The Proximal Thoracic Curve in Adolescent Idiopathic Scoliosis: Surgical Strategy and Management Outcomes

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Abstract

There is no consensus on the definition of a structural proximal thoracic curve (PTC) and the indications for fusion. As such, we assessed a single institute's experience in the management of large PTCs (>35 degrees) in patients with adolescent idiopathic scoliosis (AIS) who were either fused or not fused. A retrospective radiographic analyses of 30 consecutive AIS patients with double thoracic curves who underwent PSF with a minimum of 2 years' follow-up were included for review. The patients were divided into two groups: group 1 ($n = 15$ patients) with fusion extended up to T2 or T3 and group 2 ($n = 15$) with fusion limited to T5 or below. Shoulder balance was assessed according to clavicular angle, first-rib difference, and radiographic shoulder height difference (SHD). PTCs were defined based on a Cobb angle of >35, the presence of apical rotation, and a positive T1 tilt. The decision to fuse the PTC was based on curve magnitude only, with those between 35 and 45 degrees undergoing a selective fusion of the main thoracic curve (MTC), with both curves fused if the PTC was more than 45 degrees. In group 1, there were eight females and seven males. Their ages ranged between 12 and 33 years, with a mean of 16.2 ± 5.5 years. Postoperatively, the mean PTC correction was 45.6%, which statistically differed from preoperative status ($p = 0.001$). No statistical difference was noted in T1 tilt and the first-rib difference from preoperative to postoperative follow-up ($p > 0.05$). However, the clavicular angle and SHD were increased significantly at the immediate postoperative interval ($p < 0.05$) but demonstrated no significant changes between the initial and the last follow-up values ($p > 0.05$). Group 2 consisted of one male and 14 females. The mean age was 16.4 ± 4 years (range: 11 to 28 years). The mean spontaneous PTC correction was 28.3% and remained essentially unchanged at the end of the follow-up. The improvement in the curve from preoperative status was highly statistically significant ($p = 0.001$). All radiographic shoulder parameters exhibited a significant increase in the immediate postoperative period and at last follow-up, and shoulder balance improvement was not noted on follow-up. Although both groups were not statistically similar with regards to the preoperative PTC, AVR, apical vertebral translation, and shoulder parameters, no significant difference could be found in PTC or shoulder parameters between both groups at last follow-up ($p > 0.05$). Our study

Keywords

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illustrates important observations that should be considered in defining the PTC for fusion consideration. Spontaneous correction of the PTC occurs in structural curves greater than 35 degrees and less than 45 degrees, and this correction is maintained over time. Despite that correction, radiographic shoulder parameters are expected to slightly increase. Nonfusion strategy may be appropriate for PTCs between 35 and 45 degrees. After fusion of both the MTC and the PTC, the radiographic shoulder parameters did not significantly differ. Preoperative radiographic shoulder parameters are not predictive of postoperative shoulder imbalance.

Recognition of the proximal thoracic curve (PTC) is imperative in the preoperative planning in patients with adolescent idiopathic scoliosis (AIS). To date, no global agreement regarding the definition of the PTC exists[1–3]; moreover, when it should be fused remains controversial and subject to personal preferences. Some authors have advocated inclusion of the PTC in the fusion construct with the main thoracic curve (MTC) to prevent postoperative shoulder asymmetry and truncal decompensation. Furthermore, the criteria to fuse large PTCs are speculative.[3–6] Some authors have reported spontaneous correction of the PTC after selective fusion of the MTC, whereas others contend the contrary.[7,8]

As the overall aim of operative treatment of the PTC among authors is to obtain good shoulder balance,[1–8] the objective of this work is to review a single institute's experience in the treatment of large PTCs (>35 degrees) with either fusion of both thoracic curves or selective fusion of the lower thoracic curve, with specific reference to the shoulder balance.

Methods

This is a retrospective radiographic review of 30 consecutive patients who were diagnosed with AIS and treated at our institute with posterior spinal fusion (PSF) between January 2000 and December 2005. All patients had a minimum of 2-year follow-up after surgery and PTCs greater than 35 degrees. The patients were divided into two groups: group 1 ($n = 15$) included patients with fusion extending to T2 or T3, and group 2 ($n = 15$) in whom fusion was limited to T5 or below.

Diagnosis and Indication for Fusion

The diagnosis of a PTC was based on the presence of positive T1 tilt, a higher left shoulder, and apical vertebral rotation (AVR). The latter is based on clinical evidence of an elevated left scapula (scapula hump) and/or radiographic evidence of asymmetry of the pedicle shadows at the apex of the upper thoracic curve. Our indication for fusion was a curve magnitude of >45 degrees, whereas those less than this magnitude were left unfused.

Surgical Considerations

In all cases, PSF was performed with autogenous bone graft harvested from the posterior iliac crest. Local graft from the spinous processes was added. Hybrid segmental fixation (hooks in the upper thoracic, and pedicle screws in the lower thoracic and lumbar spine) was used in all patients. The procedure was monitored using somatosensory and motor-evoked potentials.[9–12]

Radiographic Assessment

Plain radiographic evaluation included measurements of the PTC and MTC on preoperative, immediate postoperative, and final follow-up long-standing, right and left fulcrum-bending anteroposterior (AP) radiographs. Where applicable, curve flexibility was assessed using the fulcrum-bending radiograph. Sagittal Cobb angle measurements were included for T2–T5. The apical vertebral translation (AVT) was determined for each curve on the standing AP radiographs. The AVR was assessed using the Nash and Moe method.[13] A positive T1 tilt was defined as the angle between the proximal end plate of T1 and the horizontal with the left proximal vertebral body directed upward and the right lower vertebral body directed downward.[10] Spinal imbalance was measured by the deviation of the T1 plumb line from the center sacral line on the standing radiographs. It was considered significant when the deviation exceeded 2 cm. The patients' maturity was assessed by Risser sign.[14]

A positive T1 tilt was defined as the angle between of the proximal end plate of T1 and the horizontal with the left proximal vertebral body directed upward and the right lower vertebral body directed downward.[15] Shoulder balance was determined from the standing AP radiograph and was assessed according to the following three parameters:

- The clavicular angle was measured by the intersection of the line connecting the highest two points of each clavicle and a horizontal line. A positive clavicular angle, like T1 tilt, was defined as left side up and right side down.[7]
- The first-rib difference was measured in millimeters, based on the difference of the highest points of the first ribs. This value was regarded as positive when the left was elevated and negative when the right was elevated.[7]

- The radiographic shoulder height (RSH) was defined as the difference of soft tissue shadows directly superior to the acromioclavicular joints on both sides. The difference in shoulder height was considered positive when the left shoulder was higher and negative when left shoulder was lower.[6] The RSH was graded as significant imbalance (>3 cm), moderate imbalance (2 to 3 cm), minimal imbalance (1 to 2 cm), or balanced (<1 cm) side-to-side difference.[3–7]

Radiographic assessment and measurements were performed by an orthopedic surgeon, who was fellowship-trained in spine deformities. All measurements were analyzed using the PACS system computer software (RadWorks 5.1).

Statistical analysis was performed with SPSS version 11.5 statistical software (Chicago, IL). Mann-Whitney *U* tests were performed for between-group comparisons of various time intervals, whereas Wilcoxon tests were utilized for two related samples for within-groups analysis. Chi-square and Fisher exact tests were employed for categorical data associations where appropriate. Statistical significance was noted when $p < 0.05$.

Results

All 30 patients were assessed. The analyses here forward illustrate the findings stratified based on group type, followed by comparisons of both groups.

Group 1 (Upper Thoracic Curve, Fused)

There were eight females and seven males. Their age ranged between 12 and 33 years, with a mean of 16.2 ± 5.5 years. Six cases were classified as Risser grade 5, two cases grade 2, three grade 3, one case grade 2, one case grade 1, and two cases 0. Fusion was extended to T2 in 13 cases and to T3 in two cases. The upper fusion level was determined by the upper end vertebra. If the end vertebra was T1 or T2, fusion was extended to T2; if the end vertebra was T3, fusion would stop at the same level. T1 was not fused because in the authors' experience due to size and obliquity, it was often difficult to place hooks at that level. The mean follow-up was 36.2 ± 19.6 months (range: 24 to 89 months).

Correction of Curves

The details of correction are illustrated in ►**Tables 1**, **2**, and **3**. The preoperative PTC Cobb angle ranged between 46.0 and 62.0 degrees, with a mean 51.8 ± 5.2 degrees, decreased to 32.7 ± 9.6 degrees on fulcrum bending (flexibility = 36.8%). The curves were corrected to 28.3 ± 7.1 degrees (range: 20 to 45 degrees) in the immediate postoperative period and to 33.0 ± 7.5 degrees at the end of follow-up (the mean correction was 45.6%). The difference between the preoperative angle and postoperative correction was highly statistically significant ($p = 0.001$).

In all cases, the PTCs were rotated ($n = 10$ grade 2, $n = 5$ grade 1). The mean preoperative MTC was 63.6 ± 13.9 degrees (range: 38 to 88 degrees), which was decreased to 29.5 ± 13.9 degrees on fulcrum-bending films. The mean curve was corrected to 25.1 ± 9.9 degrees in the immediate postoperative period, and to 29.3 ± 8.9 degrees (range: 13.1 to 47.5 degrees) at the end of the follow-up. The correction was highly statistically significant ($p = 0.001$). The fulcrum-bending radiograph predicted well the postoperative

Table 1 Preoperative Between-Group Analyses of Various Radiographic Parameters

	Group 1 PTC Fused, Preoperative Mean ± SD (Range)	Group 2 PTC Not Fused, Preoperative Mean ± SD (Range)	*p* Value
PTC (degrees)	51.8 5.2 (46.0–62.0)	41.0 2.3 (37.0–44.0)	<0.001[a]
MTC (degrees)	63.6 13.9 (38.0–88.0)	58.7 10.4 (45.0–84.0)	0.250
Sagittal T2–T5 (degrees)	17.2 9.2 (3.6–38.3)	19.2 10.6 (2.4–45.2)	0.678
AVT (mm)	13.7 11.8 (0–44.0)	13.9 7.2 (5.1–29.4)	0.520
Truncal shift (mm)	1.1 13.6 (−18.6–25.1)	−4.9 13.0 (−25.6–15)	0.245
T1 tilt (degrees)	13.6 3.5 (7.1–21.6)	7.2 4.0 (0.5–16.2)	<0.001[a]
Clavicular angle (degrees)	1.3 2.1 (−3.4–5.1)	−1.0 2.1 (−6.6–2.4)	0.004[a]
First-rib difference (mm)	7.2 5.9 (−8.2–14.0)	3.2 3.1 (0–9.2)	0.011[a]
SHD (mm)	9.0 11.5 (−12.1–36.2)	−0.4 12.8 (−21.2–22.2)	0.067

SD, standard deviation; PTC, proximal thoracic curve; MTC, main thoracic curve; AVT, apical vertebral translation of PTC; SHD, shoulder height difference.
[a]Statistically significant.

Table 2 Immediate Postoperative (1 wk) and Last Follow-Up Between-Group Analyses of Various Radiographic Parameters

	Group 1 PTC Fused		Group 2 PTC Not Fused			
	Immediate Postoperative, Mean ± SD (Range)	Last Follow-Up, Mean ± SD (Range)	Immediate Postoperative, Mean ± SD (Range)	Last Follow-Up, Mean ± SD (Range)	*p* Value 1	*p* Value 2
PTC (degrees)	28.3 7.1 (20.0–45.0)	33.0 7.5 (23.3–46.1)	30.6 6.5 (22–40)	30.6 5.1 (24.4–42.6)	0.191	0.534
MTC (degrees)	25.0 9.9 (11.4–48.3)	29.3 8.9 (13.1–47.5)	20.8 7.4 (6.1–36.4)	26.2 7.8 (15.3–39.5)	0.077	0.319
Sagittal T2–T5 (degrees)	16.4 8.5 (6.5–35.6)	16.5 8.9 (6.6–35.7)	19.2 10.5 (5.1–36.4)	17.9 9.9 (5.3–35.8)	0.678	0.678
AVT (mm)	10.9 7.2 (0–22.7)	16.4 8.4 (2.0–29.9)	21.2 12.5 (0–39.9)	15.4 12.1 (0–37.7)	0.020[a]	0.547
Truncal shift (mm)	−1.6 9.2 (−21.0–15.0)	2.2 10.1 (−13.5–20.2)	−6.09 17.8 (−41.0–25.0)	−1.3 12.8 (−19.3–31.9)	0.308	0.348
T1 tilt (degrees)	12.3 4.0 (7.9–18.4)	14.0 4.6 (6.0–20.0)	15.3 4.6 (9.1–26.1)	12.4 4.6 (4.6–20.6)	0.106	0.319
Clavicular angle (degrees)	3.4 1.4 (0.4–5.7)	2.4 1.6 (−2.0–5.0)	2.8 2.5 (−2.2–6.4)	2.1 1.7 (−2.0–5.0)	0.633	0.430
First-rib elevation (mm)	11.2 4.3 (3.8–18.9)	11.9 4.7 (5.1–21.5)	12.7 5.1 (4.3–20.8)	10.6 4.8 (2.9–22.5)	0.455	0.351
SHD (mm)	17.4 10.5 (0–35.3)	15.6 11.5 (−8.2–32.8)	17.0 16.5 (−8.7–41.4)	12.0 15.8 (−11.6–37.7)	0.950	0.340

SD, standard deviation; PTC, proximal thoracic curve; MTC, main thoracic curve; AVT, apical vertebral translation of PTC; SHD, shoulder height difference; *p* value 1, testing between immediate postoperative intervals; *p* value 2, testing between last follow-up intervals.
[a]Statistically significant.

Table 3 Preoperative, Immediate Postoperative (1 wk), and Last Follow-Up Within-Group Analyses of Various Radiographic Parameters

	Group 1 PTC Fused			Group 2 PTC Not Fused		
	Preoperative to Immediate Postoperative *p* Value	Immediate Postoperative to Last Follow-Up *p* Value	Preoperative to Last Follow-Up *p* Value	Preoperative to Immediate Postoperative *p* Value	Immediate Postoperative to Last Follow-Up *p* Value	Preoperative to Last Follow-Up *p* Value
PTC (degrees)	0.001[a]	0.001[a]	0.001[a]	0.011[a]	0.730	0.001[a]
MTC (degrees)	0.001[a]	0.009[a]	0.001[a]	0.001[a]	0.001[a]	0.001[a]
Sagittal T2–T5 (degrees)	0.510	0.754	0.394	0.910	0.281	0.363
AVT (mm)	0.594	0.035[a]	0.397	0.069	0.078	0.865
Truncal shift (mm)	0.865	0.300	0.955	0.820	0.629	0.315
T1 tilt (degrees)	0.173	0.069	0.650	0.001[a]	0.015[a]	0.005[a]
Clavicular angle (degrees)	0.005[a]	0.025[a]	0.147	0.002[a]	0.187	0.001[a]
First-rib difference (mm)	0.069	0.589	0.053	0.001[a]	0.096	0.002[a]
SHD (mm)	0.007[a]	0.570	0.100	0.015[a]	0.191	0.036[a]

PTC, proximal thoracic curve; MTC, main thoracic curve; AVT, apical vertebral translation of PTC; SHD, shoulder height difference.
[a]Statistically significant.

correction of the MTC but not the PTC. In addition, only two cases had preoperative truncal imbalance, and truncal decompensation was observed in only one case (i.e., 20.2 mm).

Radiographic Shoulder Parameters

The preoperative, postoperative, and last follow-up radiographic shoulder parameters are illustrated in ►**Tables 1**, **2**, and **3**. In general, both T1 tilt and the first-rib difference remained essentially unchanged in the final follow-up. However, the clavicular angle and shoulder height difference (SHD) were increased significantly postoperatively ($p < 0.05$), and ultimately showed no significant changes between the initial and the late follow-up values ($p > 0.05$).

With regards to SHD, four patients (26.7%) improved one grade, one patient (6.7%) showed no change, three (20%) declined two grades, and seven (46.7%) declined one grade. Analysis of the 10 patients who had deterioration of the SHD revealed that the mean initial PTC was 50.5 ± 7.3 degrees with a PTC fulcrum-bending curve of 34.2 ± 10 degrees and an immediate postoperative mean of 29.4 ± 7.5 degrees and final follow-up of 32.8 ± 6.9 degrees. There was a statistically significant difference between the fulcrum-bending curve and immediate postoperative PTC ($p = 0.01$; overcorrected beyond the flexibility predicted by the fulcrum bending). However, no significance was found between the PTC fulcrum-bending curve and the latest follow-up ($p = 0.397$). The mean MTC fulcrum-bending curve was 22.3 ± 9.8 degrees, corrected to 21.5 ± 6 degrees immediately postoperatively and to 27 ± 8 degrees in the latest follow-up. No significant correlation could be found between PTC fulcrum-bending curve and the immediately postoperative ($p = 0.82$) or the latest follow-up MTC ($p = 0.30$; ►**Fig. 1**).

Group 2 (Upper Thoracic Curve, Not Fused)

Group 2 consisted of one male and 14 females. The mean age was 16.4 ± 4.0 years (range: 11 to 28 years). Six cases were Risser 5 and three, Risser 4 + . Fusion extended to T7 in four cases, T6 in five cases, T5 in five cases, and one case to T4. The mean follow-up was 36.3 ± 19.6 months (range: 24 to 89 months).

Correction of Curves

The mean preoperative PTC Cobb was 41.0 ± 2.3 degrees (range: 37.0 to 49.0 degrees). As it was not the intention to fuse these curves, fulcrum-bending radiographs were not routinely performed but were available in five patients, showing a mean of 29.4 ± 6.4 degrees. Spontaneous correction was found postoperatively with a mean of 30.6 ± 6.5 degrees (range: 22.0 to 40.0 degrees). At the end of the follow-up, the mean spontaneous correction remained unchanged, with a mean of 30.6 ± 5.1 degrees (range: 24.4 to 42.6 degrees); the mean correction was 28.9%. The improvement in the curve was highly statistically significant ($p = 0.001$).

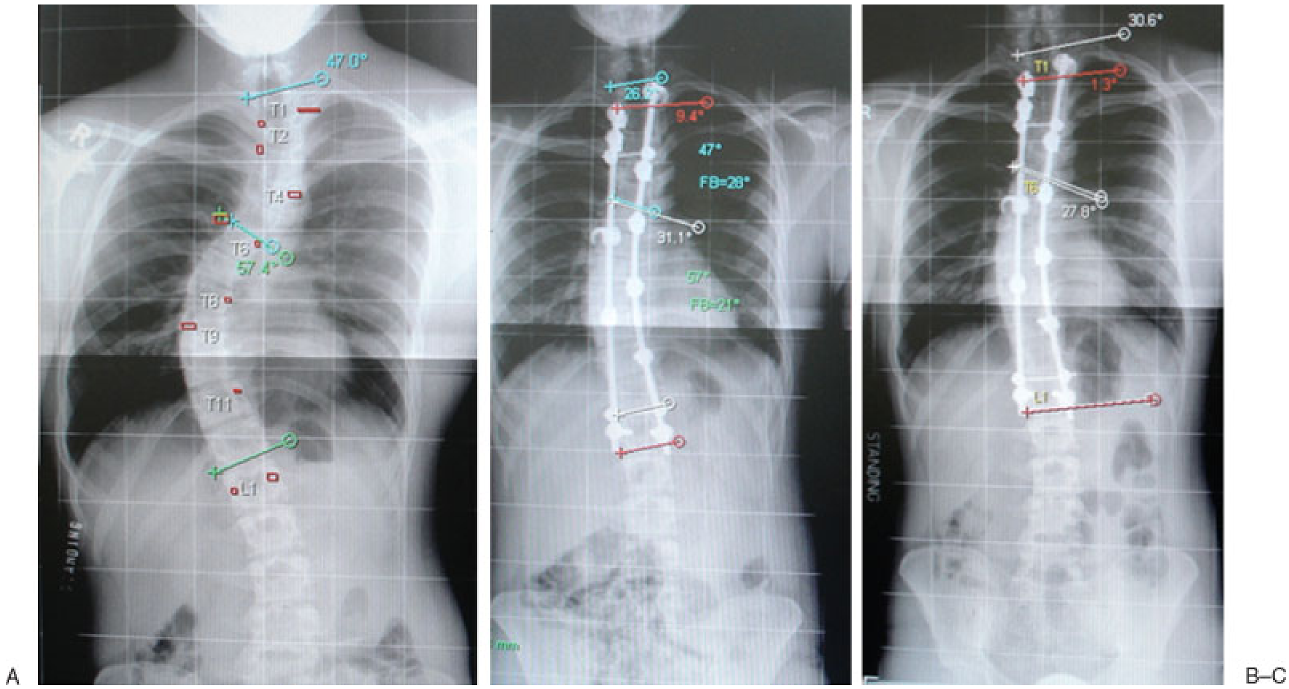


Figure 1 A 17-year-old male with adolescent idiopathic scoliosis. (A) A 47-degree proximal thoracic curve (PTC) that extended from T1 to T5 with a 57.4-degree main thoracic curve (MTC) from T6 to T12. (B) Following fusion of both curves, the shoulder height (SHD) was 7.7 mm, with the left side higher than the right. Postoperatively, PTC was corrected to 26 degrees and the MTC to 31 degrees. The SHD was increased to 12 mm with the left side higher than the right. (C) At 2-year follow-up, the PTC and the MTC were 30.6 and 27.8 degrees, respectively. The final SHD was 21.3 mm, with the left side higher than the right.

Radiographic Shoulder Parameters

All the radiographic shoulder parameters deteriorated in the immediate postoperative period and only partially recovered at the last follow-up (►**Tables 1**, **2**, and **3**; ►**Fig. 2**). The preoperative and last follow-up shoulder balance is illustrated in ►**Table 4**. Eight of 12 patients had right shoulder higher initially, and only three at the final follow-up. Overall, two patients (13.3%) improved two grades, one patient (6.7%)

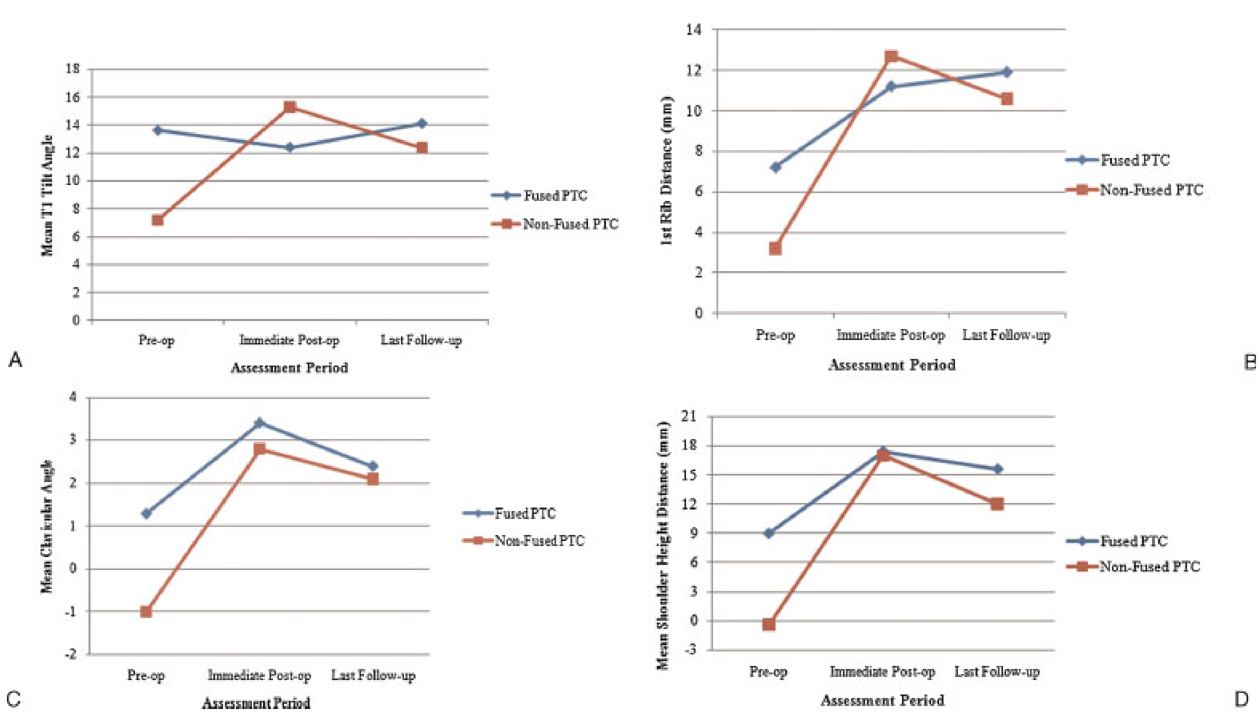


Figure 2 (A–D) Graphical illustrations demonstrating the change in various radiographic shoulder parameters at preoperative, immediate postoperative, and last follow-up intervals. PTC, proximal thoracic curve.

Table 4 Distribution of Shoulder Balance in Both Groups

	Group 1 PTC Fused		Group 2 PTC Not Fused	
	Preoperative	Last Follow-Up	Preoperative	Last Follow-Up
Balanced	7 (46.6%)	3 (20%)	9 (60%)	6 (40%)
Minimal	6 (40%)	6 (40%)	4 (26.6%)	5 (33.3%)
Moderate	1 (6.6%)	5 (33.3%)	2 (13.3%)	1 (6.6%)
Significant	1 (6.6%)	1 (6.6%)	0 (0%)	3 (20%)
Total	15 (100%)	15 (100%)	15 (100%)	15 (100%)

Values are expressed as the number of cases (%).

improved one grade, five patients (33.3%) showed no change, two declined three grades (13.3%), two declined two grades (13.3%), and three patients (20%) declined one grade.

We analyzed the cases with increased SHD at the end of follow-up (seven cases). The initial mean PTC was 43 ± 4.4 degrees, corrected to 28.7 ± 5.5 degrees in the immediate postoperative period and 30 ± 3.5 degrees at the end of the follow-up. Both results showed high significance ($p = 0.00$). The mean MTC was 60 ± 7.8 degrees, the fulcrum bending was 22.9 ± 7.1 degrees. The postoperative correction was 23.68 ± 7.74 degrees, compared with 28.02 ± 5.68 degrees at the end of the follow-up. No statistically significant difference was found between the fulcrum bending and the postoperative correction (i.e., no significant overcorrection beyond the curve flexibility, $p = 0.203$; ►**Fig. 3**).

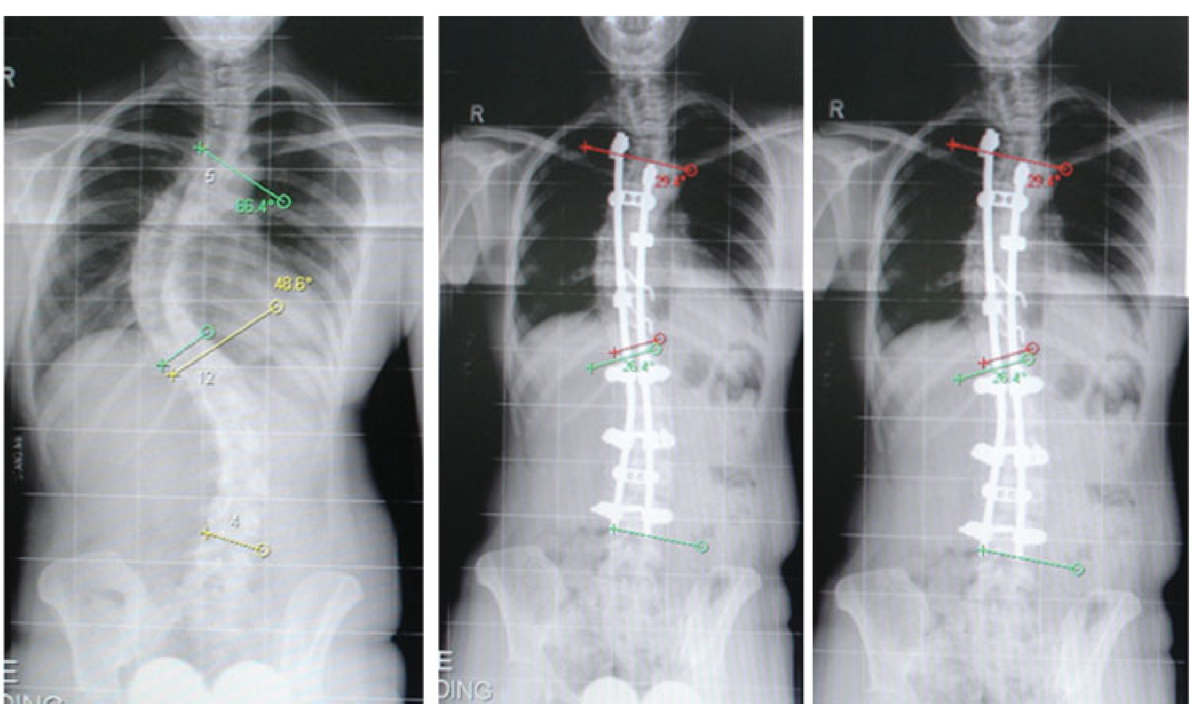
Factors Affecting Spontaneous PTC Correction

We found the only factor predictive of spontaneous PTC correction is preoperative PTC with proportional correlations ($p = 0.008$). Other factors such as age, preoperative MTC, preoperative AVT, and follow-up period were found to be nonsignificant factors in predicting correction. This finding reinforces the authors' indication for fusion of the PTC based on magnitude of the curve only.

Group Comparisons

As shown in ►**Table 3**, there is a statistically significant difference between both groups with regards to the preoperative PTC, and three radiographic parameters (T1 tilt, clavicular angle, first-rib difference). The preoperative SHD showed a trend toward significance ($p = 0.067$). Alternatively, apart

A



B–C

Figure 3 A 26-year-old female with adolescent idiopathic scoliosis. (A) A 41.1-degree proximal thoracic curve (PTC) that extended from T1 to T6 with a 66.4-degree main thoracic curve (MTC) from T5 to T11. The preoperative SHD was 0 mm. (B) Postoperatively, after selective fusion of the MTC, the PTC was spontaneously corrected to 27.1 degrees and the MTC to 29.5 degrees. The SHD was increased to 18.8 mm with the left side higher than the right. (C) At 34 months' follow-up, the PTC and the MTC were 30.6 and 29.9 degrees, respectively. The final SHD was 13.3 mm, with the left side higher than the right.

from AVT, all of the postoperative and final follow-up values were statistically insignificant ($p > 0.05$).

Last Follow-up SHD and Shoulder Radiological Parameters
In both groups, the final clavicular angle was positively, significantly correlated with the latest follow-up of the SHD ($p < 0.05$). Other parameters were not found to be statistically significant ($p > 0.05$).

Complications
We did not faced any neurological or vascular complications related to pedicle screw placement or instrumentation in all of our cases, and solid fusion was achieved in all cases. One patient from group 1 and another patient from group 2 had truncal decompensation after surgery, which failed to improve with follow-up.

Discussion

The decision to fuse a curve depends on whether, if left unfused, the curve has an ability to spontaneously correct. Parameters that are used include those that assess whether a curve is structural in nature and those that reflect its flexibility. For the former, curve magnitude and apical rotation are commonly used. Additional parameters that are used for the PTC include T1 tilt and shoulder and clavicular height. With regards to flexibility of the PTC, there is to date no demonstrated and universally accepted method of assessment. This has resulted in an inability to predict the spontaneous correction of the PTC if only the MTC is fused. If this can be predicted, then it should be possible to selectively fuse the MTC of some double thoracic curves, thus reducing the magnitude of surgery.

In a seminal article on the selection of fusion levels in idiopathic scoliosis, King et al[1] classified the double thoracic curve as a King V pattern, which was based on a positive T1 tilt and the rigidity of the PTC. Extension of fusion of both curves was recommended for this curve pattern if the PTC was greater than the side bending of MTC. This recommendation was presumably based on assessing whether the PTC could compensate for a corrected MTC based on prediction by the supine-bending radiograph. On the other hand, Lee et al[8] noted spontaneous correction of the nonfused PTC in the majority of patients after instrumentation and fusion of the MTC.

Lenke et al[2] recommended extension of fusion for structural PTC. They considered a structural PTC as the one with a minimum residual coronal curve on side-bending radiographs of at least 25 degrees (with or without a positive first thoracic tilt) and/or kyphosis (from the second to the fifth thoracic level) of at least $+20$ degrees. Subsequently in 2000, Suk et al[3] recommended that a PTC more than 25 degrees or an elevated left shoulder should be considered a double thoracic curve pattern and should be treated by fusing both the proximal and the distal curves when using pedicle screws. Moreover, they concluded that when the left shoulder is lower before surgery, fusion is optional, but the curve is best left nonfused when the discrepancy exceeds 12 mm.

Further work by Kuklo et al[7] showed that spontaneous PTC correction consistently occurs after instrumented correction of the MTC. Furthermore, they demonstrated slightly better correction following anterior spinal fusion of the MTC. Recently, Ilharreborde et al[16] proposed a strategy selecting the proximal extent of fusion depending on the rigidity of the PTC, T1 tilt, and shoulder balance.

At our institution, and due to the lack of a reliable method of assessing PTC flexibility, we have used relatively simple criteria for deciding when it should be fused, that is, the curve magnitude alone. Curves under 45 degrees are not fused, and those over 45 degrees are fused to T2. This study is an assessment of the validity of this simple rule.

PTCs identified in this study were based on a combination of the following: the presence of an apical rotation, T1 tilt, shoulder imbalance, and a curve magnitude of 35 degrees or more. Curves under 35 degrees may not have all the structural features and were therefore excluded from this study. Our observation was that the mean sagittal profile in our two groups was below 20 degrees. As such, we considered a sagittal profile of 20 degrees or more as not necessary for defining criteria of structurality of the PTC. Although some authors found no correlations between T1 tilt and a structural PTC, all our cases had a positive T1 tilt.

Lee et al[8] recognized that the PTC was often more rigid than the MTC and noted the difficulty in determining whether the proximal curve should be included in the fusion. They also noted spontaneous correction of the nonfused PTC in the majority of patients after instrumentation and fusion of the MTC. Cil et al[4] had the same observation. Occasionally, slight progression ($\sim$5 degrees) of the PTC after instrumentation and fusion of the MTC was also noted. Alternatively, Kuklo and colleagues[7] did not note any progression of the PTC after surgery. Moreover, Cil et al[4] noticed the same observation, explained by the tendency of spontaneous PTC correction as it to follows the correction of the MTC. Lee and associates[8] explained the spontaneous PTC correction after a selective MTC fusion by "tightening reflex" of the head control. However, it is reasonable to consider that spontaneous nonfused PTC correction is somewhat parallel to the spontaneous lumbar curve correction as the curves try to equal the MTC correction to "balance the spine." In our series, the spontaneous correction in the nonfusion group remains essentially unchanged and was maintained over time. Our average spontaneous correction was 28.3%, which is similar to that reported by Kuklo et al.[7]

Similar to other authors, we observed relative rigidity of the PTC in the fusion group. It should also be noted that our mean preoperative PTC was greater than the series of Kuklo et al,[7] Suk et al,[3] and Cil et al[4] Conversely, it is our observation that the only predictive factor of spontaneous PTC is preoperative PTC magnitude.

Globally, there was overall improvement in shoulder balance in both fused and unfused PTCs in different series.[3,7] In our study, all of the shoulder parameters, on average, had consistently slightly deteriorated in the nonfusion group but improved with follow-up, whereas, as expected, the shoulder parameters remained essentially unchanged after fusion of both MTC and PTC. There was no significant difference in terms of shoulder balance between the two groups at the last follow-up, suggesting that our criteria for surgery was valid. Moreover, the mean RSH at the end of follow-up was <2 cm (minimal imbalance) in both groups compared with a mean of <10 mm (balanced in both groups) initially. We are unable to explain, radiographically, why the shoulder imbalance did not significantly improve despite of the good PTC correction in the fusion group. However, according to Kuklo et al,[17] who assessed fused and unfused PTC in AIS patients with curves greater than 20 degrees (mean: 32 degrees; range: 20 to 78 degrees), the authors noted that clinically there was no statistically significant difference in shoulder balance between groups.

Our correction of MTC was slightly greater than that predicted by the fulcrum flexibility in both groups. This is expected based on the use of hybrid and screw constructs.[18–20] As such, and as according to Winter,[6] overcorrection of the MTC is not the cause of any deterioration of the shoulder parameters.

No significant correlations were found between the preoperative shoulder parameters and follow-up SHD. Therefore, all preoperative radiographic shoulder parameters, including T1 tilt, are not predictive of postoperative shoulder imbalance. However, we found that the final clavicular angle is significantly correlated with the final SHD. In the series of Kuklo et al,[7] the clavicular angle provided the best radiographic prediction of postoperative shoulder balance. We therefore questioned the reliability of the other radiographic shoulder parameters in assessing the shoulder balance. Moreover, we feel that radiographic parameters without clinical implications may not be enough for assessing the shoulder balance, and this is probably one of the limitations of this study.

Although the radiographic shoulder outcome showed residual imbalance in both groups, these were not significantly different. They support our original concept of determination of fusion of PTC based on curve magnitude alone and that PTC of between 35 and 45 degrees need not be fused. However, this study is not able to address the issue of why the shoulders remain imbalanced after surgery and whether there is a better method of improving shoulder balance.

The strength of this article is that it studied, with a minimum of 2 years' follow-up, only large PTCs greater than 35 degrees, which could be more representative of the patient population than previous studies addressing PTCs. Our study further entailed a unique strategy for managing such curves. Moreover, some important observations entailing the recognition of the PTCs have been included.

On the other hand, there are several limitations associated with this study. Besides the retrospective nature, it also analyzed the radiographic parameters without additional clinical implications or patient satisfaction. It should be noted, however, that a clinical grading for the unbalanced shoulders has not been clearly defined and may be difficult to assess. We believe that the issue of fusion versus nonfusion in the PTC remains unsolved and should be verified with a randomized, prospective study.

Conclusions

Spontaneous correction of PTC after fusion of the MTC occurs in structural curves greater than 35 degrees and less than 45 degrees, and this correction is maintained over time. Despite that correction, radiographic shoulder parameters are expected to slightly deteriorate. The nonfusion strategy may be appropriate for PTCs between 35 and 45 degrees. The radiographic shoulder parameters may remain essentially unchanged after fusion of both the MTC and PTC. Preoperative radiographic shoulder parameters are not predictive of postoperative shoulder imbalance.

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