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ORIGINAL ARTICLE

Radiographic evaluation of selective anterior thoracolumbar or lumbar fusion for adolescent idiopathic scoliosis

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Abstract According to Lenke classification of adolescent idiopathic scoliosis (AIS), patients with type 5 curve in which the structural major curve is thoracolumbar or lumbar curve with nonstructural proximal thoracic and main thoracic curves, could be surgically treated with selective anterior thoracolumbar or lumbar (TL/L) fusion. This study retrospectively analyzed the radiographies of selective anterior TL/L fusion in 35 cases of AIS with Lenke type 5 curve. Segmental fixation with a single rigid rod through anterior thoracoabdominal approach was applied in all patients. Measurements of scoliosis curve in preoperative, immediate postoperative and follow-up radiographies were analyzed. The average follow up time was 36 months (24–42 months). The average preoperative Cobb angle of the TL/L curve was 45.6° and improved into 9.7° immediate postoperatively, with 79.7% curve correction. In addition, the minor thoracic curve decreased from 29.7° preoperatively to 17.6° postoperatively, with a spontaneous correction of 41.5%. During the follow-up, a loss of 4.6° correction was found and the average Cobb angle of TL/L increased to 14.4°. Also, the minor thoracic curve increased to average 20.1° with a loss of 2.4° correction. Trunk shift deteriorated slightly immediate postoperatively and improved at the follow-up. The lowest instrumented vertebra (LIV) tilt was improved significantly and maintained its results at the follow-up. During the follow-up, the coronal disc angle immediately above the upper instrumented vertebra (UIVDA) and below the LIV (LIVDA) aggravated, while the sagittal contours of T5–T12 and T10–L2 were well maintained. The lumbar lordosis of L1–S1 and the sagittal Cobb angle of the instrumented segments were reduced slightly postoperatively and at the follow-up. There were no major complications or pseudarthrosis. The outcomes of this study show that selective anterior thoracolumbar or lumbar fusion with solid rod instrumentation is effective for surgical correction of AIS with Lenke type 5 curve. The TL/L curve, minor thoracic curve, and LIV title can be improved significantly, with good maintenance of sagittal contour. However, the UIVDA and LIVDA aggravate postoperatively when the trunk rebalances itself during follow-up. The degeneration of LIV disc warrants longer-term follow-up.

Keywords Adolescent idiopathic scoliosis · Selective fusion · Anterior spinal fusion · Thoracolumbar–lumbar scoliosis

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Introduction

The major surgical goals in the treatment of adolescent idiopathic scoliosis (AIS) include safely obtaining correction of the deformity and providing good coronal and sagittal balance with as few fused motion segments as possible. Anterior correction and fusion with solid rod instrumentation has been widely accepted as an effective and safe treatment for thoracolumbar or lumbar (TL/L) AIS [4, 15, 17, 22–25]. These curves usually are classified as Lenke type 5 curve [10], with a nonstructural thoracic curve that demonstrates significant flexibility and minimal clinical deformity. Approaching these TL/L curves anteriorly achieves a nearly complete correction of the primary

curve. However, there are a few reports regarding the spontaneous correction of the thoracic curve following anterior fusion. The purpose of this study was to retrospectively evaluate the radiographic changes of selective anterior thoracolumbar or lumbar fusion in adolescent idiopathic scoliosis with Lenke type 5 curve, including the analysis of spontaneous correction of the adjacent thoracic curve following anterior fusion.

Materials and methods

From 1998 through 2004, there was a group of 35 consecutive AIS patients with Lenke type 5 in which the structural major curve is thoracolumbar or lumbar with nonstructural proximal thoracic and main thoracic curves were surgically treated through anterior segmental fusion and fixation with a solid rod. Radiographic follow-up was obtained in all patients, with average 36 months (range 24–42 months). The clinical data are summarized in Table 1. Standing posteroanterior (PA) and lateral radiographies of the entire spine were taken preoperatively, immediate postoperatively and during follow-up. Preoperative supine bending films of the major TL/L and compensatory thoracic curves were also obtained. Measurements of scoliosis curves on radiographies were analyzed.

Measurement of radiograph: coronal Cobb measurements were performed on all curves in the thoracic, thoracolumbar, and lumbar spine. The trunk shift was measured as the distance between the C7 plumb line and the central sacral vertical line (CSVL). A postoperative trunk shift within 2 cm of the CSVL was designated as the standard for satisfactory correction. Trunk shift toward the TL/L convex side was defined as "+" and toward the concave side was defined as "–". The lowest instrumented vertebra (LIV) tilt measured the inclination in degrees of the inferior endplate of the lowest instrumented vertebra to the horizontal. The horizontal plane was defined as that perpendicular to the long axis of the radiograph. The coronal lowest instrumented vertebra disc angle (LIVDA) immediately below the LIV was measured as the angulation in degrees of the inferior endplate of the LIV relative to the superior endplate of the next caudal vertebra. The coronal upper instrumented vertebra disc angle (UIVDA) immediately above the upper instrumented vertebra (UIV) was measured as the angulation in degrees of the upper endplate of the UIV relative to the lower endplate of upper adjacent vertebra. The LIV tilt and disc angle were defined as "+" when opening to the preoperative convex side of TL/L and as "–" when opening to preoperative concave side. Sagittal Cobb measurements were made as follows: (1) T5–T12; (2) T12–L2; (3) instrumented segments; (4) L1–S1. Kyphosis was defined as "+" and lordosis was defined as "–".

The primary indication for surgery was a TL/L curve >40° and the indication for cases whose Cobb angle located between 30° and 40° were low back pain and/or significant trunk deformity. The surgeries were performed by three spine surgeon with the standard procedure protocol. Fusion and instrumentation segments in 29 patients were decided according to Zielke principle (superior end vertebra to inferior end vertebra) [27]. The fusion segment in six patients with flexible TL/L curve <60° were decided according to Hall principle (short segment fusion) [1].

Surgical technique. An anterior thoracoabdominal approach appropriate for the planned fusion levels was used. The spinal segmental vessels were isolated and ligated on the anterolateral aspect of the vertebral bodies. After exposure of the anterior and lateral aspects of the vertebral bodies to be instrumented, thorough anulectomies of the convex disc spaces were performed to allow meticulous discectomies. A portion of annulus on the concavity was preserved to act as a hinge and to help hold bone graft in place when screws were compressed on the convex. Complete discectomies were performed back to, but not through, the posterior longitudinal ligament. Care was taken to preserve the structural integrity of the vertebral endplates. The screws were inserted in the posterior part of the vertebral bodies and perforated the opposite cortex. A single solid rod was used for each patient and the rods included 5.5 mm Moss Miami (n = 5), 5.5 mm CDH (n = 15), 6.35 mm TSRH (n = 10), and 6.35 mm Isola (n = 5). The rod was bent, conforming to the normal sagittal contour of TL/L and inserted into the screws. By using a maneuver of derotation, the correction was obtained, restoring a normal sagittal contour at the same time. After structural segments of rib graft were inserted into the anterior part of evacuated disc spaces, compression was exerted on the screws and the locking systems were tightened. All patients wore a standard thoracolumbar spinal orthosis postoperatively for 6 months.

At the follow-up, an interbody space was considered fused if there was trabecular bone in continuity bridging between the adjacent vertebral endplates. The radiograph measurement and analysis were performed by an individual observer.

Statistical analysis. A repeated-measures analysis of variance (ANOVA) was used to compare changes in the preoperative, postoperative and follow-up data. All statistical tests were performed using P value of 0.05 as the level of significance.

Table 1 Data of patients

No	Age (years)	Sex	Risser	Follow up (months)	Convex of TL/L	Preop TL/L curve	Preop T curve	TL/L:T ratio
1	10	F	0	24	Left	64	35	1.83
2	15	F	2	32	Right	63	36	1.75
3	12	F	0	37	Left	62	48	1.29
4	15	F	2	36	Left	42	33	1.27
5	15	F	3	42	Right	50	30	1.67
6	16	F	2	38	Left	32	16	2.00
7	14	F	0	32	Left	44	36	1.22
8	15	M	4	41	Left	46	30	1.53
9	15	F	3	38	Left	39	27	1.44
10	15	F	2	42	Right	51	33	1.55
11	14	F	2	35	Left	60	35	1.71
12	20	F	5	42	Left	35	25	1.40
13	15	M	2	34	Right	58	40	1.45
14	14	F	1	32	Left	60	35	1.71
15	13	F	2	35	Right	52	32	1.63
16	16	F	4	36	Left	35	18	1.94
17	15	F	3	38	Left	41	28	1.46
18	15	F	2	35	Left	48	32	1.50
19	18	F	5	37	Right	44	25	1.76
20	14	F	2	36	Left	54	42	1.29
21	15	F	2	38	Left	44	32	1.38
22	12	F	1	26	Left	31	17	1.82
23	15	F	3	38	Left	49	35	1.40
24	15	F	2	35	Right	33	17	1.94
25	16	F	3	40	Left	36	34	1.06
26	17	F	4	33	Left	42	32	1.31
27	16	F	5	34	Left	52	38	1.37
28	14	F	3	42	Left	43	26	1.65
29	14	F	0	36	Left	46	28	1.64
30	14	F	3	32	Left	36	20	1.80
31	15	F	2	39	Left	36	14	2.57
32	16	F	3	33	Left	35	20	1.75
33	13	M	1	32	Left	46	35	1.31
34	13	F	1	41	Left	47	37	1.27
35	13	F	0	39	Left	40	20	2.00

TL/L Thoroaciclumbar/lumbar, *T* thoracic, *Preop* preoperation

Results

Preoperation

The average coronal Cobb angle of the TL/L curve was 45.6° (range 31°–64°) and the minor thoracic curve was 29.7° (range 14°–48°). Bending film to the convex side of TL/L curve showed the TL/L could be corrected to average 12.4° (range –15° to 40°). Bending film to the convex side of the minor thoracic curve showed minor thoracic curve could be corrected to average 8.5° (range –12° to 26°). The flexibility index of the TL/L curve and minor thoracic were 75.2% (22–143%) and 75.6% (26–136%), respectively. Trunk shift averaged 14 mm (range –22 to 39 mm) and trunk shifts in 11 patients were more than 20 mm. Before operation, the LIV tilt averaged –21.8° (range –31° to –7°), the UIVDA 0.5° (range –6° to 8°) and LIVDA 0.6° (range –10° to 8°), respectively. For sagittal plane, the average Cobb angle from T5 to T12 was 13.8° (range –10° to 37°), thoracolumbar junction (T10–L2) was 3.3° (range –19° to 49°), instrumented segments was –6.1 (–28° to 25°) and L1 to S1 was –45.8° (range –75° to –25°).

Immediate postoperation

The coronal Cobb angle of the TL/L curve after operation was improved significantly ($P < 0.001$) and it averaged 9.7° (range –14° to 36°), with 79.7% curve correction (range 28–139%). The uninstrumented thoracic curve also was improved significantly ($P < 0.001$) and averaged 17.6° (range 2°–32°), with a spontaneous correction of 41.5% (range 6–88%). Correction of the uninstrumented thoracic curve was somewhat less than the correction demonstrated on side bending radiographs. Trunk shift averaged 14.8 mm (range –50 to 48 mm). Although there were no significant changes compared with preoperation, trunk shift in 16 patients was more than 20 mm, including trunk shift toward the convex of the TL/L curve in 12 patients for coronal decompensation. The average LIV tilt was –1.5° (range –15° to 9°), which was significantly improved by the anterior operation ($P < 0.001$). Postoperatively, the average UIVDA was 0.9° (range –3° to 6°), no statistical significance ($P = 0.55$). The average LIVDA was 4.9° (range –5° to 15°), significantly aggravated postoperatively ($P < 0.001$). There were no significant changes on sagittal contours except the sagittal Cobb angle of L1–S1. The average kyphosis from T5 to T12 was 14.2° (range –8° to 31°), thoracolumbar junction (T10–L2) was 3.0° (range –14° to 35°), instrumented segments was –3.0 (–22° to 31°) and lordosis from L1 to S1 was –39.3° (range –54° to –16°).

Postoperative follow-up

At the follow-up, the coronal Cobb angle of TL/L averaged 14.4° (range –9° to 45°) with a loss of 4.6° (range –6° to 19°). The minor thoracic curve averaged 20.1° (–9° to 40°) with a loss of 2.4° (range –14° to 20°). Trunk shift improved significantly ($P = 0.01$) and averaged 5.1 mm (range –28 to 28 mm), which only included five patients with trunk shift more than 20 mm. Of these five patients, three had trunk shift more than 20 mm preoperatively. The LIV tilt averaged –2.1° (range –20° to 12°) with average loss 0.6° (range –8° to 5°). At the follow-up, the UIVDA averaged 3° (range 0° to 11°), the LIVDA 7.8° (range 0° to 16°). Both of the UIVDA and LIVDA were significantly aggravated postoperatively. The LIVDA in three cases was more than 10°. The sagittal contours at the follow-up were well maintained with no significant changes. The average kyphosis from T5 to T12 was 15.0° (range –8° to 36°), thoracolumbar junction (T10–L2) was 3.6° (range –13° to 21°), and instrumented segments was –2.1° (range –19° to 20°), and lordosis from L1 to S1 was –39.4° (range –60° to –21°). All the above data were complied in Table 2 and a typical case was shown in Fig. 1.

Table 2 Summarized results

	TL/L curve (degree)	T curve (degree)	Trunk shift (mm)	LIV tilt (degree)	UIVDA (degree)	LIVDA (degree)	T5–T12 lateral	T10–L2 lateral	L1–S1 lateral	Instrumented segments
Preop	45.6 ± 9.4	29.7 ± 8.1	14.0 ± 12.5	–21.8 ± 5.7	0.5 ± 2.2	0.6 ± 3.4	13.8 ± 10.5	3.3 ± 14.0	–45.8 ± 11.9	–6.1 ± 10.6
Postop	9.7 ± 10.0#	17.6 ± 8.2#	14.8 ± 20.1	–1.5 ± 5.6#	0.9 ± 1.7	4.9 ± 4.1#	14.2 ± 8.3	3.0 ± 8.8	–39.3 ± 9.6#	–3.0 ± 10.4
FU	14.4 ± 12.8*	20.1 ± 10.7	5.1 ± 13.2*	–2.1 ± 6.6	3.0 ± 3.3*	7.8 ± 4.0*	15.0 ± 9.1	3.6 ± 7.5	–39.4 ± 9.6	–2.1 ± 9.3

± (standard deviation, SD)

TL/L Thoracolumbar or lumbar, *T* thoracic, *LIV* low instrumented vertebra, *UIVDA* coronal upper instrumented vertebra disc angle, *LIVDA* coronal low instrumented vertebra disc angle

Difference between preoperation and postoperation is statistical significance ($P < 0.05$), * difference between postoperation and follow-up is statistical significance ($P < 0.05$)

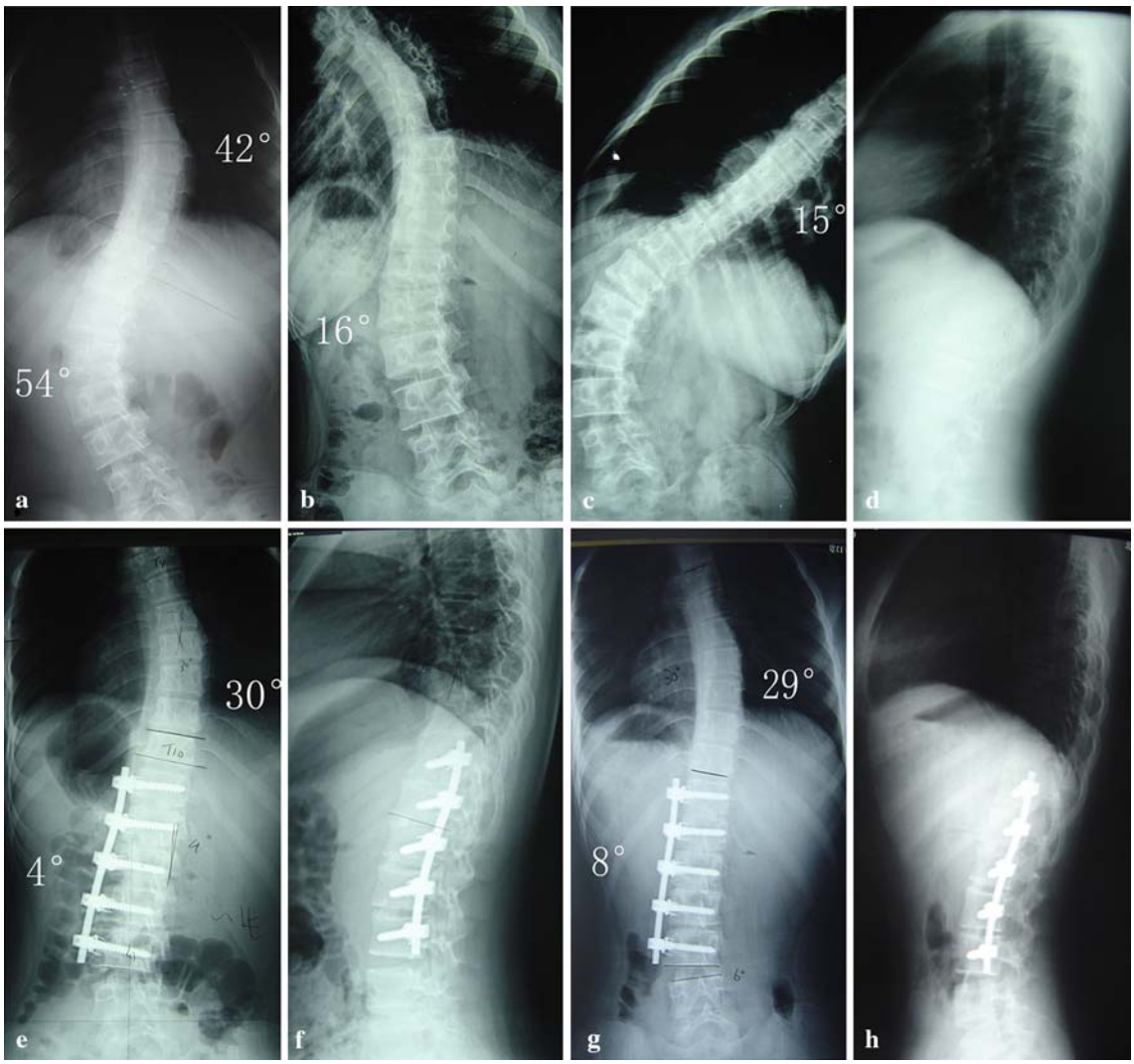

Fig. 1 A 14-year-old female patient with AIS Lenke type 5 curve (patient no. 20). **a** Preoperative Cobb angle of lumbar curve was 54°, thoracic curve 42°. Ration of L:T was 1.29. **b** Bending film of the lumbar curve was 16° with correction rate of 70.4%. **c** Bending film of the thoracic curve was 15° with a correction rate of 64.3%. **d** Lateral radiograph. **e** Anterior correction with single rod was performed from T11 to L3. Postoperatively, the lumbar curve was 4° with a correction rate of 92.6% and thoracic curve 30° with a spontaneous correction of 28.6%. **f** The physical sagittal contour was maintained postoperatively. **g** At 36 months follow-up, the lumbar curve was 8° with a loss of 4° and the thoracic curve 29°. **h** Lateral radiograph at follow-up

Complications

There was no vascular or neurologic complication. A total of 12 patients had mildly complicated of sympathectomy effects after operation and the subjective symptoms disappeared at the follow-up. There were no signs of pseudarthrosis on follow-up radiographs.

Discussion

There were many reports on the selective thoracic fusion for idiopathic scoliosis with King II type II [3, 7, 9, 11, 14, 20]. However, there were few reports on the selective TL/L fusion for double curves with a minor thoracic curve (Lenke type 5) [21, 25]. Lenke et al. [8] stated that selective TL/L fusion was recommended in patients who are Risser 2 or older, have Cobb ration between the TL/L and thoracic curve of equal or >1.25, and have preoperative thoracic curve of <50°. Sanders et al. [21] suggested the surgical success of selective anterior TL/L fusion depended on the structural changes in the thoracic and the patient's maturity. They stated that patients with closed triradiate cartilages, TL/L: T Cobb ration more than 1.25 and thoracic curve on bending film <25° would have satisfactory results. Oglivie [18] stated the indications of selection TL/L fusion for double curves were the minor compensatory thoracic curve <40°, supple enough and no cosmetic

deformity. In our series of 35 cases AIS with Lenke type 5, most of TL/L:T ration were more than 1.25 and there was only a case with ration of 1.06. Anterior selective TL/L fusion with single rod in these patients achieved 79.7% curve correction for the TL/L and 41.5% spontaneous correction for the minor thoracic curve. At the follow-up, only 4.6° and 2.4° loss for the two curves, respectively. Most of patients had coronal balance and maintained physical sagittal contours at the follow-up. The results compare favorably with the series reported by other authors [4, 17, 21, 25]. Our results show that selective anterior TL/L fusion with solid rod is effective for the surgical correction of AIS with Lenke type 5.

Kaneda et al. [5] reported postoperative disc wedging in patients with TL/L AIS following anterior spinal fusion with Kaneda dual rod instrumentation. The average disc-wedging angle was 6.6° in patients who underwent a short fusion and 3° in patients where the LEV was included in the fusion at 2–4 years postoperatively. They concluded that a parallel disc was excluded from fusion, disc wedging would occur in a high incidence, and it would increase during the 2-year postoperative course. If this parallel disc was included in the fusion, disc wedging was avoidable but results in the sacrifice of one additional motion segment. Satake et al. [22] stated that postoperative subjacent disc wedging occurred most often when the preoperative subjacent disc was nearly parallel and when a shorter fusion excluding the LEV was performed. In our study, we found the UIVDA averaged 0.9°, LIVDA 4.9° postoperatively and at the follow-up the UIVDA was 3° and LIVDA 7.8°, respectively. Postoperatively, the thoracic curve (averaged 17.6°) was often more than the TL/L (averaged 9.7°) because of the powerful correction of anterior TL/L instrumentation. Some cases lose trunk balance and shift toward the convex side of TL/L curve immediately after the operation, but during the follow-up the trunk had the tendency to rebalance. In the process of rebalance, the fused curve of TL/L would act as a whole segment and only with the aggravated UIVDA and LIVDA could TL/L reconstruct its balance to accommodate the residual thoracic curve [26]. This may be the reason for the UIVDA and especially the LIVDA aggravated at follow-up. There were three cases with LIVDA more than 10° in our group. Because LIVDA is the distal junction of the grafted segment with the rest of the spine and will undergo considerable remodeling associated with re-equilibration of the whole spine after curve correction, the relationship with low-back pain and disc degeneration are most concerned. All patients in this study are adolescents, so the relationships may take decades to fully understand.

When in approaching the problem of AIS double curve (Lenke type 5) with anterior instrumentation, the major goal is to achieve a balanced spine rather than maximal instrumented curve correction alone. It is certainly possible to technically achieve full correction of the instrumented curve, but in some of the patients of our group would lead to an unbalanced spine or a gaping of the nonfused distal lumbar discs. For a balance spine, complete correction of the instrumented curve was not suggested in Lenke type 5. Therefore, in AIS Lenke type 5 curve with a large thoracic curve, a residual curve might be left in the TL/L curves to accommodate the structural portion of the uninstrumented minor thoracic curve for a balanced spine and avoiding large LIV.

Since the introduction of rigid rod implants in the early 1990s, there have been reports on the anterior correction of TL/L scoliosis [12, 18]. Most of the authors describe the fusion of the whole Cobb curve from the upper to the lower end vertebrae (Zielke principle) [27]. Hall put forward the technique of short fusion in flexible TL/L scoliosis with a Cobb angle <60° [1]. His criteria (Hall principle) recommend fusion at least one disc above and one disc below the most horizontal element. If the element is a vertebral body, the fusion should incorporate two disc levels (three vertebrae). If the element is the disc, then the fusion should extend three disc spaces (four vertebrae). This technique requires overcorrection or reversal of the structural curvature. In our series, the fusion segments in six patients with a flexible TL/L curve were decided according to Hall principle. The fusion segments in other 29 patients were decided according to Zielke principle. Further comparison between the two groups was not performed because a few patients (six cases) were operated according to Hall principle.

After the anterior TL/L fusion in our 35 cases, the uninstrumented thoracic curve had a spontaneous correction of 41.5%, which was less than the correction demonstrated on side bending radiographs (75.6%). This is in consistent with the result of Sanders et al. [21] and Puno [19], who stated a spontaneous thoracic correction of 38 and 38.7%, and in contrast to the findings of Wojcik [25] or Korovessis [6], who stated that the correction in the thoracic curve was equal or better than in bending film.

Most studies have reported the occurrence of segmental kyphosis after anterior spinal instrumentation for scoliosis of the lumbar and thoracolumbar spine [2, 12, 13, 16, 17]. All of these techniques, such as Dwyer and Zielke are potentially kyphogenic because the compressive forces used to shorten the convexity are anterior to the instantaneous axis of rotation. In the current study, with a solid rod instrumentation we found most of the patients maintained their preoperative physical sagittal contour. Only the instrumented segments and lordosis L1–S1 were reduced slightly by the operation, but still maintained in the physical range at follow-up. This might be related to the structural segments rib and the site of screw placement. As

during the procedure, the screws were placed in the posterior part of the vertebral body and the structural segmental rib in the anterior part of the evacuated disc space. After segmental compression between screws with solid rod was applied, the instrumented fusion segment of TL/L will be kept to avoid kyphosis. This fusion technique and wearing brace for 6 months postoperatively may contribute to the solid fusion in all patients without pseudarthrosis at follow-up. The Kaneda two-rod system is biomechanically stronger to a single rod instrumentation. This two-rod system combined with structural interbody fusion, such as titanium mesh cages might obviate the need of brace postoperatively that required in our single rod technique.

Conclusions

Selective anterior TL/L fusion with a solid rod is an effective and safe treatment for Lenke type 5 curve. It can achieve significant improvement of TL/L curve, minor thoracic curve and LIV tilt, and meanwhile maintain the physical sagittal contour. The UIVDA and LIVDA aggravated immediate postoperatively and at follow-up. The degeneration of LIV disc warrants longer-term follow-up.

This study complies with the current laws of the authors' country and gets the permission of ethic committee in the hospital where the study performed.

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