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ORIGINAL ARTICLE

Sagittal balance of thoracic lordoscoliosis: anterior dual rod instrumentation versus posterior pedicle screw fixation

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Abstract Posterior pedicle screw fixation is now the standard treatment for surgical correction of idiopathic scoliosis and has largely replaced anterior techniques, but there have been reports describing a lordogenic effect of segmental pedicle screw instrumentation in the thoracic spine. This clinical study compared anterior dual rod instrumentation with posterior pedicle screw fixation for idiopathic thoracic lordoscoliosis, including 42 patients (7 male, 35 female; average age 16 years, range 12–34) who underwent posterior pedicle screw fixation ($n = 20$) or anterior dual rod instrumentation ($n = 22$) at two centers. The average follow-up period was 33 months (24–108 months). Inclusion criteria were a diagnosis of adolescent idiopathic scoliosis with a structural thoracic curve (Lenke 1–3) and thoracic hypokyphosis (T4–T12 < 20°). The main thoracic curve magnitude and sagittal profile on standing radiographs were evaluated. Thoracic kyphosis was significantly restored from preoperatively 10.2° to 23.4° postoperatively in the anterior group and from 7.6° to 12.9° in the posterior group ($P < 0.005$). Kyphosis improved significantly better in the anterior group than in the posterior group ($P < 0.005$). The preoperative and postoperative main thoracic curve values were 63° (48–80°) and 25.2° in the anterior group and 60.6° (50–88°) and 23.6° in the posterior group, with no significant differences between the groups. No neurological or other severe complications were observed. Anterior dual rod instrumentation in patients with thoracic lordoscoliosis allows significantly better restoration of thoracic kyphosis than posterior pedicle screw instrumentation.

Keywords Sagittal plane · Idiopathic scoliosis · Lordoscoliosis · Pedicle screw · Thoracic kyphosis

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Introduction

The aim of surgical treatment in patients with scoliosis is three-dimensional correction of the deformity. It is important to take into account not only frontal correction but also sagittal correction, to prevent progressive pathologic curvature in the unfused spine. Sagittal-plane parameters have become increasingly important in maintaining the long-term health of the spine [1, 2]. For example, segmentally flat lumbar fusions and distraction forces in the lumbar spine are associated with the development of fixed sagittal imbalance syndromes [3, 4]. Restoring sufficient thoracic kyphosis should prevent posterior sagittal imbalance and thus reduce the risk of progressive junctional kyphosis [5]. In addition, thoracic hypokyphosis may be associated with respiratory dysfunction [6–8].

Currently, anterior or posterior instrumentation can be used in the treatment of idiopathic scoliosis. Several reports have demonstrated that pedicle screws are superior for correcting scoliosis, in terms of the mean absolute degrees and percentage of curve correction, in comparison with posterior hook-and-wire or hybrid constructs [9–11]. Among the several surgical techniques available, pedicle screw instrumentation is considered to be reliable and safe [12–14], but clinical trials have reported a lordogenic effect with this form of posterior instrumentation [15–17].

Anterior fusion is still considered to be a good option and is even preferred for some types of adolescent idiopathic scoliosis curve associated with thoracic hypokyphosis. In addition, anterior fusion provides better curve correction and can save fusion levels distally [4, 18]. However, some studies have reported a postoperative decrease in pulmonary function [19, 20].

The purpose of this study was to compare anterior dual rod instrumentation with posterior pedicle screw fixation in relation to sagittal-plane parameters in patients with adolescent idiopathic scoliosis (AIS).

Methods

A total of 42 patients (7 male, 35 female) with idiopathic thoracic lordoscoliosis who underwent surgery between 2003 and 2008 in two centers were included (Tables 1, 2); retrospective and prospective data were evaluated. Twenty patients underwent posterior pedicle screw fixation using a 5.5-mm titanium rod (Expedium; DePuy Spine, Leeds, England) and 22 patients received anterior dual rod instrumentation (Halm-Liljenqvist Instrumentation; DePuy Spine) via a standard open thoracotomy. The average follow-up period was 33 months (24–108 months); the patients' average age at surgery was 16.7 years (12–34 years). The inclusion criteria were a diagnosis of AIS with a structural thoracic curve (Lenke 1, 2 or 3) and thoracic hypokyphosis (T4–T12 $< 20°$). The operations were carried out by two spinal surgeons at two different institutions.

The choice of surgical approach was at the discretion of the attending surgeon, on the basis of the clinical examination and radiographs (standing anteroposterior and lateral, supine anteroposterior bending). For objective assessment of the patients' postoperative quality of life, a validated German-language version of the SRS-22 questionnaire was completed at the last follow-up consultation [21].

Surgical techniques

Anterior correction and dual rod instrumentation was performed via double thoracotomy as described by Liljenqvist et al. [22]. After thorough disc release the lid plates and screws are placed and correction is performed with intersegmental compression routinely using the more posteriorly placed smooth 4 mm rod (in the early series 4 mm threaded Zielke rod). The segmental derotation is achieved by bringing the individually and according to the vertebral rotation displaced screw heads into one line by inserting the posterior rod. Prior to curve correction the endplates are prepared and the disc spaces are filled with morselized bone chips from the resected rib. Finally, the solid rod is bent according to the residual frontal curve and to the aimed thoracic kyphosis and is inserted into the lid-plates. Additionally either slight segmental compression (to increase kyphosis) or distraction (to decrease kyphosis) can be administered.

For the posterior approach, patients were placed in the prone position. The posterior elements of the spinal fusion levels previously decided on were exposed using subperiosteal paraspinal muscle stripping. Segmental pedicle screw fixation using polyaxial and monoaxial screws was carried out using the Weinstein approach [23]. Curve correction was achieved using the rod-rotation maneuver with over bended concave sided rod and a contoured convex rod, using the principles established by Cotrel et al. [24, 25], followed by slight convex compression and concave distraction. Finally, the frame construct was completed by spinal arthrodesis with bone graft substitute. In the posterior group, rib hump resection was performed in 12 patients.

Measurements were made on coronal and lateral radiographs of the spine with the patient standing. Curve flexibility was determined on preoperative supine side-bending films. All of the radiographic measurements were made manually by one author, independent of the surgical team.

Standing anteroposterior and lateral radiographs from the preoperative, postoperative, and final follow-up (after a minimum of 2 years) examinations were analyzed using the Cobb method on the coronal and sagittal planes [26]. The Stagnara angle for thoracic kyphosis and the posterior tangent method for cervical measurement were also used [27]. Sagittal measurements included cervical lordosis (tangents drawn at the posterior body margins of C2 and C7); thoracic kyphosis (T4–T12); thoracolumbar junction (T10–L2); lumbar lordosis (T12–L5); C7 plumbline (horizontal distance from the center of the C7 body to the posterosuperior corner of the S1 body); proximal junctional measurement (Cobb angle between the most proximal instrumented vertebra and the segment two levels cranial); distal junctional measurement (Cobb angle between the most distal instrumented vertebra and the segment two levels caudal). Positive values were used to denote kyphosis and negative values to indicate lordosis. Radiographs were also analyzed for evidence of instrumentation failure (e.g., broken implants, pullout). Pseudarthroses were identified radiographically, or their presence was inferred from failed instrumentation or progression of curvature over the instrumented levels.

Data were analyzed using SPSS version 10.0 (SAS Institute Inc., Cary, North Carolina, USA). Distributions of variables are given as means, standard deviation, and ranges. The Wilcoxon rank-sum test and Mann–Whitney test were used to compare the groups and postoperative changes between the two groups.

Table 1 Data for 22 patients treated with anterior dual rod instrumentation, with the Cobb angle of the main curve and thoracic kyphosis

Patient no.	Curve type	Approach	Curve length	Fusion length	LIV	Age	Preop. MC	Bend MC	Postop. MC	FU MC	Preop. TK	Postop. TK	FU TK
1	1CN	Anterior	D5–D11	D5–D11	D11	16	65	40	28	24	18	28	20
2	2A–	Anterior	D6–D12	D6–D12	D12	20	44	22	10	14	–2	10	8
3	1B–	Anterior	D6–D11	D6–D11	D11	13	58	35	23	23	8	32	32
4	3C–	Anterior	D5–D11	D5–D11	D11	16	76	55	42	39	9	16	16
5	1C–	Anterior	D6–D12	D6–D12	D12	14	64	36	25	24	8	14	20
6	1C–	Anterior	D5–D11	D5–D11	D11	14	62	38	30	30	7	25	27
7	1C–	Anterior	D6–D10	D6–D10	D10	14	60	36	20	26	18	24	28
8	1BN	Anterior	D7–D12	D7–D12	D12	15	50	20	21	25	16	35	22
9	1BN	Anterior	D6–D12	D6–D12	D12	14	50	26	14	21	19	27	32
10	1A–	Anterior	D6–D12	D6–D12	D12	12	74	24	24	28	9	23	25
11	1A–	Anterior	D6–D12	D6–D12	D12	12	53	27	10	29	10	22	30
12	2A–	Anterior	D6–D12	D6–D12	D12	13	77	50	36	36	19	20	20
13	1C–	Anterior	D7–D12	D7–L3	L3	18	66	43	30	30	9	28	38
14	1C–	Anterior	D5–D11	D5–D11	D11	13	66	33	20	18	0	22	20
15	1CN	Anterior	D6–D11	D6–D11	D11	16	48	26	22	12	16	21	34
16	1A–	Anterior	D6–12	D6–12	D12	15	70	36	18	22	16	28	26
17	1BN	Anterior	D7–D12	D7–D12	D12	19	50	32	20	23	18	40	46
18	1C–	Anterior	D5–L1	D6–12	D12	16	72	45	40	34	10	20	20
19	2A–	Anterior	D5–D11	D5–D11	D11	15	60	32	14	26	10	24	28
20	1B–	Anterior	D6–D12	D6–D12	D12	17	69	49	24	26	–1	8	10
21	2C–	Anterior	D6–D11	D6–D11	D11	20	54	38	34	38	0	15	15
22	1A–	Anterior	D6–D12	D6–D12	D12	14	80	43	32	43	8	32	34
Average							61.7 ± 10.4	35.3 ± 9.4	23.6 ± 8.9	25.5 ± 7.8	10.2 ± 6.7	23.4 ± 7.9	25.0 ± 9.1

FU follow-up, *LIV* last instrumented vertebra, *MC* main curve, *TK* thoracic kyphosis

Table 2 Data for 20 patients treated with posterior pedicle screw instrumentation, with the Cobb angle of the main curve and thoracic kyphosis

Patient no.	Curve type	Approach	Curve length	Fusion length	LIV	Age	Preop. MC	Bend MC	Postop. MC	FU MC	Preop. TK	Postop. TK	FU TK
23	1A–	Posterior	D6–L2	D5–L3	L3	14	60	33	24	26	−12	4	6
24	1A–	Posterior	D6–L1	D2–L1	L1	14	74	43	25	26	−3	20	26
25	1A–	Posterior	D6–D12	D2–L1	L1	13	68	40	26	30	14	10	18
26	1A–	Posterior	D5–D12	D5–L1	L1	16	60	23	14	12	−7	−2	−2
27	2BN	Posterior	D6–D12	D3–D12	D12	17	68	42	44	28	18	20	28
28	2A–	Posterior	D5–D12	D3–L1	L1	14	60	28	22	22	12	32	30
29	1A–	Posterior	D5–D12	D5–L1	L1	13	52	26	10	14	18	16	32
30	2A–	Posterior	D6–D12	D3–L1	L1	20	55	30	20	25	14	12	18
31	1AN	Posterior	D5–D12	D5–L1	L1	15	50	28	20	20	14	16	20
32	1AN	Posterior	D5–D12	D5–L1	L1	12	58	28	23	28	6	16	18
33	2A–	Posterior	D6–D12	D2–D12	D12	13	88	48	33	40	16	12	18
34	2A–	Posterior	D5–D11	D3–D12	D12	15	52	40	20	24	14	19	22
35	1A–	Posterior	D5–D12	D2–L1	L1	18	62	28	22	24	8	10	16
36	2A–	Posterior	D7–L2	D3–L3	L3	17	58	46	26	30	−2	4	2
37	1A–	Posterior	D3–D10	D3–D12	D12	34	50	28	24	24	19	16	14
38	1A–	Posterior	D7–L2	D7–L2	L2	18	56	18	20	22	8	16	14
39	1A–	Posterior	D4–D11	D3–L1	L1	14	64	28	24	26	8	20	26
40	1A–	Posterior	D3–L1	D3–L1	L1	16	72	42	32	35	6	2	4
41	1A–	Posterior	D5–D11	D5–D11	D11	13	53	26	24	26	−10	0	5
42	2A–	Posterior	D6–L1	D6–L2	L2	21	52	28	18	18	10	14	20
Average							60.6 ± 9.6	32.9 ± 8.6	23.6 ± 7.1	25 ± 6.4	7.6 ± 9.5	12.9 ± 8.2	16.8 ± 9.6

FU follow-up, *LIV* last instrumented vertebra, *MC* main curve, *TK* thoracic kyphosis

Results

No neurological or other severe complications were observed. One patient developed respiratory insufficiency 1 day postoperatively and underwent bronchoscopy. Two patients with anterior instrumentation experienced implant failures, with broken threaded rods (after 1 and 8 years, respectively) without significant loss of correction or clinical or radiological signs of pseudarthrosis. An adding-on phenomenon without clinical relevance occurred in one patient who underwent posterior instrumentation.

On the coronal plane, the main thoracic curve in the anterior group measured 62.2° (48–80°) preoperatively, 24.4° postoperatively, and 26.9° at final follow-up—a curve correction rate of 55% (Table 1). The main thoracic curve in the posterior group measured 60.6° (50–88°) preoperatively, 23.6° postoperatively, and 25.0° at final follow-up—a curve correction rate of 58% (Table 2). There were no significant differences between the groups.

Both groups were hypokyphotic preoperatively, with no significant differences. In the anterior group, thoracic kyphosis was significantly restored from +10.2° preoperatively to +23.4° postoperatively ($P < 0.005$) and reached approximately normal values, with a mean of +25.0°, at final follow-up. By contrast, the patients in the posterior group were still hypokyphotic, with a mean of +16.8° at final follow-up. However, thoracic kyphosis was also significantly restored in the posterior group, from +7.6° preoperatively to +12.9° postoperatively ($P < 0.005$). Thoracic kyphosis improved significantly better in the anterior group than in the posterior group ($P < 0.005$) (Fig. 1).

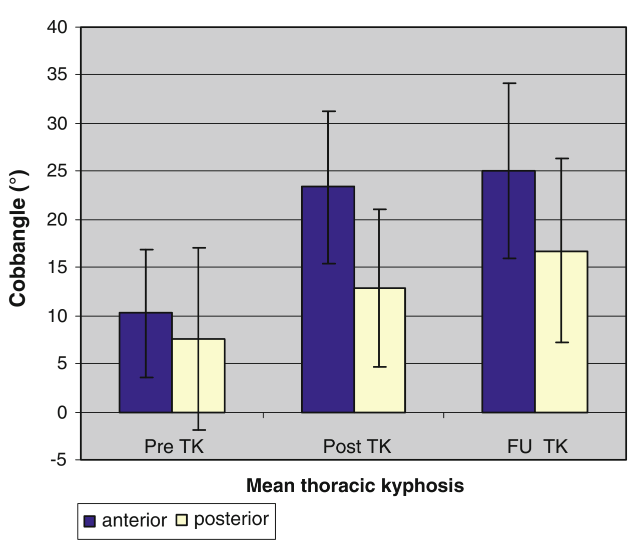

Fig. 1 Restoration of thoracic kyphosis (*TK*) in the two groups (*$P < 0.005$)

All of the patients had cervical kyphosis preoperatively (+5.9° in the anterior group and +6.5° in the posterior group), with no significant differences between the groups. Both anterior and posterior instrumentation produced lordogenic effects (anterior: +5.9° preoperatively to +2.3° postoperatively and +1.5° at final follow-up; posterior: +6.5° preoperatively to +6.9° postoperatively and −0.9° at final follow-up).

Patients in both groups had a lordotic thoracolumbar junction preoperatively (anterior: −7.5°, posterior: −4.5°). No significant changes were noted in either group postoperatively or at final follow-up (anterior: −3.9° and −3.2° at final follow-up; posterior: −4.5° postoperatively and −2.2° at final follow-up; ns).

Anterior instrumentation led to the largest positive displacement in the C7 sagittal plumbline, from +13 mm preoperatively to +29 mm postoperatively ($P < 0.005$). Posterior instrumentation also produced positive displacement in the plumbline, from +19 mm preoperatively to +29 mm postoperatively. At the last follow-up, the displacement had decreased to +23 mm in the anterior group and +18 mm in the posterior group (Table 3).

Anterior thoracic instrumentation led to a significant increase in the proximal junctional measurement (PJM), from +3.8° preoperatively to +7.4° at final follow-up. There was also a kyphogenic trend in the posterior group (+4.6° preoperatively, +7.1° postoperatively, and +6.6° at final follow-up). There were no significant differences between the groups (Table 3).

No significant changes in the distal junctional measurement (DJM) were observed in either group between the preoperative findings and the final follow-up. However, the DJM decreased (with a more lordotic effect) after anterior and posterior instrumentation (anterior: −1.4 preoperatively, −1.9 postoperatively, −2.4 at last follow-up; posterior: −7.4 preoperatively, −9.9 postoperatively, −11.2 at last follow-up). Patients who underwent posterior instrumentation had a more lordotic DJM postoperatively (Table 3).

Lumbar lordosis increased slightly postoperatively and at final follow-up in both groups (anterior: −35.2° preoperatively, 36.2° postoperatively, −40.9° at final follow-up; posterior: −27.3° preoperatively, −24.9° postoperatively, −30.8° at final follow-up) (Table 3).

The average operating times were 195 min (120–330 min) in the anterior group and 260 min (140–320 min) in the posterior group ($P = 0.001$). Intraoperative blood losses were 483 mL (150–1500 mL) in the anterior group and 1,023 mL (230–2,300 mL) in the posterior group ($P = 0.001$).

Analysis of the questionnaire responses showed that there were no significant differences between the two

Table 3 Sagittal measurements in the anterior dual rod instrumentation group and the posterior pedicle screw instrumentation group

	Mean		Range		Standard deviation	
	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior
C2–C7 pre	5.9°	6.5°	−10° to 22°	−18° to 28°	±8.6°	±10.5°
C2–C7 post	2.3°	6.9°	−18° to 24°	−20° to 40°	±10.1°	±14.5°
C2–C7 FU	1.5°	−0.9°	−20° to 20°	−35° to 12°	±9.6°	±11.8°
PJM pre	3.8°	4.6°	−2° to 18°	−2° to 24°	±4.7°	±5.7°
PJM post	6.1°	7.1°	−2° to 18°	−4° to 28°	±4.9°	±7.1°
PJM FU	7.4°	6.6°	0° to 16°	−2° to 26°	±5.0°	±7.8°
DJM pre	−1.4°	−7.4°	−10° to 10°	−26° to 9°	±5.6°	±9.2°
DJM post	−1.9°	−9.9°	−14° to 8°	−30° to 4°	±6.0°	±9.5°
DJM FU	−2.4°	−11.2°	−24° to 10°	−38° to 9°	±8.6°	±12.4°
C7/S1 pre (cm)	1.3	1.9	−2 to 5	−1 to 5	±1.9	±2.1
C7/S1 post (cm)	3.9	2.9	−1 to 6	−2 to 7	±2.1	±2.6
C7/S1 FU (cm)	2.3	1.8	−2 to 5	−2 to 10	±2.2	±2.6

DJM distal junctional measurement, *FU* follow-up, *PJM* proximal junctional measurement, *post* postoperative, *pre* preoperative

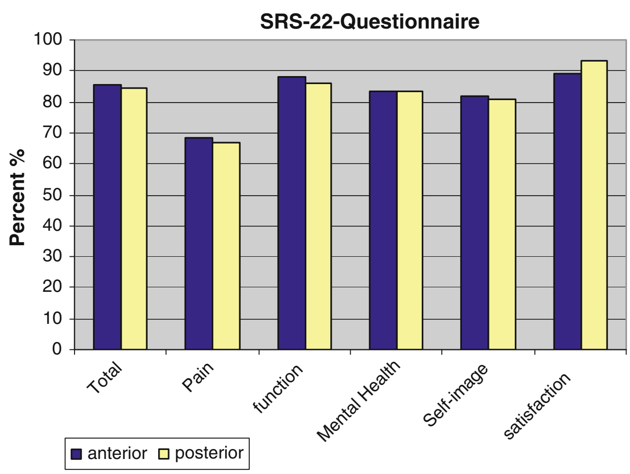

Fig. 2 Topics in the SRS-22 questionnaire completed by the two groups at the final follow-up examination, with no significant differences between the groups

groups, with similar scores for pain (68 vs. 67%), general self-image (82 vs. 81%), general function (88 vs. 86%), mental health (83 vs. 83%) and patient satisfaction (89 vs. 93%) (Fig. 2).

Discussion

One of the primary goals of surgery in patients with AIS is to achieve the maximum coronal plane correction while maintaining sagittal balance. Thoracic curves often show hypokyphosis (0–20°), and it is generally agreed that the aim in surgery for idiopathic thoracic scoliosis should be to improve sagittal-plane deformities, restoring thoracic kyphosis to normal values (20–40°), as defined by Bernhardt and Bridwell [28], and maintaining lumbar lordosis and good overall sagittal balance.

Different approaches and instrumentation methods can affect postoperative sagittal-plane parameters. In a retrospective multicenter study, Sucato et al. [29] demonstrated that anterior instrumentation is the best method for restoring thoracic kyphosis in comparison with posterior techniques. Similarly, Betz et al. [4] reported that anterior instrumentation corrects hypokyphosis better than posterior techniques. This is consistent with the results presented by Potter et al. [30], who compared anterior and posterior spinal fusion in patients with Lenke 1 curves and showed that the anterior group had a significantly greater increase in thoracic kyphosis (5.7° vs. 4.4°; $P = 0.004$).

Vora et al. [17] observed a lordosing effect in the thoracic spine with posterior pedicle screw instrumentations. Quan et al. [15] also documented a significant correlation between reduced sagittal kyphosis and the magnitude of coronal Cobb angle correction in 49 consecutive patients with Lenke 1 main thoracic AIS who underwent single-stage posterior correction and instrumented spinal fusion with pedicle screw fixation. In contrast, Clement et al. [31] documented a mean gain of 14° of thoracic kyphosis with pedicle screw instrumentation in patients with severe preoperative hypokyphosis.

The present study compared anterior dual rod instrumentation with posterior pedicle screw fixation in the surgical treatment of idiopathic thoracic lordoscoliosis. The two groups were comparable with regard to the preoperative magnitude of the coronal Cobb angle (62.2° vs. 60.6°; n.s.) and preoperative flexibility (bending 35.7° vs. 32.9°;

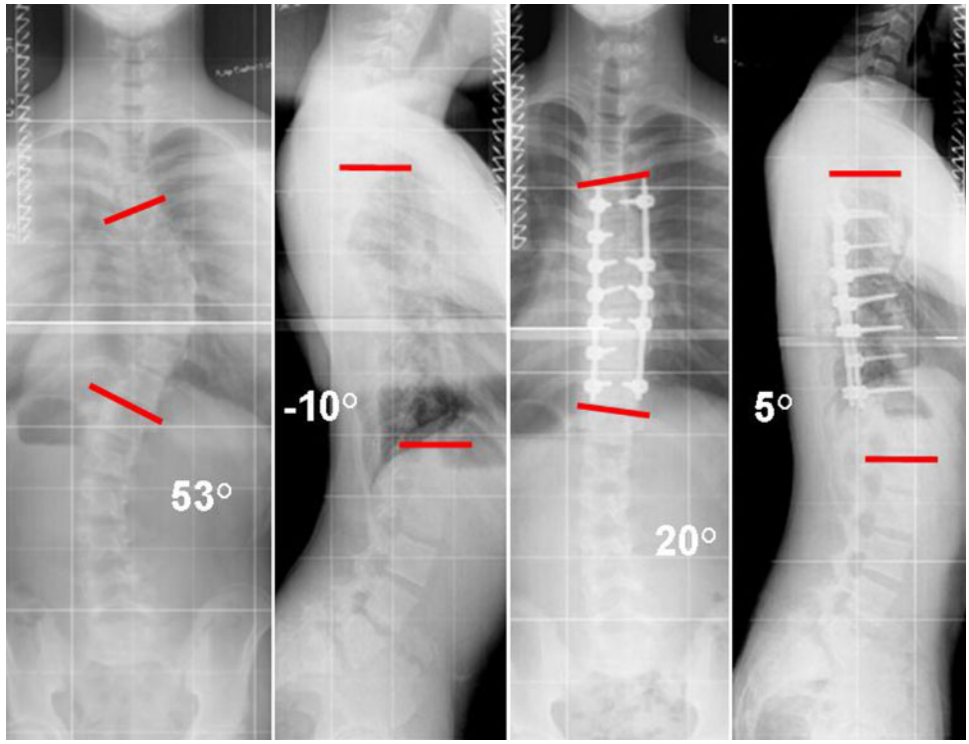

Fig. 3 A 13-year-old boy, Lenke 1A–, before posterior instrumentation and 12 months after operation with residual thoracic hypokyphosis

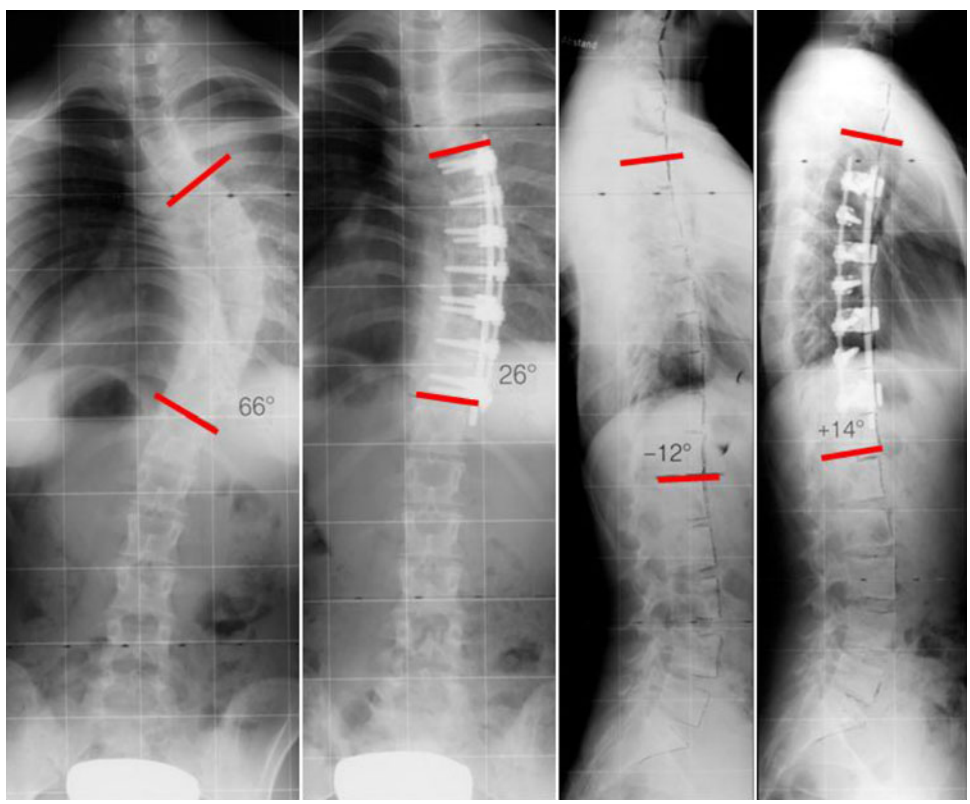

Fig. 4 A 12-year-old girl, Lenke 1A–, before anterior dual rod instrumentation and 24 months after surgery, with good restoration of thoracic kyphosis

n.s.). A mean correction of more than 55% of the main curve was achieved with both techniques. In the literature, pedicle screw instrumentation achieves corrections as great as 75%, but at the expense of the sagittal contour, with a significant postoperative decrease in thoracic kyphosis [10, 32].

No significant loss of coronal correction was observed in either group during the follow-up period. Relative to the sagittal plane, the results show that both anterior and posterior instrumentation with the techniques described can be used to restore thoracic kyphosis (Figs. 3, 4). However, thoracic kyphosis improved significantly better in the anterior group than in the posterior group, from +10.2° preoperatively to +23.4° postoperatively ($P < 0.005$), reaching approximately normal values with a mean of +25.0° at final follow-up. In a previous study [33], our group documented a kyphogenic trend when an anterior dual rod instrumentation system was used to treat thoracic scoliosis in 23 patients. The better restoration provided by anterior dual rod instrumentation is probably due to using a second solid rod, allowing individual contour adjustment.

In this study the authors regularly used monoaxial and polyaxial top-loading screws and a 5.5 mm titanium rod in the posterior instrumentation. To achieve hypokyphosis correction intraoperatively prebending of the rod and re-in situ-bending of the concave sided rod after rotation maneuver were steps to improve the operative technique.

The results of this study demonstrate an improvement of the sagittal profile in the posterior group but not the desired physiological kyphosis of the thoracic spine. Therefore, we have modified the posterior technique for improved restoration of kyphosis with two tools. First, we use reduction screws with dual-innie mechanism for segmental derotation. Secondly due to the fact that the flattening of the pre-bended concave titanium rod during the rotation maneuver was identified as further reason for insufficient restoration of thoracic kyphosis we have replaced the concave rod with a more rigid 5.5 mm cobalt chrome rod in hypokyphotic patients.

In both groups, the C7 plumbline value was positive preoperatively and remained so at final follow-up. The positive displacement of the C7 plumbline up to the normal value (+2 cm) observed immediately postoperatively can be explained by postoperative pain. At the last follow-up in nine patients in the anterior group and seven in the posterior group, the C7 plumbline was still more than +2 cm, with no sign of decompensation of thoracic kyphosis or lumbar lordosis.

Anterior thoracic instrumentation led to a significant increase in the PJM from +3.8° preoperatively to +7.4° at final follow-up. An abnormal proximal junctional kyphosis was recorded if the proximal junction Cobb angle was ≥10° and the angle for the corresponding two-level spinal segment was at least 10° greater than the preoperative measurement. Both criteria were required for to establish abnormality, as some proximal junctional kyphoses were lordotic preoperatively [34]. Although a significant increase in the PJM was documented, there were no abnormal PJMs on this basis.

Two cases of fracture of the threaded rod, without relevant loss of correction, were observed. Rod fractures have been reported in the literature in up to 31% of cases, as well as a pseudarthrosis rate of up to 6% [2, 4, 35]. We now routinely use a 4-mm smooth rod to prevent this.

Limitations of this study include its retrospective nature and lack of randomization. Pulmonary function was also not examined. Several studies have reported a postoperative decrease in pulmonary function, which may persist for as long as 2 years [19, 20, 36]. However, any procedure in which the rib cage is opened—e.g., for rib hump resection in posterior instrumentation—can lead to similar negative effects.

Conclusions

Posterior pedicle screw instrumentation and anterior dual rod instrumentation allow restoration of thoracic kyphosis, with comparable coronal plane correction. In patients who have hypokyphotic thoracic curves preoperatively, however, better restoration of thoracic kyphosis can be achieved with anterior instrumentation in contrast to posterior pedicle screw instrumentation.

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