not provide three-dimensional data. Future work will delve into more detail with the newer generation of x-ray machines that can reconstruct three-dimensional images. Another limitation of the study is its multicenter nature, potentially introducing center-specific confounders. However, this allows for adequate sample size, and we were able to maintain an acceptable percentage follow-up ($>75\%$ at 2 years). Lastly, the average overall improvement with Ponte osteotomies in our cohort with respect to coronal, sagittal, and rotational correction was statistically significant but likely does not represent a clinical significance. The extent of improvement will vary with the patient, and future work will try to identify those patients who do attain the most clinically significant increases.

In conclusion, it appears that Ponte osteotomies increase correction in all 3 planes in patients with Lenke 1A and 1B AIS treated with pedicle screws even though there may not be clinically significant improvement. Ponte osteotomies appear to result in an increased amount of estimated blood loss with a trend toward more cell saver transfused, but they do not increase the length of surgery or hospital length of stay.

Key points:

1. Ponte osteotomies were performed in larger, stiffer curves and resulted in greater correction in all three planes.
2. Restoration of thoracic kyphosis was greater in patients who underwent Ponte osteotomies, whereas those without Ponte osteotomies showed no change.
3. Greater correction of the rib prominence was obtained when Ponte osteotomies were performed.

References

[1] Smith-Petersen MN, Larson CB, Aufranc OE. Osteotomy of the spine for correction of flexion deformity in rheumatoid arthritis. *Clin Orthop Relat Res* 1969;66:6−9.

[2] Ponte A, Vero B, Siccardi GL. *Surgical treatment of Scheuermann's hyperkyphosis. Progress in Spinal Pathology: Kyphosis*. Bologna: Aulo Gaggi; 1984. p. 75−80.

[3] Grevitt M, Kamath V, Avadhani A, Rajasekaran S. Correction of thoracic kyphosis with Ponte osteotomy. *Eur Spine J* 2010;19(2):351−2.

[4] Lagrone MO, Bradford DS, Moe JH, Lonstein JE, Winter RB, Ogilvie JW. Treatment of symptomatic flatback after spinal fusion. *J Bone Joint Surg Am* 1988;70(4):569−80.

[5] Lee MJ, Wiater B, Bransford RJ, Bellabarba C, Chapman JR. Lordosis restoration after Smith-Petersen osteotomies and interbody strut placement: a radiographic study in cadavers. *Spine (Phila Pa 1976)* 2010;35(25):E1487−91.

[6] Lewis SJ, Gray R, David K, Kopka M, Magana S. Technique of Reverse Smith Petersen Osteotomy (RSPO) in a patient with fixed lumbar hyperlordosis and negative sagittal imbalance. *Spine (Phila Pa 1976)* 2010;35(15):E721−5.

[7] McClendon Jr J, O'Shaughnessy BA, Sugrue PA, et al. Techniques for operative correction of proximal junctional kyphosis of the upper thoracic spine. *Spine (Phila Pa 1976)* 2012;37(4):292−303.

[8] McMaster MJ. A technique for lumbar spinal osteotomy in ankylosing spondylitis. *J Bone Joint Surg Br* 1985;67(2):204−10.

[9] Voos K, Boachie-Adjei O, Rawlins BA. Multiple vertebral osteotomies in the treatment of rigid adult spine deformities. *Spine (Phila Pa 1976)* 2001;26(5):526−33.

[10] Zhu Z, Wang X, Qian B, et al. Loss of correction in the treatment of thoracolumbar kyphosis secondary to ankylosing spondylitis: a comparison between Smith-Petersen osteotomies and pedicle subtraction osteotomy. *J Spinal Disord Tech* 2011;25(7):383−90.

[11] Samudrala S, Vaynman S, Thiayananthan T, et al. Cervicothoracic junction kyphosis: surgical reconstruction with pedicle subtraction osteotomy and Smith-Petersen osteotomy. Presented at the 2009 Joint Spine Section Meeting. Clinical article. *J Neurosurg Spine* 2010;13(6):695−706.

[12] Hehne HJ, Zielke K, Bohm H. Polysegmental lumbar osteotomies and transpedicled fixation for correction of long-curved kyphotic deformities in ankylosing spondylitis. Report on 177 cases. *Clin Orthop Relat Res* 1990;258:49−55.

[13] Geck MJ, Macagno A, Ponte A, Shufflebarger HL. The Ponte procedure: posterior only treatment of Scheuermann's kyphosis using segmental posterior shortening and pedicle screw instrumentation. *J Spinal Disord Tech* 2007;20(8):586−93.

[14] Cho KJ, Bridwell KH, Lenke LG, Berra A, Baldus C. Comparison of Smith-Petersen versus pedicle subtraction osteotomy for the correction of fixed sagittal imbalance. *Spine (Phila Pa 1976)* 2005;30(18):2030−7.

[15] Gill JB, Levin A, Burd T, Longley M. Corrective osteotomies in spine surgery. *J Bone Joint Surg Am* 2008;90(11):2509−20.

[16] Burton DC. Smith-Petersen osteotomy of the spine. *Instr Course Lect* 2006;55:577−82.

[17] Shufflebarger HL, Clark CE. Effect of wide posterior release on correction in adolescent idiopathic scoliosis. *J Pediatr Orthop B* 1998;7(2):117−23.

[18] Pizones J, Izquierdo E, Sanchez-Mariscal F, Alvarez P, Zuniga L, Gomez A. Does wide posterior multiple level release improve the correction of adolescent idiopathic scoliosis curves? *J Spinal Disord Tech* 2010;23(7):e24−30.

[19] Halanski MA, Cassidy JA. Do multilevel Ponte osteotomies in thoracic idiopathic scoliosis surgery improve curve correction and restore thoracic kyphosis? *J Spinal Disord Tech* 2013;26(5):252−5.

[20] Wiemann J, Durrani S, Bosch P. The effect of posterior spinal releases on axial correction torque: a cadaver study. *J Child Orthop* 2011;5(2):109−13.

[21] Shufflebarger HL, Geck MJ, Clark CE. The posterior approach for lumbar and thoracolumbar adolescent idiopathic scoliosis: posterior shortening and pedicle screws. *Spine (Phila Pa 1976)* 2004;29(3):269−76.

[22] Shah SA, Dhawale AA, Oda JE, et al. Ponte osteotomies with pedicle screw instrumentation in the treatment of adolescent idiopathic scoliosis. *Spine Deform* 2013;1:196−204.

[23] Min K, Sdzuy C, Farshad M. Posterior correction of thoracic adolescent idiopathic scoliosis with pedicle screw instrumentation: results of 48 patients with minimal 10-year follow-up. *Spine (Phila Pa 1976)* 2005;30(14):1602−9.

[24] Luhmann SJ, Lenke LG, Erickson M, Bridwell KH, Richards BS. 63% correction of moderate (< 70 degrees) Lenke 1A and 2A curve patterns: comparison of hybrid and all-pedicle screw systems at 2-year follow-up. *Eur Spine J* 2013;22(2):345−54.

[25] Suk SI, Lee SM, Chung ER, Kim JH, Kim SS. Selective thoracic fusion with segmental pedicle screw fixation in the treatment of thoracic idiopathic scoliosis: more than 5-year follow-up. *Spine (Phila Pa 1976)* 2005;30(14):1602−9.

[26] Bridwell KH, Betz R, Capelli AM, Huss G, Harvey C. Sagittal plane analysis in idiopathic scoliosis patients treated with Cotrel-Dubousset instrumentation. *Spine (Phila Pa 1976)* 1990;15(7):644−9.

[27] Sucato DJ, Agrawal S, O'Brien MF, Lowe TG, Richards SB, Lenke L. Restoration of thoracic kyphosis after operative treatment of adolescent idiopathic scoliosis: a multicenter comparison of three surgical approaches. *Spine (Phila Pa 1976)* 2008;33(24):2630−6.

[28] Bernhardt M, Bridwell KH. Segmental analysis of the sagittal plane alignment of the normal thoracic and lumbar spines and thoracolumbar junction. *Spine (Phila Pa 1976)* 1989;14(7):717−21.