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Clinical Research

Is the Combination of Convex Compression for the Proximal Thoracic Curve and Concave Distraction for the Main Thoracic Curve Using Separate-rod Derotation Effective for Correcting Shoulder Balance and Thoracic Kyphosis?

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Abstract

Background Posterior correction of the proximal thoracic curve in patients with adolescent idiopathic scoliosis has been recommended to achieve shoulder balance. However, finding a good surgical method is challenging because of the small pedicle diameters on the concave side of the proximal thoracic curve. If the shoulder height can be corrected using screws on the convex side, this would appear to be a more feasible approach.

Questions/purposes In patients with adolescent idiopathic scoliosis, we asked: (1) Is convex compression with separate-rod derotation effective for correcting the proximal thoracic curve, shoulder balance, and thoracic kyphosis? (2) Which vertebrum is most appropriate to serve as the uppermost-instrumented vertebra? (3) Is correction of the proximal thoracic curve related to the postoperative shoulder balance?

Methods Between 2015 and 2017, we treated 672 patients with scoliosis. Of those, we considered patients with elevated left shoulder, Lenke Type 2 or 4, or King Type V idiopathic scoliosis as potentially eligible. Based on that, 17% (111 of 672) were eligible; 5% (6 of 111) were excluded because of other previous operations and left-side

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Ethical approval for this study was obtained from the institutional review board of Asan Medical Center (IRB No. 2019-0086).
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main thoracic curve, 22% (24 of 111) were excluded because they did not undergo surgery for the proximal thoracic curve with only pedicle screws, 21% (23 of 111) were excluded because the proximal thoracic curve was not corrected by convex compression and separate rod derotation, and another 3% (3 of 111) were lost before the minimum study follow-up of 2 years, leaving 50% (55 of 111) for analysis. During the study period, we generally chose T2 as the uppermost level instrumented when the apex was above T4, or T3 when the apex was T5. Apart from the uppermost-instrumented level, the groups did not differ in measurable ways such as age, sex, Cobb angles of proximal and main thoracic curves, and T1 tilt. However, shoulder balance was better in the T3 group preoperatively. The median (range) age at the time of surgery was 15 years (12 to 19 years). The median follow-up duration was 26 months (24 to 52 months). Whole-spine standing posteroanterior and lateral views were used to evaluate the improvement of radiologic parameters at the most recent follow-up and to compare the radiologic parameters between the uppermost-instrumented T2 (37 patients) and T3 (18 patients) vertebra groups. Finally, we analyzed radiologic factors related to shoulder balance, defined as the difference between the horizontal lines passing both superolateral tips of the clavicles (right-shoulder-up was positive), at the most recent follow-up.

Results Convex compression with separate-rod derotation effectively corrected the proximal thoracic curve (41° ± 11° versus 17° ± 10°, mean difference 25° [95% CI 22° to 27°]; $p < 0.001$), and the most recent shoulder balance changed to right-shoulder-down compared with preoperative right-shoulder-up (8 ± 11 mm versus -8 ± 10 mm, mean difference 16 mm [95% CI 12 to 19]; $p < 0.001$). Proximal thoracic kyphosis decreased (13° ± 7° versus 11° ± 6°, mean difference 2° [95% CI 0° to 3°]; p = 0.02), while mid-thoracic kyphosis increased (12° ± 8° versus 18° ± 6°, mean difference -7° [95% CI -9° to -4°]; $p < 0.001$). Preoperative radiographic parameters did not differ between the groups, except for shoulder balance, which tended to be more right-shoulder-up in the T2 group (11 ± 10 mm versus 1 ± 11 mm, mean difference 10 mm [95% CI 4 to 16]; p = 0.002). At the most recent follow-up, the correction proportion of the proximal thoracic curve was better in the T2 group than the T3 group (67% ± 10% versus 49% ± 22%, mean difference 19% [95% CI 8% to 30%]; $p < 0.001$). In the T2 group, T1 tilt (6° ± 4° versus 6° ± 4°, mean difference 1° [95% CI 0° to 2°]; p = 0.045) and shoulder balance (-14 ± 11 mm versus -7 ± 9 mm, mean difference -7 mm [95% CI -11 to -3]; p = 0.002) at the most recent follow-up improved compared with those at the first erect radiograph. The most recent shoulder balance was correlated with the correction proportion of the proximal thoracic curve (r = 0.29 [95% CI 0.02 to 0.34]; p = 0.03) and change in T1 tilt (r = 0.35 [95% CI 0.20 to 1.31]; p = 0.009).

Conclusion Using the combination of convex compression and concave distraction with separate-rod derotation is an effective method to correct proximal and main thoracic curves, with reliable achievement of postoperative thoracic kyphosis and shoulder balance. T2 was a more appropriate uppermost-instrumented vertebra than T3, providing better correction of the proximal thoracic curve and T1 tilt. Additionally, spontaneous improvement in T1 tilt and shoulder balance is expected with upper-instrumented T2 vertebrae. Preoperatively, surgeons should evaluate shoulder balance because right-shoulder-down can occur after surgery in patients with a proximal thoracic curve.

Level of Evidence Level III, therapeutic study.

Introduction

Posterior spinal instrumentation and fusion with pedicle screws using rod derotation and distraction or compression maneuvers have been performed predominantly in patients with adolescent idiopathic scoliosis. A balanced shoulder and trunk with three-dimensional correction of scoliosis is another treatment goal. To correct the shoulder's balance, correction of the proximal thoracic curve has been recommended when it is structural [4, 10, 17, 29, 30]. Spontaneous correction of the proximal thoracic curve, on the other hand, has been recommended when the curve is not structural [11, 14, 21]. There is no consensus about the appropriate upper-instrumented vertebra in patients undergoing surgical treatment [9, 17]. The differences in findings from these studies may have been a function of the age of the patient or flexibility of the curve, but we believe one overriding factor is the lack of a reliable surgical method to correct the proximal thoracic curve. This curve is short and rigid, and the pedicle diameter is small on the concave side [7, 12, 15]. Most importantly, rod derotation should be in the opposite direction to that of the main thoracic curve to create thoracic kyphosis [4, 7, 28, 29].

To correct the main thoracic curve and thoracolumbar and lumbar curve, single-rod derotation changes a coronal deformity that transforms into thoracic kyphosis and lumbar lordosis. If this rod is elongated to the proximal thoracic curve, proximal thoracic lordosis would develop, similar to what occurs in the thoracolumbar and lumbar curves. To avoid this, the use of a temporary distraction rod, separate-rod derotation, or direct vertebral rotation has been reported [4, 28, 29]. However, proximal thoracic lordosis may occur if a long rod on the concave side of the main thoracic curve is derotated with the proximal thoracic curve. Separate rods on both sides are not recommended because of the potential for instability. If convex compression is comparable to distractive correction on the concave side, the proximal thoracic curve could be corrected using compressive correction on the convex side, connected to the concave side of the main thoracic curve. Then, a long rod could be applied on the opposite side to increase mechanical stability. The reported advantages of convex compressive correction include low neurologic and vascular risks as well as a correction rate comparable with that of distractive correction [3, 32]. If combined distractive and compressive correction of the main and proximal thoracic curves with a separate rod connection preserves thoracic kyphosis, the effect of proximal thoracic curve correction on shoulder balance and the appropriate uppermost-instrumented vertebra could be decided using this effective and uniform procedure.

In patients with adolescent idiopathic scoliosis, we therefore asked: (1) Is convex compression with separate-rod derotation effective for correcting the proximal thoracic curve, shoulder balance, and thoracic kyphosis? (2) Which vertebrum is most appropriate to serve as the uppermost-instrumented vertebra? (3) Is correction of the proximal thoracic curve related to the postoperative shoulder balance?

Patients and Methods

Study Design and Setting

Convex compression with separate-rod derotation to correct the proximal thoracic curve has been used in our center since 2015. A single senior scoliosis surgeon (CSL) with 30 years of experience performed all the operations.

Participants

We reviewed the data of 672 patients who underwent posterior correction and fusion for scoliosis between 2015 and 2017. The general indications for proximal thoracic curve correction were elevated left shoulder, structural proximal thoracic curve, or positive T1 tilt [26]. The inclusion criteria were elevated left shoulder, Lenke Type 2 or Type 4 curves or King Type V idiopathic scoliosis [20], and age between 12 and 18 years at the time of the operation. The exclusion criteria were a main thoracic curve on

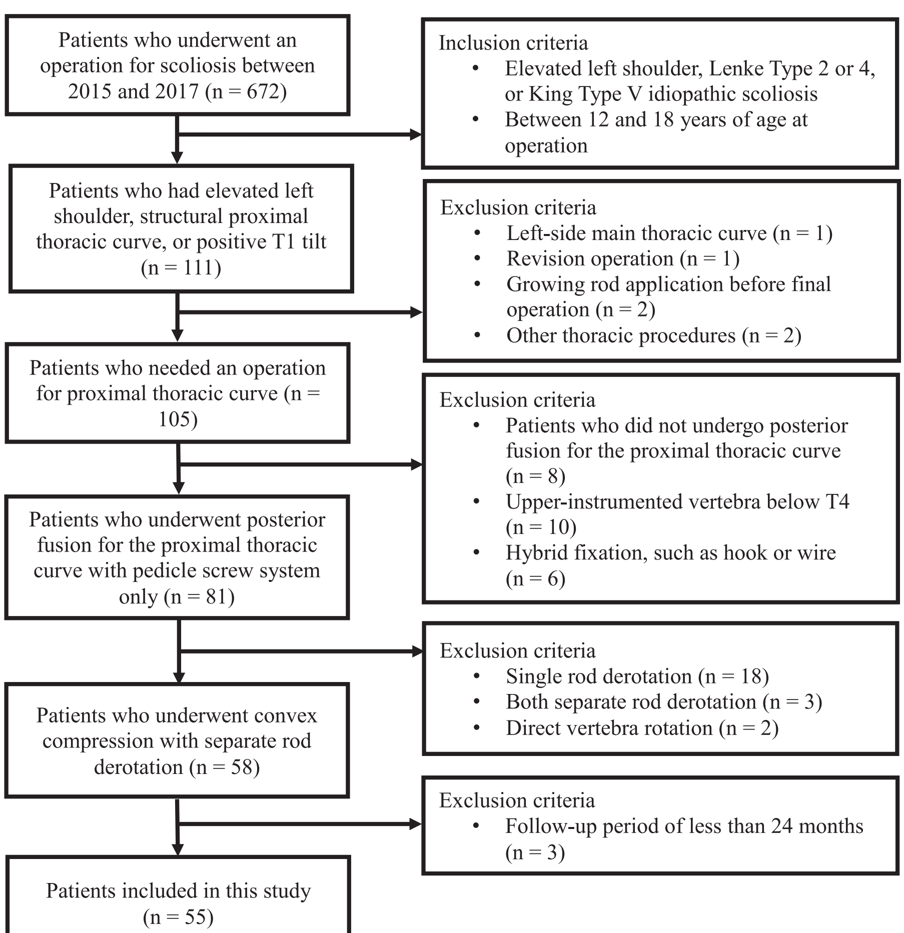

Fig. 1 Flow diagram of the inclusion and exclusion process in the current study.

the left side, a revision procedure, a growing-rod insertion before the final operation, other thoracic procedures, patient did not undergo posterior fusion for a proximal thoracic curve, upper-instrumented vertebra below T4, hybrid fixation such as a wire or hook, single-rod derotation, separate-rod derotation, direct vertebra rotation, and follow-up period of less than 24 months (Fig. 1).

After applying prespecified exclusion criteria as described, 55 patients who underwent convex compression with separate-rod derotation to correct a proximal thoracic curve were included. Nine patients were boys and 46 were girls. The median (range) age at the time of operation was 15 years (12 to 19 years). The median follow-up duration was 26 months (24 to 52 months). The average operation time was 220 ± 44 minutes, and the average blood loss was 461 ± 254 cc. Seven patients had Lenke Type 4 curves and 45 patients had Lenke Type 2 curves. King type V scoliosis was seen in 46 patients. The lowermost-instrumented vertebra was T12 in one patient, L1 in nine, L2 in 23, and L3 in 22. There were no complications, including infections, skin problems related to the implants, metal failure, neurologic complications, proximal junctional kyphosis, adding-on, or decompensation.

Whole-spine standing posteroanterior and lateral views, prone views, and supine passive side-bending views were obtained preoperatively. Patients were followed at 5 days (first erect), 1 month, 6 months, 12 months, and annually after surgery with whole-spine standing posteroanterior and lateral views.

Surgical Procedure

Pedicle screws were inserted using the posteroanterior image-intensifier rotation technique [19]. The screw was not inserted at the junction level between the main and proximal thoracic curves to position a rod connector. The rod was contoured according to the concave side of the main thoracic curve or the convex side of the thoracolumbar or lumbar curve. A short rod was slightly overcontoured along the convex side of the proximal thoracic curve, with consideration of kyphosis and compression after correction. A rod connector joined the two rods. Derotation of the long rod in the counter-clockwise direction was performed for thoracic kyphosis and lumbar lordosis. The rod inserted on the convex side of the proximal thoracic curve was rotated clockwise to create kyphosis. Distraction or compression was performed along the main thoracic, thoracolumbar, or lumbar curve. Compression on the convex side of the proximal thoracic curve was performed from the rod connector to the uppermost-instrumented vertebra. Another rod spanning the fusion length was contoured according to the sagittal alignment and inserted into the right side (Fig. 2). Then, decortication and bone grafting were performed.

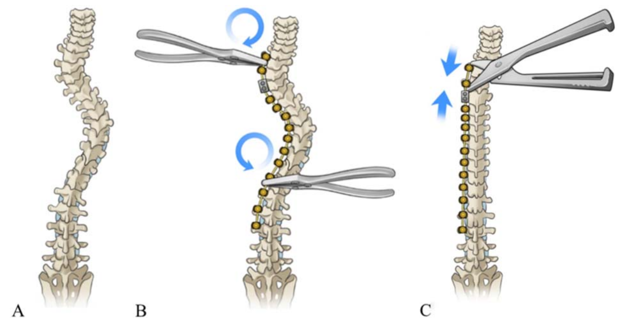

Fig. 2 A-C (**A**) This illustration shows the surgical technique of convex compression with separate-rod derotation to correct a proximal thoracic curve. After pedicle screws were inserted, two separate rods for the proximal and main thoracic curves were connected with a rod connector and inserted into the left side. (**B**) Counter-clockwise derotation at the main thoracic curve and clockwise derotation at the proximal thoracic curve were performed. The main thoracic, thoracolumbar, and lumbar curves were corrected with distraction and compression. (**C**) Additional correction of the proximal thoracic curve was performed using convex compression.

When it was difficult to connect the rods because of a severe proximal thoracic curve, a temporary short rod was used on the concave side and distraction was applied to decrease the proximal thoracic curve [28]. After the same procedure was performed, the temporary rod was changed to a rod spanning the fusion length.

During the study period, we generally chose T2 as the uppermost-instrumented level when the apex of the proximal thoracic curve was above T4, or T3 when the apex was T5. The T2 group included 37 patients, and 18 patients were in the T3 group. In the T2 group, five patients were boys and 32 were girls. In T3 group, four patients were boys and 14 were girls ($p = 0.42$). The median (range) age at the time of operation was 15 years (12 to 19 years) for the T2 group and 15 years (13 to 19 years) for the T3 group ($p = 0.20$). The median follow-up durations were 26 months (24 to 38 months) for the T2 group and 29 months (24 to 52 months) for the T3 group ($p = 0.10$). There was no difference in the number of pedicle screws fixed on the separate rod for the proximal thoracic curve between the T2 and T3 groups (2 ± 0 versus 2 ± 1, mean difference 0 [95% CI -1 to 0]; $p = 0.06$). In the T2 group, the lowermost-instrumented vertebra was T12 in one patient, L1 in six, L2 in 19, and L3 in 11, and in the T3, the lowermost-instrumented vetebra was L1 in three patients, L2 in four, and L3 in 11 ($p = 0.93$).

Primary and Secondary Study Outcomes

Our primary study goals were the assessment of correction of the proximal thoracic curve, shoulder balance, and thoracic kyphosis after convex compression with separate-rod derotation. To achieve this, we evaluated radiologic parameters on the preoperative, first erect, and most recent whole-spine radiographs. The magnitude of curve correction was evaluated using the Cobb angles of each curve, measured on whole-spine standing posteroanterior views. The correction proportion was calculated as follows: (preoperative Cobb angle postoperative Cobb angle)/preoperative Cobb angle × 100%. Shoulder balance was measured as the difference between the horizontal lines passing both superolateral tips of the clavicles (right-shoulder-up was positive). Proximal thoracic kyphosis (T2 to T5), mid-thoracic kyphosis (T5 to T12), thoracolumbar lordosis (T10 to L2), and lumbar lordosis (T12 to S1) were measured on whole-spine standing lateral views. Additionally, we evaluated (1) T1 tilt, defined as the angle between the T1 upper endplate and a horizontal line (left-side-up was positive), and (2) trunk shift, assessed as the distance between the C7 plumb line and the central sacral vertical line (right-side deviation was positive). The intraclass correlation coefficient was 0.992 (0.987 to 0.996) for coronal measurements and 0.986 (0.976 to 0.992) for sagittal measurements.

Our secondary study goals were to decide the most appropriate uppermost-instrumented vertebra and the effect of correction of the proximal thoracic curve on the shoulder balance. Patients with uppermost-instrumented T2 and T3 vertebrae were compared with each other to evaluate the effect of uppermost-instrumented vertebra on the postoperative thoracic kyphosis, T1 tilt, shoulder balance, and trunk shift. Postoperative changes in shoulder balance may be affected by not only immediate correction but also by the amount of change in the curve, T1 tilt, shoulder balance, or trunk shift after operation. The increase or decrease in T1 tilt, shoulder balance, and trunk shift were calculated at the first erect radiograph and compared with the preoperative value. Cobb angle ratios between the proximal and main thoracic curves at the first erect radiograph were calculated. We investigated potential correlations between shoulder balance at the most recent follow-up and radiographic parameters at the first erect radiograph.

Ethical Approval

Ethical approval for this single-center, retrospecive study was obtained from the institutional review board of Asan Medical Center (IRB No. 2019-0086).

Statistical Analysis

The statistical analysis was performed using SPSS Version 22.0 (IBM Corp). We evaluated improvement in parameters using a paired t-test. The uppermost-instrumented T2 and T3 vertebrae groups were compared using an independent t-test and chi-square test. We conducted a correlation analysis using the Pearson correlation coefficient to identify any association between the most recent shoulder balance and radiographic parameters at the first erect radiograph. Two orthopaedic surgeons (KBP, SP) performed the radiographic measurements. The intraclass correlation coefficient was used to define interobserver reliability. The level of significance was set at $p < 0.05$.

Results

Improvement of Radiologic Parameters

Comparing preoperative to most recent follow-up, we found that convex compression with separate-rod derotation effectively corrected the proximal thoracic curve (41° ± 11° versus 17° ± 10°, mean difference 25° [95% CI 22° to 27°]; p < 0.001). The most recent shoulder balance changed to right-shoulder-down compared with preoperative right-shoulder-up (8 ± 11 mm versus -8 ± 10 mm, mean difference 16 mm [95% CI 12 to 19]; p < 0.001). Proximal thoracic kyphosis decreased (13° ± 7° versus 11° ± 6°, mean difference 2° [95% CI 0° to 3°]; p = 0.02), but midthoracic kyphosis

Table 1. Changes in radiographic parameters

Parameter	Preoperative	Most recent follow-up	Mean difference (95% CI)	p value
Proximal thoracic curve in °	41 ± 11	17 ± 10	25 (22-27)	< 0.001
Main thoracic curve in °	63 ± 13	14 ± 7	49 (46-51)	< 0.001
Thoracolumbar/lumbar curve in °	31 ± 8	6 ± 4	25 (23-27)	< 0.001
T1 tilt in °	5 ± 5	7 ± 6	-2 (-4 to -1)	< 0.001
Shoulder balance in mm	8 ± 11	-8 ± 10	16 (12-19)	< 0.001
Trunk shift in mm	3 ± 12	-3 ± 9	7 (4-10)	< 0.001
Proximal thoracic kyphosis in °	13 ± 7	11 ± 6	2 (0-3)	0.02
Middle thoracic kyphosis in °	12 ± 8	18 ± 6	-7 (-9 to -4)	< 0.001
Thoracolumbar lordosis in °	-1 ± 9	-4 ± 8	3 (0-6)	0.051
Lumbar lordosis in °	-52 ± 11	-55 ± 20	3 (-2 to 8)	0.2

Data are presented as mean ± SD.

increased (12° ± 8° versus 18° ± 6°, mean difference -7° [95% CI -9° to -4°]; p < 0.001) (Table 1).

Comparison of Radiologic Parameters Between Uppermost-instrumented T2 and T3 Vertebrae

Preoperative radiographic parameters did not differ between the groups except for shoulder balance, which tended to be right-shoulder-up in the T2 group (11 ± 10 mm versus 1 ± 11 mm, mean difference 10 mm [95% CI 4 to 16]; p = 0.002).

At the most recent follow-up, the correction proportion of the proximal thoracic curve was better for patients in whom the uppermost level was T2 than for those in whom it was T3 (67% ± 10% versus 49% ± 22%, mean difference 19% [95% CI 8% to 30%]; p < 0.001). There was no difference in the shoulder balance (-7 ± 9 mm versus -9 ± 9 mm, mean difference 1 [95% CI -4 to 7]; p = 0.65). Proximal thoracic kyphosis was higher in the T3 group (10° ± 4° versus 14° ± 9°, mean difference -4° [95% CI -9° to 0°]; p = 0.02); however, there was no difference in the main thoracic kyphosis (18° ± 5° versus 18° ± 7°, mean difference 1° [95% CI -3° to 5°]; p = 0.73). T1 tilt was smaller in the T2 group (6° ± 4° versus 10° ± 8°, mean difference -5° [95% CI -9° to 0°]; p = 0.03) (Table 2).

In the T2 group at the most recent follow-up, T1 tilt (6° ± 4° versus 6° ± 4°, mean difference 1° [95% CI 0° to 2°]; p = 0.045) and shoulder balance (-14 ± 11 mm versus -7 ± 9 mm, mean difference -7 mm [95% CI -11 to -3]; p = 0.002) improved compared with those at the first erect. In the T3 group, these parameters did not change, but trunk shift deviated to the left (3 ± 13 mm versus -4 ± 10 mm, mean difference 7 mm [95% CI 0 to 13]; p = 0.048) (Fig. 3).

Factors Related to the Most Recent Shoulder Balance

Better shoulder balance at the most recent follow-up was correlated with increased correction proportion of the

Table 2. Comparison of radiographic parameters between the T2 and T3 groups

	Parameter	T2	T3	Mean difference (95% CI)	p value
Preoperative	Proximal thoracic curve in °	40 ± 9	44 ± 15	-5 (-12 to 3)	0.15
	Main thoracic curve in °	61 ± 12	65 ± 14	-3 (-11 to 4)	0.4
	T1 tilt in °	4 ± 6	6 ± 4	-2 (-5 to 1)	0.11
	Shoulder balance in mm	11 ± 10	1 ± 11	10 (4 to 16)	0.002
	Trunk shift, in mm	4 ± 11	3 ± 13	0 (-7 to 7)	0.91
	Proximal thoracic kyphosis in °	12 ± 6	14 ± 7	-2 (-6 to 1)	0.21
	Main thoracic kyphosis in °	11 ± 8	12 ± 9	-1 (-6 to 3)	0.65
First erect	Proximal thoracic curve in °	12 ± 5	21 ± 12	-9 (-14 to -3)	< 0.001
	Correction proportion, %	70 ± 11	55 ± 16	15 (7 to 24)	< 0.001
	Main thoracic curve in °	12 ± 7	14 ± 8	-2 (-6 to 2)	0.39
	Correction proportion, %	80 ± 7	79 ± 9	2 (-3 to 6)	0.5
	T1 tilt in °	6 ± 4	10 ± 7	-4 (-7 to 0)	0.05
	Shoulder balance in mm	-14 ± 11	-3 ± 15	-11 (-18 to -4)	0.007
	Trunk shift in mm	2 ± 17	3 ± 13	-1 (-10 to 8)	0.82
	Proximal thoracic kyphosis in °	9 ± 3	12 ± 7	-3 (-7 to 0)	0.01
	Main thoracic kyphosis in °	17 ± 5	15 ± 8	2 (-2 to 6)	0.26
Most recent follow-up	Proximal thoracic curve in °	13 ± 4	25 ± 13	-12 (-19 to -5)	< 0.001
	Correction proportion, %	67 ± 10	49 ± 22	19 (8 to 30)	< 0.001
	Main thoracic curve in °	12 ± 6	19 ± 7	-7 (-11 to -4)	0.001
	Correction proportion, %	81 ± 7	73 ± 10	9 (3 to 14)	0.003
	T1 tilt in °	6 ± 4	10 ± 8	-5 (-9 to 0)	0.03
	Shoulder balance in mm	-7 ± 9	-9 ± 9	1 (-4 to 7)	0.65
	Trunk shift in mm	-3 ± 9	-4 ± 10	1 (-4 to 6)	0.76
	Proximal thoracic kyphosis in °	10 ± 4	14 ± 9	-4 (-9 to 0)	0.02
	Main thoracic kyphosis in °	18 ± 5	18 ± 7	1 (-3 to 5)	0.73

Data are presented as mean ± SD.

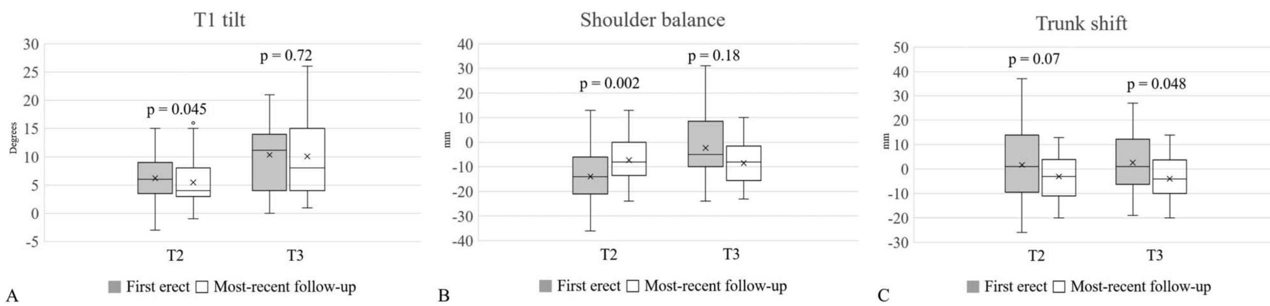

Fig. 3 A-C These graphs show changes in (**A**) T1 tilt, (**B**) shoulder balance, and (**C**) trunk shift between the first erect and most recent follow-up examination in the uppermost-instrumented T2 and T3 vertebrae groups. T1 tilt and shoulder balance spontaneously improved in the T2 group. However, these did not improve, and trunk shift deviated left in the T3 group. T1 tilt: degrees, left-side-up is positive; shoulder balance: mm, right-shoulder-up is positive; trunk shift: mm, right-side deviation is positive.

proximal thoracic curve (r = 0.29 [95% CI 0.02 to 0.34]; p = 0.03) and decreased T1 tilt (r = 0.35 [95% CI 0.20 to 1.31]; p = 0.009) (Table 3).

Discussion

Correction of the proximal thoracic curve has been emphasized because correcting the main thoracic curve without correcting the proximal thoracic curve can result in shoulder imbalance after surgery in patients whose proximal thorcic curves are structural. However, there are no reliable surgical techniques for the correction of structural proximal thoracic curves, and there is no consensus about the appropriate upper-instrumented vertebra [17, 28] because the proximal thoracic curve is short and rigid, and the pedicle diameter is small on the concave side [12, 15]. Furthermore, rod derotation should be in the opposite direction to that of the main thoracic curve to create thoracic kyphosis [4, 28]. This study demonstrated a mean 25° of correction of the proximal thoracic curve using convex-side compression, separate-rod derotation, and connection to the concave side of the main thoracic curve, with a single long rod on the opposite side for stability, and without postopertive shoulder imbalance or loss of thoracic kyphosis (Fig. 4). Furthermore, we found that T2 was a better uppermost-instrumented vertebrae than was T3 in terms of correcting the proximal thoracic curve and T1 tilt, as well as spontaneously improving the shoulder's balance by the most recent follow-up examination.

Limitations

Our study has several limitations. Because this was a retrospective study, there are concerns for selection, transfer, and assessment bias. In the T2 and T3 group, patients were not assigned randomly, but there were no differences in the preoperative parameters, except for

Table 3. Correlation coefficients between shoulder balance at the most recent follow-up and radiographic parameters at the first erect radiograph

Parameter	r (95% CI)	p value
Proximal thoracic curve	-0.23 (-0.51 to 0.05)	0.10
Correction proportion	0.29 (0.02 to 0.34)	0.03
Main thoracic curve	-0.24 (-0.65 to 0.04)	0.08
Correction proportion	0.24 (-0.03 to 0.57)	0.08
Ratio between the proximal and main thoracic curves	0.13 (-0.01 to 0.03)	0.36
T1 tilt	-0.14 (-0.71 to 0.22)	0.30
Change in T1 tilt	0.35 (0.20 to 1.31)	0.009
Shoulder balance	0.06 (-0.15 to 0.23)	0.66
Change in shoulder balance	0.03 (-0.11 to 0.14)	0.83
Trunk shift	0.24 (-0.02 to 0.29)	0.09
Change in trunk shift	-0.22 (-0.26 to 0.03)	0.12

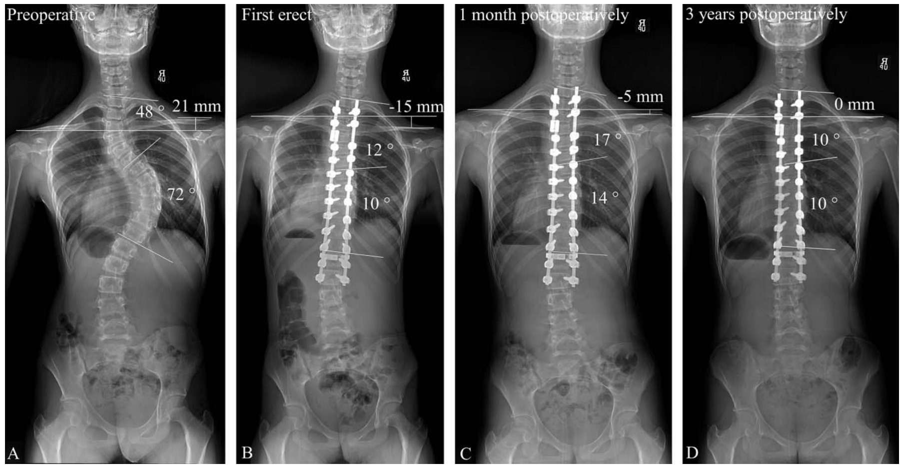

Fig. 4 A-D A 12-year-old girl underwent deformity correction and posterior fusion (T2 to L2) using convex compression with separate-rod derotation. (**A**) This preoperative image shows a proximal thoracic curve of 48° with right-shoulder-up of 21 mm. (**B**) At the first erect radiograph, the proximal thoracic curve was corrected to 12° with a correction percentage of 75%. There was a right-shoulder depression of 15 mm. (**C**) Shoulder balance was improved at 1 month postoperatively and (**D**) was level after 3 years of follow-up.

shoulder balance. We selected T3 because of a lower apex of the proximal thoracic curve and the shoulder was more balanced preoperatively. However, the correction proportion was smaller and shoulder balance progressed to right-side-down in the T3 group. These findings suggest that T2 is the more appropriate uppermost-instrumented vertebra; however, the number of patients in the T3 group was small compared with the T2 group. In addition, preoperative right-shoulder-up in the T2 group, unlike the T3 group, may have affected shoulder balance at the most recent follow-up. We also did not include patients who underwent direct vertebral rotation and fixation using a wire or hook because this is not a routine procedure. Using a different anchor system on the vertebral body may affect the correction rate and shoulder balance; for this reason, we used only a pedicle screw system [8, 13]. Previous studies have demonstrated that direct vertebral rotation has no benefit in terms of postoperative shoulder balance and thoracic kyphosis [4, 24]. Ideally, the efficacy of the surgical technique could be evaluated by comparing it with alternative techniques; unfortunately, there is no widely accepted maneuver for correcting the proximal thoracic curve.

Improvement of Radiologic Parameters

We found that convex compression with separate-rod derotation effectively corrected the proximal thoracic curve, shoulder balance, and thoracic kyphosis. Suk et al. [29] reported a 55% correction proportion using the separate-rod technique, and Sudo et al. [28] presented a final 58% correction proportion using temporary distraction rods. Tsirikos et al. [32] reported a 68% correction proportion for the proximal thoracic curve and a 71% correction proportion for the main thoracic curve using the convex pedicle screw technique. In the current study, the correction proportion was 61% (mean difference 25% [22% to 27%]) for the proximal thoracic curve and 77% (mean difference 49% [46% to 51%]) for the main thoracic curve. For the main thoracic curve, we used traditional distraction on the concave side, which may be why the proportion of correction of the main thoracic curve was superior to that of the main thoracic curve of Tsirikos et al. [32]. Although the correction proportion is important, it is critical to note that the goal of scoliosis surgery is a fused spine with balanced pelvis and level shoulders, not a perfectly straight spine. Right shoulder depression is frequently encountered after surgery for a double thoracic curve accompanied by a rigid proximal thoracic curve. In this study, the most recent shoulder balance also changed to right-shoulder-down, but shoulder balance was within a 10-mm difference and the mean trunk shift was just 3 mm toward the left side [17, 33]. Restoration of thoracic kyphosis is another surgical goal [1, 22, 27]. Our study demonstrated greater proximal thoracic kyphosis (11°) than that in the study by Sudo et al. (7°) [28]. However, proximal thoracic kyphosis decreased compared with the preoperative value. A possible drawback to convex compression may be that posterior compression decreases proximal thoracic kyphosis [3]. Instead, midthoracic kyphosis increased considerably, and this increase in midthoracic kyphosis compensated for low proximal thoracic kyphosis.

Convex pedicle screws could be located in the correct transpedicular position, and they have strong pullout resistance compared with the extrapedicular position; therefore, using a convex pedicle screw is more effective for correction [25, 32]. Because the pedicle width and interpedicular distance are the smallest around T4, separate-rod contouring with a rod connector around T4 is more natural [6, 15]. The spinal cord deviates to the concave side of the curvature in this small canal, and pedicle screw misplacement increases the risk of neurologic injury [23]. Furthermore, convex-side compression of the proximal thoracic curve does not stretch the spinal cord, which is inevitable during concave-side distraction [2, 5]. There were no procedure-related complications in the current study.

Comparison of Radiologic Parameters Between Uppermost-instrumented T2 and T3 Vertebrae

We found that using T2 as the uppermost-instrumented level resulted in better correction than when T3 was used in terms of the correction proportion of the proximal thoracic curve and the improvement of T1 tilt and shoulder balance. T1 tilt and shoulder balance did not improve between the first erect radiograph and the most recent follow-up in the T3 group. Instead, trunk shift changed toward the left side. In a previous study, there was increased distal adding-on in patients with shoulder imbalance [18, 34]. Distal adding-on could be a compensation mechanism to restore shoulder balance using a relatively flexible lumbar curve [4, 17]. In our opinion, change of trunk shift toward the left side in the T3 group may have been related to insufficient correction of the proximal thoracic curve and T1 tilt. Also, trunk shift to the left side may have compensated for the right-shoulder-down in the T3 group. Furthermore, balanced T1 tilt is important because this is associated with the tilt of the base of the cervical spine. In this study, patients in the T2 group exhibited more favorable shoulder balance and trunk shift with less than 10° of T1 tilt. However, we are unable to determine the acceptable amount of postoperative T1 tilt, and further study on this would be helpful. Additionally, while pedicles on the concave side of the proximal thoracic curve are extremely small and distorted, the pedicle width of the T2 vertebra is wide enough for standard pedicle screw insertion [12, 15]. Currently, we consider fusion to T2 even for the proximal thoracic curve of T5 apex when the patient has a level shoulder or right-shoulder-down.

Factors Related to the Most Recent Shoulder Balance

Better shoulder balance at the most recent follow-up was correlated with increased correction proportion of the proximal thoracic curve and increased improvement of T1 tilt. It is controversial whether it is better to fuse to T2 because of proximal junctional kyphosis, scarring, and the effect of preoperative shoulder balance. However, if the proximal thoracic curve is included in the fusion level, we recommend T2 as the uppermost-instrumented vertebra because shoulder balance at the most recent follow-up would be better with more correction of the proximal thoracic curve and T1 tilt [9, 16, 21, 26, 31, 33].

Conclusion

Effective correction of the proximal thoracic curve was achieved through convex compression with separate-rod derotation without high-density pedicle screw insertion in small and distorted concave-side pedicles. This combination of convex compression for the proximal thoracic curve and concave distraction for the main thoracic curve was reliable for the correction of both curves with the acceptable achievement of postoperative thoracic kyphosis and shoulder balance. Thoracic kyphosis is preserved using a rod connector and distraction for the main thoracic curve, although compression of the proximal thoracic curve may slightly decrease proximal thoracic kyphosis. With this correction technique, T2 was a better uppermost-instrumented vertebra for correcting the proximal thoracic curve and balancing T1 tilt than T3. Additionally, spontaneous improvement in T1 tilt and shoulder balance are expected with uppermost-instrumented T2 vertebrae. Preoperatively, surgeons should evaluate shoulder balance because right-shoulder-down can occur after surgery in patients with proximal thoracic curve.

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