Anterior lumbar instrumentation improves correction of severe lumbar Lenke C curves in double major idiopathic scoliosis

Howard B. Yeon · Jacob Weinberg · Vincent Arlet ·
Jean A. Ouelett · Kirkham B. Wood

Received: 1 September 2006 / Revised: 10 February 2007 / Accepted: 26 March 2007 / Published online: 27 April 2007
© Springer-Verlag 2007

Abstract Fifteen skeletally immature patients with double major adolescent idiopathic scoliosis with large lumbar curves and notable L4 and L5 coronal plane obliquity were retrospectively studied. Seven patients who underwent anterior release and fusion of the lumbar curve with segmental anterior instrumentation and subsequent posterior instrumentation ending at L3 were compared with eight patients treated with anterior release and fusion without anterior instrumentation followed by posterior instrumentation to L3 or L4. At 4.5 years follow-up (range 2.5–7 years), curve correction, coronal balance and fusion rate were not statistically different between the two groups; however, the group with anterior instrumentation had improved coronal plane, near normal angulation in the distal unfused segment compared with the group without anterior instrumentation. In cases involving severe lumbar curva-

tures in the context of double major scoliosis, when as a first stage anterior release is chosen, the addition of instrumentation appears to restore normal coronal alignment of the distal unfused lumbar segment, and may in certain cases save a level compared with traditional fusions to L4.

Keywords Anterior instrumentation · Double major scoliosis · Lenke C lumbar modifier

Introduction

The goals of scoliosis surgery are to halt curve progression, effect maximum safe correction of the coronal, sagittal and rotational deformities, and preserve mobile segments while maintaining appropriate coronal and sagittal balance. In the case of double major scoliosis, specifically those with large lumbar curves, and significant coronal plane angulations of L4 and L5, these goals may be conflicting as the application of established guidelines for determining distal fusion levels frequently suggests primary anterior release and/or extending the posterior fusion to L4 or below [11, 15]. Distal extension of the fusion to the lower lumbar spine decreases the number of remaining motion segments and increases stress concentration below the fused segments [2, 4, 8, 26, 32].

Lenke proposed a comprehensive classification system for adolescent idiopathic scoliosis that incorporates modifiers to describe the magnitude of lumbar curves [13, 15]. Using standing AP radiographs, this system classifies lumbar curves into three types: A, B and C. Lumbar curves where the center sacral vertical line (CSVL) falls between the pedicles of the apical lumbar vertebra are assigned modifier “A”. Those whose CSVL falls between the

Paper presented at the Scoliosis Research Society, October 2005, Miami, FL. No funding or grants were used to prepare this manuscript

H. B. Yeon · J. Weinberg · K. B. Wood (✉)
Department of Orthopaedic Surgery, Spine Service,
Massachusetts General Hospital,
55 Fruit Street, Yawkey Center for Outpatient Care,
Suite 3800, Boston, MA 02114, USA
e-mail: kbwood@partners.org

J. Weinberg
Department of Orthopaedic Surgery, Texas Children's Hospital,
Houston, TX, USA

V. Arlet
Department of Orthopaedic Surgery,
University of Virginia, Charlottesville, VA, USA

J. A. Ouelett
Department of Orthopaedic Surgery,
McGill University Health Center, Montreal, QC, Canada

medial border of the pedicle and the lateral margin of the apical vertebral body are assigned modifier “B”, and large lumbar curves where the apical vertebra is translated so far laterally that the CSVL does not intersect any part of the apical vertebral body are assigned modifier “C” [13, 15]. Although selective thoracic fusion may be considered in patients with A and B lumbar curves, with type C curves, there is an increased risk of postoperative lumbar curve progression or decompensation [3, 12, 13, 17].

To improve curve correction as well as limit the distal extent of the fusion, authors have added anterior discectomies and interbody fusion over the lumbar curve to posterior segmental thoracolumbar instrumentation. While correction has been substantial, many were left with distal segments tilted out of balance in the coronal plane risking late degeneration.

The use of anterior instrumentation in the lumbar spine is a method to address the therapeutic dilemma of correcting and stabilizing large lumbar curves while sparing clinically and functionally important distal motion segments. Anterior instrumentation is thought to preserve distal fusion levels because the instrumentation can be stopped at the distal Cobb level, while posterior instrumentation alone often requires fusion to the distal stable vertebra [1, 6, 11, 13, 14, 19, 30], in this case, typically to L4 or even L5. To date, reports on anterior instrumentation of thoracic or thoracolumbar curves in adolescent idiopathic scoliosis have focused on the anterior approach as an alternative to posterior instrumentation [1, 13, 18, 19, 29, 30]. Selective anterior instrumentation of thoracic or thoracolumbar curves has shown comparable deformity correction, saving of distal levels, and acceptable maintenance of sagittal profile when comparison with traditional posterior fusion techniques [1, 13, 19, 30].

The purpose of this study was to compare a group of patients with double major curves (Lenke type IIIC) and significant lumbar curves who were first treated with anterior release to L3 fixed with corrective and stabilizing segmental anterior instrumentation followed by posterior instrumentation ending at L3 with a similar group of patients who had the same initial anterior release and fusion to L3 but without segmental anterior instrumentation. Our hypothesis was that the use of rigid segmental anterior instrumentation would more effectively correct and maintain normal coronal alignment in the distal unfused spine and may, in cases save a distal fusion level compared with traditional posterior fusions to L4.

Materials and methods

The authors retrospectively reviewed the records of 15 skeletally immature patients with double major curves with

large lumbar curves (greater than 70°) who underwent spinal fusion for idiopathic adolescent scoliosis between January 1995 and December 2002. The average age of the patients at surgery was 13.9 years (range 12–15 years), and the corresponding average Risser stage was 1.06 (range 0–2). There were 14 females and one male. The procedures were performed by the senior authors (VA, JAO, KBW). The mean follow-up period for all patients was 4.5 years (range 2.5–7 years). Patients selected for inclusion had a large preoperative lumbar curvature (mean 64.9°, range 42°–77°). Based on preoperative radiographs, all of the patients had double major type IIIC [13–15].

Subjects were divided into two groups: seven patients underwent anterior release to L3 with segmental anterior instrumentation to effect an anterior derotation–translation maneuver followed by posterior thoracolumbar instrumentation (Group 1). Eight patients with similar preoperative deformities were similarly treated with a first stage anterior discectomy and fusion alone from T11 to T12 to L3, but without any anterior instrumentation (Group 2).

The surgical technique consisted of a two stage approach, all on the same day. The first stage consisted of anterior discectomies with interbody fusions using iliac crest and/or rib allograft bone over the thoracolumbar curve. Those patients in Group 1 then subsequently had transvertebral screw placement, a single longitudinal rod, and a derotation–translation maneuver to effect curve correction and horizontalization of the distal instrumented vertebrae. The decision to instrument anteriorly (Group 1) was based on the inability of L3 to bend into the stable zone and the surgeon preference to avoid fusion to L4. The number of instrumented anterior levels depended on the rigidity of the lumbar curve and whether apex of the curve was a disk or a vertebral body. When the curve had an apical disk, four lumbar vertebral bodies were instrumented anteriorly. Three were instrumented with an apical vertebral body. In Group 2, L4 was included in the posterior construct when the L4 tilt measured greater than 15° and the L3 vertebral body bent into the stable zone.

Thoracic and lumbar coronal and sagittal curves were measured using the Cobb method on preoperative and postoperative long-cassette standing upright anteroposterior (AP) radiographs. Side bending views were obtained supine. The measurements were performed by a senior author (KWB) and two research assistants. Using preoperative coronal curve measurements, the side bending curve correction for the thoracic and lumbar curves was calculated. The flexibility index was derived by subtracting the percentage of side bending thoracic curve correction from the percentage of side bending lumbar curve correction as described by King [11]. Lateral trunk shift was assessed as the distance measured in cm from the plumb-line dropped from C7 to the sacrum [12]. Apical vertebral

translation (AVT) was defined as the distance from the middle of the lumbar apical vertebral body to the CSVL [12]. The distance from the C7 vertical plumb line to the CSVL was also measured. Apical vertebral rotation (AVR) was measured using Nash–Moe criteria and rating scale [24]. The coronal tilt of L4 and L5 was also measured relative to a line drawn perpendicular to the CSVL. Shoulder imbalance was also measured in cm from the horizontal. Sagittal thoracic alignment was measured using the Cobb method from T2 to T12 on standing lateral radiographs. Thoracic and thoracolumbar/lumbar curve percent correction were calculated by dividing the preoperative coronal curve Cobb angle measurements by the postoperative coronal curve Cobb angle measurements using the same reference vertebrae for each curve. *P*-values were calculated using a Mann–Whitney test.

Results

There were no significant intraoperative or postoperative complications in this series of 15 patients. No pseudarthrosis or implant failures were noted on follow-up radiographs. None of the patients in this study had neurological or vascular injuries in association with their anterior or posterior procedures. There were no significant differences in operative time, blood loss, hospital stay, instrumentation costs, or postoperative pain between the two groups. From a clinical perspective, there were no differences in clinical trunk balance, shoulder symmetry, or pelvis symmetry.

Preoperative thoracic shift in Group 1 was 2.8 cm (range 1–4.7 cm), and in Group 2, it was 2.6 cm (range

0–4.1 cm). The Group 1 preoperative lumbar apical vertebral translation averaged 3.96 cm (range 3.5–5.1 cm) versus 3.29 cm (range 2.0–4.2 cm) in Group 2. The preoperative distance from the C7 plumb line to the CSVL was 0.43 cm to the left in Group 1 (range –1 to 2 cm) and 0.06 cm to the left in Group 2 (range –0.5 to 1.5 cm). Thoracic kyphosis measured from T2 to T12 was 32° in Group 1 (range 6°–65°). In Group 2, thoracic kyphosis was 35° (range 16°–47°).

The average preoperative main thoracic coronal Cobb angle measurement in Group 1 was 75.1° (range 51°–90°), decreasing to 43.1° (range 22°–54°) with side bending (Figs. 1, 2). In Group 2, the mean measurement was 58° (range 40°–78°), decreasing to 39.63° (range 21°–60°) with side bending. The average preoperative thoracolumbar / lumbar Cobb angle measurement in Group 1 was 69.71° (range 44°–82°), decreasing to 29.6° on side bending (range 10°–42°). In Group 2 the mean preoperative thoracolumbar/lumbar Cobb angle was 59.1° (range 42°–76°), which decreased to 31° (range 18°–54°) with side bending. There was no statistical difference between the groups with respect to side bending measurements of the main thoracic (*P* = 0.5244) or thoracolumbar/lumbar curves (*P* = 0.9999). Preoperative L4 and L5 tilt averaged 25° (range 15°–35°), and 13° (range 8°–16°), respectively, in Group 1; in Group 2, L4 and L5 tilt averaged 24° (range 12°–32°) and 14° (range 7°–21°), respectively, (Table 1).

In Group 1, an average of 12.3 levels (range 11–13) were fused (Fig. 3) versus an average of 12.6 levels (range 11–14) in Group 2. For all of the patients in Group 1, the last instrumented vertebra was L3, while in Group 2, six (75%) of the patients received posterior instrumented

Fig. 1 Preoperative standing radiographs of a 14-year-old girl, Risser 1, with a double major curve

Fig. 2 Side bending views **Table 1** Curve correction data, mean values

	Group 1	Group 2	<i>P</i> -value
Age at surgery (years)	13.75 (12–14.5)	13.95 (12–15)	0.9079
Risser stage	0.85 (0–2)	1.29 (0–3)	0.4875
No. of levels fused	12.3 (11–13)	12.57 (11–14)	0.8622
Main thoracic curve (coronal), preop	75.14 (51–90)	58 (40–78)	0.0323
Main thoracic bending curve (coronal), preop	43.14 (22–54)	39.63 (21–60)	0.5244
Thoracic kyphosis, preop	32.14 (6–65)	34.5 (16–47)	0.7285
Main thoracic curve (coronal), postop	25.57 (16–36)	25.5 (17–51)	0.6838
Main thoracic coronal curve correction (%)	65.74 (55–77.1)	55.13 (27–70.5)	0.2472
Thoracic kyphosis, postop	33.43 (21–45)	34.5 (28–45)	0.4179
Thoracolumbar curve (coronal), preop	69.71 (44–82)	59.13 (42–76)	0.0562
Thoracolumbar bending curve (coronal), preop	29.57 (10–42)	31 (18–54)	0.9999
Thoracolumbar curve (coronal), postop	21.29 (14–29)	26.63 (14–59)	0.6434
Thoracolumbar coronal curve correction (%)	69.51 (64–76.4)	58.36 (9.2–75.4)	0.4519
Thoracic shift, preop (cm)	2.76 (1–4.7)	2.64 (0–4.1)	0.7723
Thoracic shift, postop (cm)	0.76 (0–1.8)	1 (0.5–2)	0.4519
Lumbar shift, preop (cm)	3.96 (3.5–5.1)	3.29 (2–4.2)	0.1325
Lumbar shift, postop (cm)	1.06 (0.5–2)	1.31 (0.5–3)	0.4758

fusion to L4. In the other two patients in Group 2 (25%), the last instrumented vertebra was L3. The mean postoperative correction in the thoracic spine was 65.74 (range 55–77.1%) in Group 1 and 55.13 (range 27–70.5%) in Group 2. The average lumbar correction was 69.51% (range 64–76.4%) in Group 1 and 58.36% (range 9.2–75.4%) in Group 2. The distance from the C7 plumb line to the center sacral vertical line was 0.29 cm to the left in Group 1 (range –1 to 0 cm) and 0.29 cm to the left in Group 2 (range –1.5 to 0 cm) (Table 2). The tilt of L4 postoperatively was 5°, respectively, (range 1°–11°) in Group 1 and 12° (range 2°–28°) in Group 2. The L5 postoperative tilt was 3° in Group 1 (range 1°–7°) and 9° in Group 2 (range 2°–18°) (Table 3). Statistical difference was noted between the postoperative tilts of L5 in the two groups ($P = 0.0372$). At final follow-up, the tile of L4 was

maintained at 6° (2°–13°) in Group 1 and 15° (range 3°–29°) in Group 2. The L5 tilt was 3° (range 1°–8°) in Group 1 and 11° in Group 2 (range 3°–20°).

Discussion

Surgical management of patients with adolescent idiopathic scoliosis and double major curves with a large lumbar component has traditionally been accomplished with posterior segmental instrumented fusion often with an anterior thoracolumbar release to improve correction. In severe curves, or those with significant horizontal tilt to L3 or L4, the fusion often extends to L4. Fusion to L4 or below, however, leaves few residual mobile distal lumbar segments and results in increased stress concentration

Fig. 3 Postoperative radiographs at 8 years follow-up **Table 2** Coronal balance, mean values*

	Group 1	Group 2	<i>P</i> -value
C7 plumb line (cm), preop	−0.43 (−1 to 2)	−0.06 (−0.5 to 1.5)	0.4519
C7 plumb line (cm), postop	−0.29 (−1 to 0)	−0.29 (−1.5 to 1)	0.7015
Shoulder imbalance (cm), preop	0.79 (0.5–1.5)	1.43 (0.5–2.5)	0.1252
Shoulder imbalance (cm), postop	−0.43 (−2 to 0.5)	0.5 (−1 to 1.5)	0.0845

* Negative values indicate translation to the left; positive values indicate translation to the right

Table 3 L4, L5 tilt, mean values

	Group 1	Group 2	<i>P</i> -value
L4 tilt (preop)	25 (15–35)	24 (12–32)	0.7285
L5 tilt (preop)	13 (8–16)	14 (7–20)	0.6025
L4 tilt (postop)	5 (1–11)	12 (2–28)	0.1832
L5 tilt (postop)	3 (1–7)	9 (2–18)	0.0372

below the fusion construct and hypermobility of the remaining lumbar discs [4, 20]. These biomechanical factors may accelerate degenerative changes in the unfused lumbar spine and result in low back pain or radiographic signs of degeneration associated with coronal tilting of the last instrumented vertebra (LIV) or caudal unfused lumbar vertebrae, junctional scoliosis, or retrolisthesis [4, 8, 26, 32]. Rotation or angulation at the LIV or below may also lead to sagittal or coronal decompensation. Richards et al. [25] reported that persistent postoperative coronal plane obliquity between L4 and the pelvis was associated with greater overall truncal shift, and Schwender [28] has emphasized the role of lumbosacral hemicurves in the development of coronal decompensation.

We hypothesized that in addition to the initial anterior release, the use of segmental anterior instrumentation and manipulation of large lumbar curves in the context of Lenke type IIIC deformities with significant tilting of L4 and L5 would have a dual benefit—saving distal levels and improving the coronal and sagittal profile of the distal unfused lumbar segments. Indirect evidence in support of this proposition may be found in reports regarding selective anterior fusion of thoracic curves showing superior coronal, sagittal and rotational correction of the thoracic curve and concomitant improvement in the three-dimensional alignment of compensatory lumbar curves [1, 7, 9, 19, 31, 33]. Others have further suggested that anterior segmental instrumentation of rigid or large major curves may be preferable to PSF as a result of a more significant rotational correction achievable through the anterior approach [21, 32].

Improved alignment of distal unfused lumbar segments after anterior instrumented fusion in comparison with posterior techniques may be attributable to differences in rotational, sagittal or coronal compression forces as a result of anterior instrumentation [13]. Particularly relevant to the results presented here, Kaneda [10] reported 83–97% improvement in the lower end vertebra tilt angle in 25

patients followed for three years after anterior multisegmental instrumentation of large thoracolumbar and lumbar curves. Lowe [19] has further indicated that important predictive factors for good clinical and radiographic postoperative results included correction of the fractional lumbosacral curve and lowest instrumented vertebra angulation.

Our results also support the hypothesis that initial anterior instrumented fusion of large (Lenke lumbar modifier “C”) curves may enable the sparing of distal fusion levels. Among the seven patients in Group 1, none required fusion below L3, and there was no evidence of coronal or sagittal plane decompensation at a minimum of 2.5 year follow-up. In the group of eight patients undergoing posterior instrumentation and fusion with only predicate anterior release and fusion of the lumbar curve, 75% required fusion to L4. These findings are consistent with existing literature showing that anterior instrumentation may allow for the sparing of distal motion segments by fusion from Cobb to Cobb end vertebrae rather than requiring fusion to the distal stable vertebra as is the case with traditional posterior techniques [1, 11, 13, 15, 19, 22, 30].

Data we present further suggests that initial anterior segmental instrumentation and manipulation (e.g. derotation, translation) appears to result in improved alignment of the distal unfused lumbar segments. Assessing postoperative coronal tilt of the L4 and L5 vertebrae, correction of the lumbosacral hemicurve was significantly better among subjects in Group 1 after anterior instrumentation. Postoperative tilt of the LIV greater than 5° has been shown to be associated with worsening of correction at long-term follow-up in curves with Lenke C lumbar modifiers [34].

One weakness of this study is the heterogeneous nature of the posterior instrumentation procedures grouped together in each of the study arms, especially in regard to the length of the posterior instrumented fusion. We chose to instrument anteriorly to test the hypothesis that we could gain and maintain better correction with fewer fused levels. Although the patients were not randomized, they were followed prospectively. The relatively small number of patients included in each study group may also result in low statistical power.

Despite the advantages of saving distal fusion levels and improved alignment of the distal unfused segment that our data suggest result from initial anterior instrumentation, a larger, prospective, randomized study would be required to establish long term clinical or radiographic benefit. Inclusion of clinical data, especially regarding the development of low back pain, would also be instructive in future studies, as disagreement persists among published reports regarding whether radiographic degenerative changes including narrowing of disc spaces, osteophytosis and facet

joint hypertrophy that develop in distal motion segments after posterior fusion to the low lumbar spine consistently result in low back symptoms [4, 8, 23, 27, 32]. It is also possible that the use of multisegmental posterior instrumentation using modern pedicle screw systems which can effect three-dimensional changes in vertebral alignment may, in part, obviate the need for supplemental anterior instrumentation. Pedicle screw constructs may provide similar corrections in large curves (> 90°) without the morbidity of anterior approaches [5]. Multisegmental use of pedicle screws, even in the lumbar spine, may not always be possible, however, especially in the relatively less mature individual, due to the pedicle malformations associated with idiopathic scoliosis [16]. The balance of these factors, however, is thus far unproved.

References

1. Betz RR, Harms J, Clements DH III, Lenke LG, Lowe TG, Shufflebarger HL, Jeszenszky D, Bruno B (1999) Comparison of anterior and posterior instrumentation for correction of adolescent thoracic idiopathic scoliosis. *Spine* 24:225–239
2. Bradford DS (1979) Anterior spinal surgery in the management of scoliosis: Indications-techniques-results. *Orthop Clin North Am* 10:801–12
3. Bridwell KH, McAllister JW, Betz RR, Huss G, Clancy M, Schoenacker PL (1991) Coronal decompensation produced by Cotrel–Dubousset “derotation” maneuver for idiopathic right thoracic Scoliosis. *Spine* 16:769–77
4. Cochran T, Irstam L, Nachemson A (1983) Long-term anatomic and functional changes in patients with adolescent idiopathic scoliosis treated with Harrington rod fusion. *Spine* 8: 576–84
5. Dobbs MB, Lenke LG, Bridwell KH (2005) Comparison of combined anterior/posterior fusion alone for the treatment of adolescent idiopathic curves greater than 90 degrees. Book of abstracts. Scoliosis Research Society. 40th annual meeting, October 2005, pp 44–45
6. Dwyer AF, Schafer MF (1974) Anterior approach to scoliosis: results of treatment in 51 cases. *J Bone Joint Surg Br* 56:218–224
7. Edwards CC, Lenke LG, Peele M, Sides B, Rinella A, Bridwell KH (2004) Selective thoracic fusion for adolescent idiopathic scoliosis with C Modifier Lumbar curves: 2–16 year radiographic and clinical results. *Spine* 29:536–546
8. Ginsburg HH, Goldstein LA, Robinson SC, et al (1979) Back pain in postoperative idiopathic scoliosis: long-term follow up study. *Spine* 4:518
9. Kaneda K, Shono Y, Satoh S, Abumi K (1997) Anterior correction of thoracic scoliosis with Kaneda anterior spinal system: a preliminary report. *Spine* 22:1358–68
10. Kaneda K, Shono Y, Satoh S, Abumi K (1996) New anterior instrumentation for the management of thoracolumbar and lumbar scoliosis: application of the Kaneda two-rod system. *Spine* 21:1250–1261
11. King HA, Moe JH, Bradford DS, Winter RB (1983) The selection of fusion levels in thoracic idiopathic scoliosis. *J Bone Joint Surg Am* 65:1302–1313
12. Lenke LG, Bridwell K, Baldus C, Blanke K (1992) Preventing decompensation in King Type II curves treated with Cotrel–Dubousset instrumentation: strict guidelines for selective fusion. *Spine* 17S:274–81

13. Lenke LG, Betz RR, Bridwell KH, Harms J, Clements DH, Lowe TG (1999) Spontaneous lumbar curve coronal correction after selective anterior or posterior thoracic fusion in adolescent scoliosis. *Spine* 24:1663–72
14. Lenke LG, Betz RR, Haheer TR, Lapp MA, Merola AA, Harms J, Shufflebarger HL (2001) Multisurgeon assessment of surgical decision-making in adolescent idiopathic scoliosis. *Spine* 26:2347–2353
15. Lenke L, Betz R, Harms J, Bridwell KH, Clements DH, Lowe TG, Blanke K (2001) Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. *J Bone Joint Surg Am* 83:1169–81
16. Liljenqvist UR, Allkemper T, Hackenberg L, Link TM, Steinbeck J, Halm HH (2002) Analysis of vertebral morphology in idiopathic scoliosis with use of magnetic resonance imaging and multiplanar reconstruction. *J Bone Joint Surg Am* 84:359–368
17. Lonstein J. Decomensation with Cotrel–Dubousset instrumentation: a multicenter study (1991) 25th Anniversary Meeting of the Scoliosis Research Society, Minneapolis, MN, September, 1991
18. Lowe TG, Alongi PR, Smith DAB, O'Brien MF, Mitchell SL, Pinteric RJ (2003) Anterior single rod instrumentation for thoracolumbar adolescent idiopathic scoliosis with and without use of structural interbody support. *Spine* 28:2232–2242
19. Lowe TG, Betz R, Lenke L, Clements D, Harms J, Newton P, Haheer T, Merola A, Wenger D (2003) Anterior single-rod instrumentation of the thoracic and lumbar spine: saving levels. *Spine* 28:S208–S216
20. Luk KDK, Lee FB, Leong JCY, Hsu LCS (1987) The effect on the lumbosacral spine of long spinal fusion for idiopathic scoliosis: a minimum of 10 year follow-up. *Spine* 12:996–1000
21. Luk KDK, Leong JCY, Reyes L, Hsu LCS (1989) The comparative results of treatment in idiopathic thoracolumbar and lumbar scoliosis using the Harrington, Dwyer, and Zielke instrumentations. *Spine* 14:275–280
22. McCance SE, Denis F, Lonstein JE, et al (1998) Coronal and sagittal balance in surgically treated adolescent idiopathic scoliosis with the King II curve pattern: a review of 67 consecutive cases having selective thoracic arthrodesis. *Spine* 23:2063–72
23. Moskowitz A, Moe JH, Winter RB, Binner H (1980) Long-term follow-up of scoliosis fusion. *J Bone Joint Surg Am* 62:364–76
24. Nash CL Jr, Moe JH (1969) A study of vertebral rotation. *J Bone Joint Surg Am* 51:223–229
25. Richards BS (1992) Lumbar curve response in type II idiopathic scoliosis after posterior instrumentation of the thoracic curve. *Spine* 17:S282–6
26. Richards BS, Birch JG, Herring JA, Johnston CE, Roach JW (1989) Frontal plane and sagittal plane balance following Cotrel–Dubousset instrumentation for idiopathic scoliosis. *Spine* 14:733–737
27. Rinella A, Bridwell K, Kim Y, Rudzki J, Edwards C, Roh M, Lenke L, Berra A (2004) Late complications of adult idiopathic scoliosis primary fusions to L4 and above. *Spine* 29:318–325
28. Schwender JD, Denis F (2000) Coronal plane imbalance in adolescent idiopathic scoliosis with left lumbar curves exceeding 40 degrees: the role of the lumbosacral hemicurve. *Spine* 25:2368–2363
29. Suk SI, Choon KL, Chung SS (1993) Comparison of Zielke ventral derotation system and Cotrel–Dubousset instrumentation in the treatment of idiopathic lumbar and thoracolumbar scoliosis. *Spine* 19(4):419–429
30. Sweet FA, Lenke LG, Bridwell KH, Blanke KM (1999) Maintaining lumbar lordosis with anterior single solid-rod instrumentation in thoracolumbar and lumbar adolescent idiopathic scoliosis. *Spine* 24:1655–62
31. Sweet FA, Lenke LG, Bridwell KH, Blanke KM, Whorton J (2001) Prospective radiographic and clinical outcomes and complications of single solid rod instrumented anterior spinal fusion in adolescent idiopathic scoliosis. *Spine* 26:1956–1965
32. Takahashi S, Delecun J, Passuti N (1997) Changes in the unfused lumbar spine in patients with idiopathic scoliosis: a 5–9 year assessment after Cotrel–Dubousset instrumentation. *Spine* 22:517–523
33. Turi M, Johnston CE, Richards BS (1993) Anterior correction of idiopathic scoliosis using TSRH instrumentation. *Spine* 18:417–422
34. Yazici M, Cil A, Pekmezci M, Acaroglu E, et al (2005) The effects of residual lower end vertebral tilt on the outcome of surgical correction in patients with AIS. Book of abstracts. Scoliosis Research Society. 40th annual meeting, October 2005, p 176