Enhanced Capacity for Spontaneous Correction of Lumbar Curve in the Treatment of Major Thoracic–Compensatory C Modifier Lumbar Curve Pattern in Idiopathic Scoliosis

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Study Design. Retrospective radiographic review.

Objective. To evaluate the outcome of maximal selective thoracic correction with controllable corrective forces provided by cantilevel bending technique (CBT) for idiopathic scoliosis (IS) in the presence of widely deviated compensatory lumbar curve.

Summary of Background Data. Current intraoperative instrumentation and fusion techniques for selective fusion involve undercorrection of the thoracic curve while allowing for spontaneous lumbar curve correction and maintaining overall coronal balance. Since the lumbar curve is nonstructural and compensatory, procedures for selective thoracic fusion should approximate the best possible correction of thoracic curve such that resultant spontaneous lumbar curve correction and compensation is maximized.

Methods. Thirty-seven consecutive IS patients with main thoracic compensatory minor "C" modifier lumbar curves underwent maximal selective thoracic correction by CBT at a single institution. Radiographs were analyzed before surgery, immediately after surgery, and at most recent follow-up (range, 2–6 years).

Results. A mean 83% thoracic correction was closely matched by a 81% lumbar correction at most recent follow-up. The mean thoracic curve correction/flexibility ratio was 2.4. Enhanced capacity for spontaneous correction of lumbar curve was evidenced by the mean correction/flexibility ratio of 1.2. Spontaneous correction of lumbar apical translation occurred in all patients. Global coronal imbalance was common before surgery (mean, 11 mm), and remained similarly so after surgery (mean, 12 mm).

Conclusion. Use of CBT facilitates 3-dimensional control of corrective forces and allows for maximum selective instrumentation-assisted thoracic and spontaneous lumbar curve correction in patients with Lenke 1C or 2C IS.

Key words: cantilevel bending technique, controllable corrective forces, correction/flexibility ratio, selective fusion, spontaneous correction, undercorrection.

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The treatment of major thoracic-compensatory lumbar idiopathic scoliosis (IS) curve patterns (*e.g.*, King II, Lenke1B, 1C, 2B and 2C) by selective thoracic fusion remains controversial. Ideally, after selective thoracic fusion, the unfused lumbar curve will spontaneously accommodate to the corrected position of the thoracic curve. Although selective fusion has the advantage of preserving lumbar motion segments, it may in certain cases result in postoperative coronal decompensation.[1–4] Inappropriate curve selection and/or excessive thoracic correction have been identified as the most common etiologies.[1,3,4]

Lenke *et al*[5] describe a surgical classification system for adolescent IS that specifically quantifies the structural aspects of regional scoliosis curve based on relative curve magnitude, flexibility, and position. They established structural criteria for nonstructural and compensatory lumbar curve. Preparation for selective fusion begins with careful radiographic analysis of the Lenke curve pattern. Ratio criteria for main thoracic curve (MT) and compensatory lumbar curve (CL), structural characteristics pertaining to Cobb magnitude, apical vertebral translation (AVT) and apical vertebral rotation (AVR), and flexibility ratios must also be assessed. It is thought that, when the ratio of the major curve intended for selective fusion to the minor compensatory curve is >1.2, selective fusion should be possible.[4–6]

Since the lumbar curve is compensatory, the development of the lumbar curve is dependent on the development of the thoracic curve. Kalen and Conklin[7] found that the behavior of the noninstrumented lumbar curve echoed that of the thoracic curve in the frontal plane, with both having nearly equal percentage of correction to maintain proper alignment. This is precisely the finding Lenke *et al*[8] noted in their observation of spontaneous lumbar curve coronal correction after selective thoracic fusion. Therefore, we thought that intraoperative techniques for selective thoracic fusion should provide optimal correction of the thoracic curve so that the lumbar curve can echo, and hence maximize, spontaneous correction and maintain coronal balance. This is certainly not a concept that most would agree with. Surgeons usually err on being cautious in obtaining too much thoracic correction since decompression with a left trunk shift is a resulting problem. Current instrumentation and fusion techniques for selective thoracic fusion lead to undercorrection of the thoracic curve. Hence,
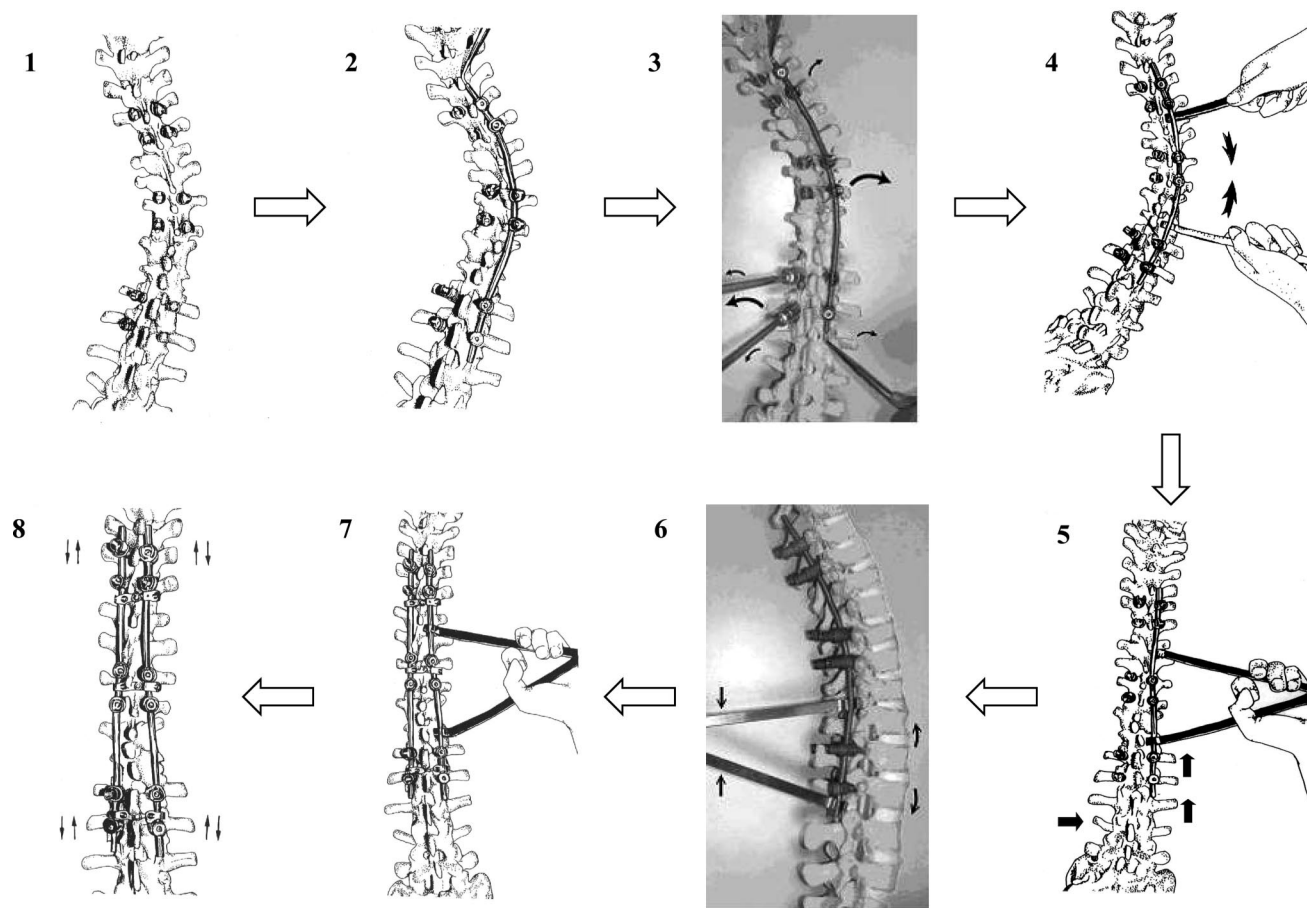
Figure 1. Cantilever bending technique to provide controllable corrective forces for selective thoracic fusion.

there is a conflict between our hypothesis and current practical application. The technique used in this study facilitates optimal correction of thoracic curve, and enhanced spontaneous compensation and correction of the lumbar spine to maximize lumbar correction and avoid postoperative decompensation. To our knowledge, the use of such a technique has not yet been reported.

■ **Materials and Methods**

Thirty-seven consecutive patients with major thoracic, compensatory "C" modifier lumbar IS curves, in which the lumbar curve bent to <25°, lacked a junctional thoracolumbar kyphosis of ≥20° between T10 and L2, the ratio criteria of MT:CL Cobb magnitude, AVT and AVR were all >1.2, were treated with selective thoracic fusion at a single institution between 2001 and 2004. Clinical and radiographic follow-up was for a minimum of 2 years.

In each patient, the central sacrum vertical line (CSVL) was completely medial to all portions of the lumbar apical vertebral body (lumbar modifier C). Procedures involved a posterior approach with the distal fusion level ending at L1 or above in all cases. The lowest level of instrumentation and fusion was the stable vertebra at T12 (n = 20) or L1 (n = 17).

Surgical Techniques. We used cantilever bending technique (CBT) to correct the thoracic curve. The surgical procedures have been described previously.[9,10] Three important procedures were used to control the corrective forces for correction

of thoracic curve (Figure 1, nos. 3, 5, 6). The technique is described as follows.

In patients undergoing surgical correction, 6 groups of pedicle screws were inserted on the upper, apical, and lower segments on both sides of the thoracic curve (Figure 1, no. 1). After the pedicle screw was positioned, a prebent rod was connected to the pedicle screws on the convex side (Figure 1, no. 2). The apical portion of the implant was tightened first. Derotation of the apex of the thoracic curve was achieved by derotating the convex rod with a hexangular wrench while rotating the lower and upper segments of the thoracic curve in the opposite direction by rotating the pedicle screws on the lower and upper segment of the thoracic curve at the concave side with 2 or 3 screwdrivers (Figure 1, no. 3). While this was being performed, pedicle screws on the lower and upper segment of the thoracic curve at the convex side were locked tightly. This procedure facilitates freezing of the corrective detorque for the thoracic curve in the curve and tries to initiate corrective torsion for the lumbar curve or the proximal thoracic curve at the lower and upper segment of thoracic curve. Two long *in situ* benders were secured to the convex side of the rod (above and below the attachment of the apical pedicle screws) in the coronal plane to provide lever arms (Figure 1, no. 4). Bringing the free ends of the lever arms closer together generates a powerful force to correct the curve in the coronal plane. This maneuver lifts the convex lower thoracic spine and subsequently pulls up the concavity of the upper lumbar curve, thereby shifting it to the midline (Figure 1, no. 5). If necessary, a further 2 long *in situ*

benders were secured to the rod above and below the attachment of pedicle screws at the lower segment of the thoracic curve in the sagittal plane. These benders act as lever arms in the sagittal plane and can correct and/or prevent junctional kyphosis with separate application of lordotic corrective force *via* cantilever bending (Figure 1, no. 6). A rod prebent to conform to the corrected curve was secured to the screws on the concave side, thus supporting and maintaining the corrected curvature (Figure 1, no. 7). After connecting both rods by transverse links and finely adjusting the end vertebrae according to the intraoperative posteroanterior radiographs to balance the body, the lever arms were released (Figure 1, no. 8). The *in situ* benders were not removed until the corrected curvature was rigidly fixed.

Radiographic Evaluation. Preoperative long-cassette standing upright anteroposterior (AP) and lateral radiographs, as well as right and left supine best-effort side bending coronal radiographs, were independently reviewed. Standing long cassette AP and lateral radiographs from preoperative, immediate postoperative, and most recent follow-up were evaluated to determine changes in radiographic characteristics. Coronal and sagittal curves were measured according to the Cobb method. The junctional kyphosis between the major and secondary curve was noted. Curve types were classified according to the Lenke *et al* classification system.[5]

All patients in this study had a definite C lumbar modifier position before surgery. The stable vertebra was defined as being the most proximal lumbar or lower thoracic vertebra bisected (or nearly bisected) by the CSVL. If a disc was nearly bisected, then the next caudad vertebra was chosen as the stable vertebra. The stable vertebra was the distal level of instrumentation and fusion.

Curve flexibility was determined by measuring the proximal thoracic curve (PT), MT, and CL curve magnitudes on the preoperative standing AP and lateral, and supine right and left best-effort side bending radiographs. Flexibility and correction for the PT, MT, and CL curves were determined. Flexibility was calculated as follows: preoperative standing posterior-anterior Cobb angle − side-bending Cobb angle/preoperative standing posterior-anterior Cobb angle × 100%. Correction was calculated as follows: preoperative standing posterior-anterior Cobb angle − postoperative standing posterior-anterior Cobb angle/preoperative standing posterior-anterior Cobb angle × 100%. The correction/flexibility ratio (C/F) was calculated for the major and secondary curves to reflect surgical correction with relation to side-bending flexibility for the thoracic curve, and spontaneous correction with relation to flexibility for the lumbar curve.

Additional criteria measured from the AP radiograph were MT and CL AVT, and AVR. Apical vertebral translation for the MT curve was measured relative to the coronal C7 plumb line. Apical vertebra translation for the CL curve was measured relative to the CSVL. AVR for the main thoracic and lumbar curves were assessed according to the system devised by Nash and Moe.[6] Global coronal and sagittal balance were determined by measuring the horizontal distance from a vertical line extended from the center of the C7 vertebral body relative to the CSVL and posterior superior corner of S1. When averaging the translational measurement (coronal and sagittal balance), we used absolute values so that positive and negative value do not cancel each other out. Comparisons between preoperative and postoperative measures of balance were made. Each post-

operative radiograph was assessed for evidence of implant failure, loss of fixation, and nonunion.

Statistical Analysis. Descriptive statistical analysis was performed for each dependent variable comparing the preoperative radiographic data to that obtained at the various postoperative time points using a mixed model analysis of variance. Specific comparisons of radiographic criteria were performed by analysis of covariance. Pairwise comparisons of the radiographic data were performed using the Fisher exact test. Statistical significance was set at $P < 0.05$.

■ Results

Of the 37 patients, 34 were female and 3 male. The mean age was 17.3 years (range, 14.3–29.2 years). The mean duration of radiographic follow-up was 3.5 years (range, 2–5 years). Curve types according to the Lenke system were: 1CN (n = 18), 1C- (n = 2), 1C+ (n = 3), 2CN (n = 13), and 2C- (n = 1). Only MT curve was fused for IC curves and both PT and MT curves were fused for IIC curves.

The average preoperative MT curve was 63° (range, 54°–78°). This decreased to 41° (range, 30°–65°) on side bending (flexibility, 35%). The MT curve had corrected to an average 10° (range, 0°–18°) shortly after surgery, and to 11° (range, 0°–19°) at most recent follow-up (correction, 83%). The C/F MT ratio was 2.4 (range, 1.8–13.3).

The average preoperative lumbar curve was 47° (range, 40°–61°). This decreased to 16° (range, 8°–21°) on side bending (flexibility, 66%). In no patient was the CL flexibility lesser then that of the MT curve. The CL curve had corrected to an average 11° (range, 5°–21°) shortly after surgery, and to 9° (range, 5°–18°) at most recent follow-up (correction, 81%). The C/F ratio of CL was 1.2 (range, 0.9–1.6, Figure 2).

The preoperative MT:CL Cobb ratio was 1.34. Preoperative AVT-MT averaged 51 mm (range, 31–93 mm), and AVT-CL averaged 29 mm (range, 23–41 mm). The AVT ratio was 1.76. The preoperative AVR-MT Nash-Moe grade averaged 2.1 (range, 1.8–2.3), and AVR-CL averaged 1.3 for the lumbar curve (range, 1.2–1.5), with an AVR ratio of 1.62. In no patient was the lumbar Cobb magnitude, AVT, or AVR greater than that of the MT curve (Table 1).

All posterior fusions were to the stable vertebra. Lumbar Cobb improvement was evident in each patient who underwent selective MT fusion, and true correction of thoracic and lumbar AVT was consistent. The patients' improvement was based on whether there was any change in the AVT-CL. AVT-CL improved to an average 20 mm immediately after surgery, and to 18 mm (range, 6–23 mm) at final follow-up with a mean correction of 11 mm (range, 8–24 mm). Lumbar apical vertebral translation improved in all patients and led to a change in the lumbar modifier grade (C into A in 16 patients, C into B in 21 patients). AVT-MT improved to 15 mm at final follow-up with a mean correction of 36 mm. Apical
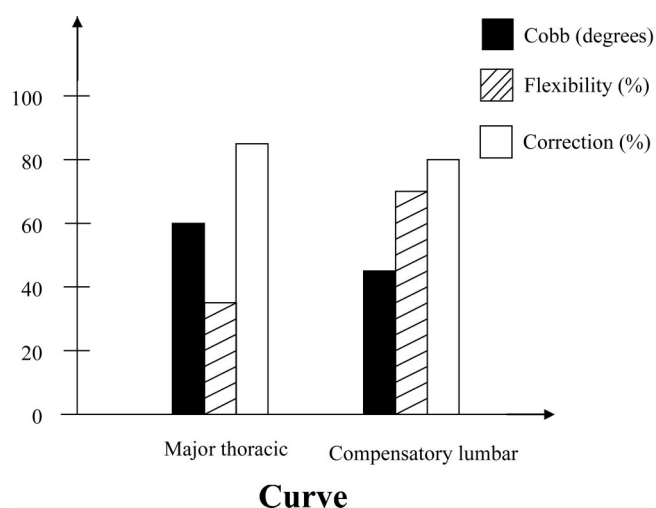
Figure 2. Histogram demonstrating the magnitude, flexibility, and correction of the main thoracic and compensatory lumbar curves. Comparing the column height of correction and flexibility demonstrates that the thoracic curve was overcorrected and the capacity for spontaneous correction of lumbar curve was enhanced. A mean 83% thoracic correction was closely matched by a 81% lumbar correction.

vertebral rotation-CL exhibited inconsistent spontaneous correction after surgery or at later follow-up. The average preoperative AVR-CL was 1.3 Nash-Moe grade. This decreased to 1.1 at final follow-up, but it was not a significant difference in the improvement. The average AVR-MT improved from preoperation 2.1 Nash-Moe grade to latest follow-up 1.9 (range, 1.5–2.1). However, the improvement was not a significant difference (Table 2).

No significant change in the global sagittal balance observed after surgery. The averaged global sagittal balance was 6 mm (range, −16 to 15 mm) before surgery, and 4 mm (range, −14 to 15 mm) at latest follow-up. There was no evidence of increased kyphosis at the thoracolumbar junction (T10–T12) after surgery. The mean

Table 1. Preoperative Radiographic Data in 37 Patients With Lenke 1C or 2C Curve Patterns

Radiographic Factor	Value
Thoracic Cobb (°)	63 (54 to 78)
Lumbar Cobb (°)	47 (40 to 61)
Thoracic flexibility (%)	35
Lumbar flexibility (%)	66
AVT-MT (mm)	51 (31 to 93)
AVT-CL (mm)	29 (23 to 41)
AVR-MT (N-M grade)	2.1 (1.8 to 2.3)
AVR-CL (N-M grade)	1.3 (1.2 to 1.5)
Thoracic/lumbar Cobb ratio	1.34
Thoracic/lumbar AVT ratio	1.76
Thoracic/lumbar AVR ratio	1.62
Thoracolumbar sagittal alignment (°)	−2 (−7 to −5)
Sagittal balance (mm)	6 (−16 to 15)
Coronal balance (mm)	11 (−35 to 25)

Data are presented as the mean or mean (range) unless otherwise specified. MT indicates main thoracic curve; CL, compensatory lumbar curve; AVT, apical vertebral translation; AVR, apical vertebral rotation; N-M, Nash-Moe.

Table 2. Correction in 37 Patients With Lenke 1C or 2C Curve Patterns

Deformity	Preoperative	Ultimate Follow-up	Correction	C/F
MT Cobb (°)	63	11	83%*	2.4
CL Cobb (°)	47	9	81%*	1.2
Coronal balance (mm)	11	12	−1	
Sagittal balance (mm)	6	4	2	
AVT-MT (mm)	51	15	36*	
AVT-CL (mm)	29	18	11*	
AVR-MT (N-M grade)	2.1	1.9	0.2	
AVR-CL (N-M grade)	1.3	1.1	0.2	

Mean values are given.
*Statistically significant change ($P < 0.05$).
MT indicates main thoracic curve; CL, compensatory lumbar curve; AVT, apical vertebral translation; AVR, apical vertebral rotation; N-M, Nash-Moe; C/F, correction/flexibility.

sagittal alignment at the thoracolumbar junction was −2° (range, −7° to 5°) before surgery, and −5° (range, −10° to 1°) after surgery. The mean global coronal balance was 11 mm before surgery (range, −35 to 25 mm) and did not change significantly after surgery (mean, 12 mm; range, −38 to 21 mm) (Table 2). Figures 3 and 4 illustrate representative radiographs.

■ **Discussion**

The goals of surgical treatment for IS are to correct deformity and maintain balance, while fusing the least number of motion segments and avoiding complications. Current selective thoracic fusion techniques provide for the control and partial correction of the major curve while maintaining mobile lumbar motion segments. Numerous reports describe the potential of the unfused lumbar curve to accommodate to the corrected thoracic curve while maintaining global balance.[2,7,8,11,12] Occasionally, the unfused lumbar curve is not able to accommodate to the corrected alignment and position of the thoracic curve, and the development of global imbalance follows. Inappropriate curve selection and/or excessive thoracic correction have been identified as the most common etiologies in this regard.[1,3,4]

In 1983, King et al[12] described a classification system to help surgeons identify those curve types that are most amenable to selective thoracic fusion. Unfortunately, the King system has limited utility in defining the structural nature of specific regional curves. Limitations of the King system in this regard stem from the absence of rigid quantitative criteria by which to assess curve flexibility, as well as suboptimal interobserver and intraobserver reliability in curve classification.[13,14] In 2001, Lenke et al[5] described a new surgical classification system for adolescent idiopathic scoliosis that specifically quantified the structural aspects of regional scoliotic curves based on relative curve magnitude, flexibility, and position as well as sagittal profile and displacement of the lumbar apex from the central sacral vertical line. The system defines many of the false double major curves as Lenke Type 1B and 1C curves. In this curve pattern,
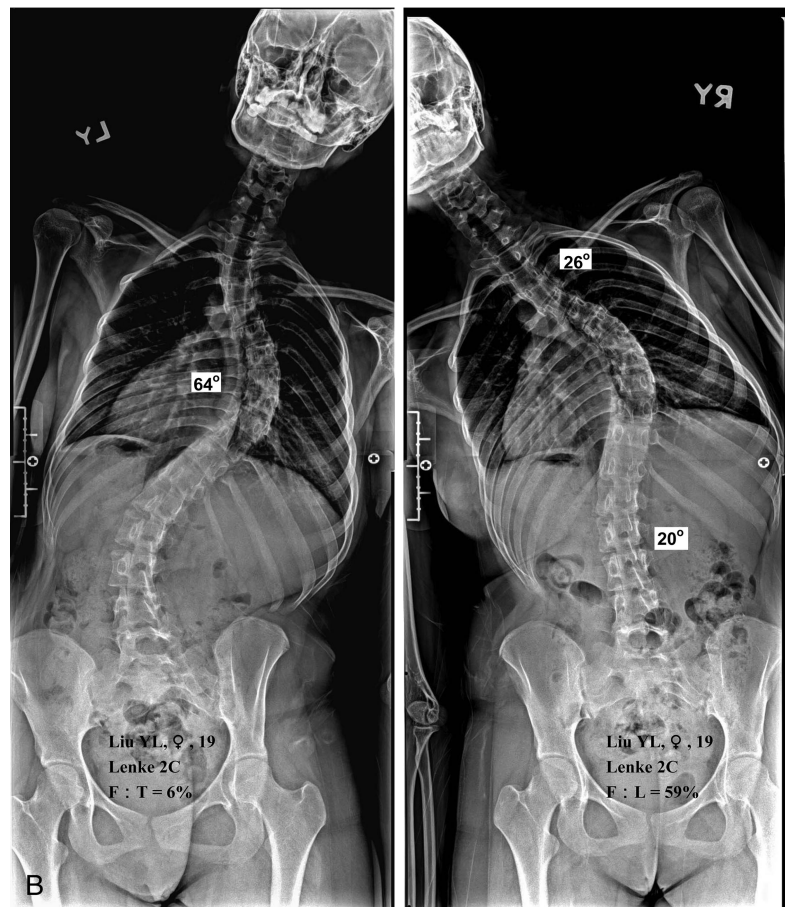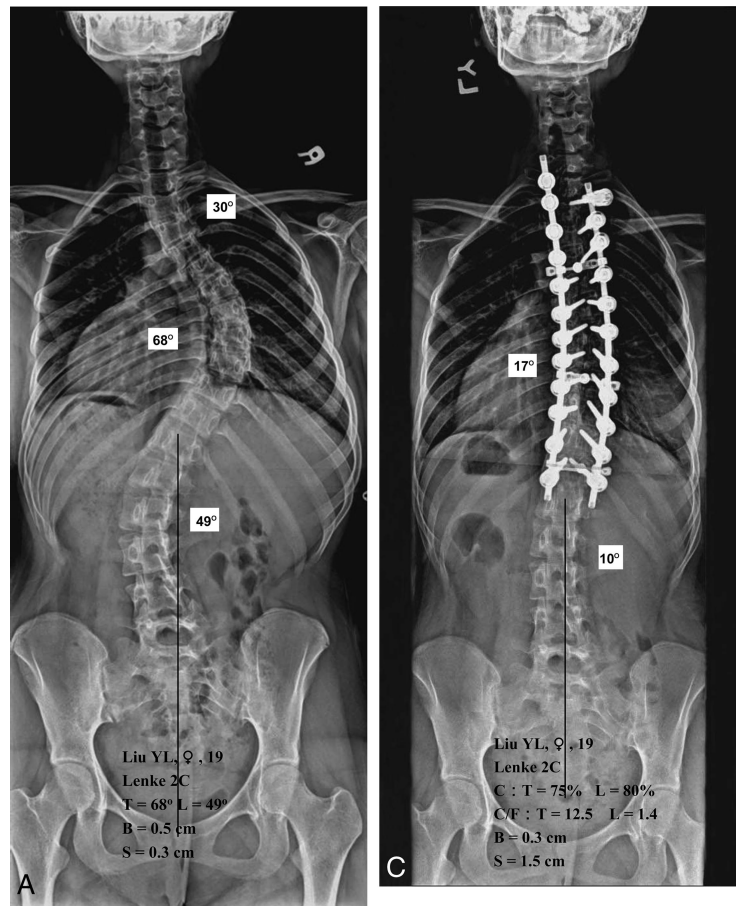
Figure 3. **A**, Preoperative standing coronal radiograph illustrating a patient with a Lenke 2C curve pattern with a 68° thoracic curve and a 49° lumbar curve. **B**, The side bending film shows that the thoracic curve was very rigid, bending to 64° with flexibility of 68 − 64/68 × 100% = 6%. The proximal thoracic curve bent to 26°. The lumbar curve was flexible, bending out to 20° with flexibility of 49 − 20/49 × 100% = 59%. **C**, After selective thoracic correction and fusion by cantilever bending technique, the thoracic curve was corrected to 17° (C = 75%). The C/F ratio was 12.5. It was very much overcorrected. The lumbar curve was spontaneously corrected to 10° (C = 80%), exceeding the original capacity for spontaneous correction. The C/F ratio was 1.4, and balance improved by 2 mm.
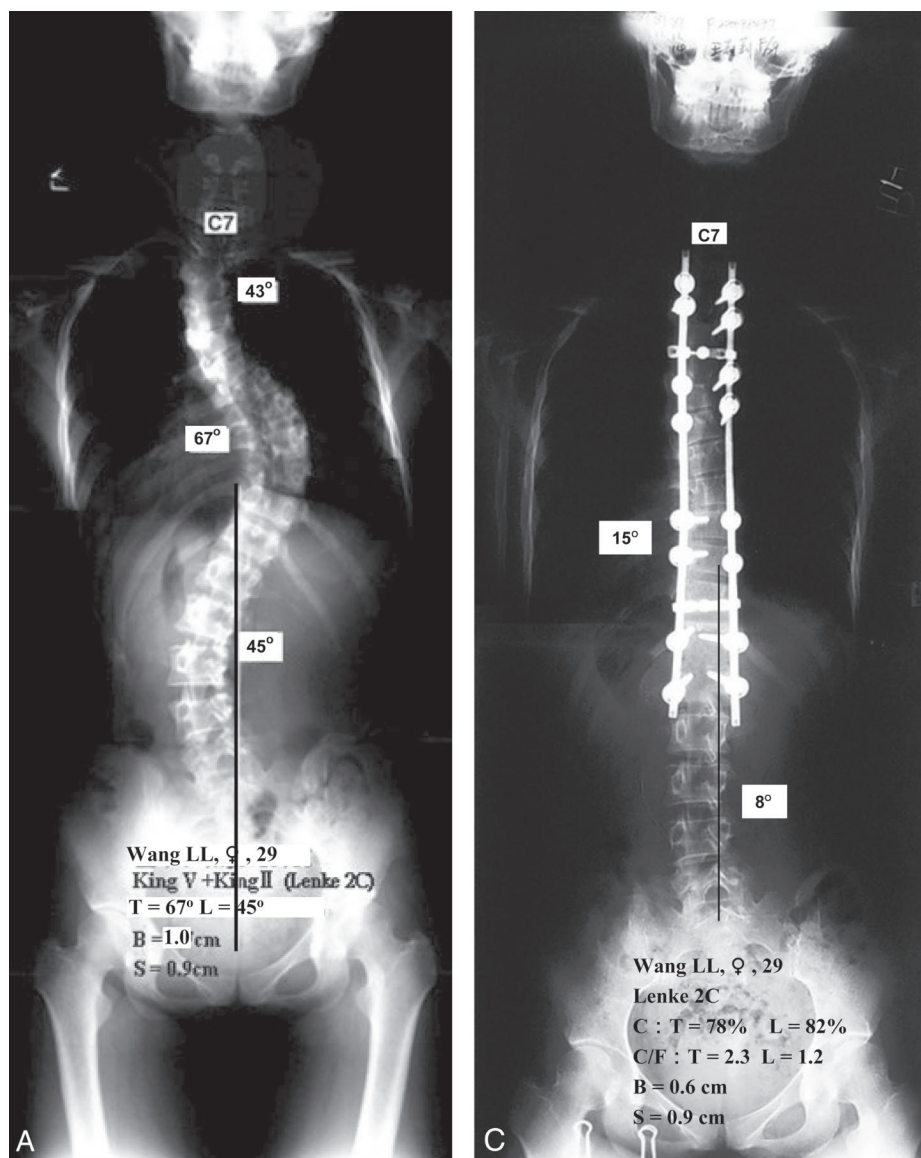
Figure 4. **A**, Upright coronal radiographs illustrate a Lenke 2C curve pattern with a 43° proximal thoracic curve, 67° main thoracic curve, and 45° compensatory lumbar curve. **B**, On the side bending radiographs, the proximal thoracic curve was bent to 35°, and the thoracic and lumbar curves were bent to 44° (F = 34%) and 15° (F = 67%), respectively. **C**, Stranding radiograph 2 years postoperative demonstrates that the thoracic curve was corrected to 15° (C = 78%), with a C/F of 2.3 (meaning overcorrection), and that the lumbar curve was corrected to 8° (C = 82%), with C/F of 1.2 (meaning enhanced capacity for spontaneous correction). Balance improved by 4 mm.

the thoracic curve is the largest curve. The smaller lumbar curve is nonstructural (*i.e.*, has a side-bending Cobb measurement of ≤25°) and has thoracolumbar kyphosis that is <+20°. The system further classifies these curve patterns by the degree of apical displacement of the lumbar apex (A, B, or C). In general, for curves in which the lumbar apical vertebral body is incompletely translated from the midline (lumbar modifier A and B) selective thoracic fusion is recommended. The more challenging curves in which the lumbar apical vertebra is totally translated from the midline (lumbar modifier C) may also be treated with selective thoracic fusion, but the potential for subsequent decompensation is high.

Proposed advantages of the Lenke classification system are the strict criteria used to define the structural character of individual curves and improved intraobserver and interobserver reliability relative to the King system. Lenke also recommended, when contemplating a selective fusion, that it is essential to evaluate the structural criteria present in the MT and CL regions of the spine including ratios of: Cobb magnitude, AVT, AVR, and relative flexibility assessments of the 2 curves.[4,5] The AVR is measured at the apex of both curves using Nash-Moe terminology.[6] Overall, for a selective thoracic fusion to be successful, the MT:CL ratios should be >1.2. The higher the ratio, the greater the likelihood of a successful outcome.[5]

In this consecutive study series, the curve patterns were 1C or 2C, and MT:CL Cobb magnitude, AVT, and AVR were all >1.2. These are consistent with Lenke's report.[5] We chose 1C or 2C curve patterns as the study group because these patterns are more challenging for selective thoracic fusion.

Since the lumbar curve is nonstructural and compensatory, the behavior of the lumbar curve should echo that of thoracic curve in the frontal plane, with both having nearly equal percentage of correction to maintain proper alignment. This is precisely the finding Kalen and Conklin[7] noted in their radiographic evaluation of selective thoracic fusions. Theoretically, the greater the degree of thoracic curve correction, the greater the extent of compensatory spontaneous lumbar curve correction. However, this theory contrasts with the wealth of information regarding selective thoracic fusion, and the suggestion excessive posterior thoracic curve correction may in itself be a causative factor in producing coronal decompensation.[5,15–20] It has been hypothesized that the unfused lumbar compensatory curve cannot compensate for excessive correction of the main thoracic curve and that this therefore results in coronal decompensation. This is most common in those patients with large and deviated lumbar curves, lumbar modifiers "C" as described by Lenke *et al*.[5,8] The lumbar curve can compensate for correction achieved in the thoracic spine, within limits. The degree of correction achieved with surgery must be tempered by the compensatory capacity of the lumbar curve after surgery. Lenke recommended that excess pre-

operative flexibility, *i.e.*, correction/flexibility (C/F) >1, should be avoided in instrumentation of the major thoracic curve.

The current intraoperative instrumentation and fusion techniques used for selective fusion involved undercorrection of the thoracic curve while allowing for potential spontaneous lumbar curve correction and maintaining overall coronal balance. We think that balance and correction of the uninstrumented lumbar curve are dependent on the capacity of the lumbar spine to spontaneously correct and compensate. The preoperative original capacity for spontaneous correction and compensation is indicated by flexibility and balance. Correction of the major thoracic curve could either enhance or impair this capacity. A report by Thompson *et al*[15] discussed the potential of transmitting torque to the lumbar spine through derotation of the thoracic spine. The theoretical concern is that derotation potentially transmits forces to the lumbar spine, aggravates torsional deformity of the lumbar spine,[3,4,15,21,22] and induces deformity in the coronal and sagittal planes, thereby reducing the lumbar curve's ability to compensate for thoracic curve correction. Thompson *et al*[15] recommended that derotation should be avoided in instrumentation of major thoracic curve. These recommendations reflect the ineffectiveness of current selective thoracic fusion techniques in controlling the transmission of the forces used for correction of thoracic curve.

The technique used in this study resulted in enhanced capacity for spontaneous correction and compensation of the lumbar spine. The capacity for spontaneous correction (as determined by the magnitude of correction of the lumbar curve) exceeded the original capacity for spontaneous correction (as determined by the flexibility of lumbar curve), *i.e.*, C/F >1. Such a finding has not previously been reported.

The use of CBT, using pedicle screws for 3-dimensional controllability in conjunction with rods for deformability, facilitated the simple and easy control of correctional forces in this study. Thoracic deformities were corrected in straightforward manner, without detrimental effect on the lumbar spine. In the axial plane, the direction of detorque for the thoracic curve was in the same direction as the torque of rotational deformity of the lumbar curve and thus needed to be frozen in the instrumented thoracic curve and not allowed to transmit to the lumbar spine. This was achieved by derotation of the lower end of the instrumented thoracic curve in the opposite direction to the derotation of the thoracic apical vertebra. This technique try to initiate correction of the lumbar curve by derotation at the low end of thoracic curve in the same direction as the lumbar detorque. The CL AVR was improved, but there was not a significant difference in the improvement. No aggravation of torsional deformity of lumbar curve occurred, thus demonstrating the effectiveness of the method in freezing thoracic apical detorque.

In the coronal plane, the CBT lifts up the convex lower thoracic spine and subsequently pull up the con-

cavity of the upper lumbar curve, thereby translating it to the midline. In the sagittal plane, the corrective force for prevention and/or correction of junctional kyphosis could be easily provided by CBT during corrective procedures. All these thoracic corrective forces were either forced or guided to the same direction as required for correction of the lumbar curve. Through cooperation and coordination, the capacity for spontaneous correction and compensation of the lumbar spine could be enhanced to maximize correction of the lumbar curve and to maintain balance. Overcorrection of the thoracic curve achieved using this technique would not impair but could enhance the capacity for spontaneous correction and compensation of the lumbar spine. Our results demonstrate that spontaneous correction of the C modifier compensatory lumbar curve is significant. True spontaneous correction of the lumbar curve with significant improvement in AVT was consistent and led to a change in the lumbar modifier grade from C into B or A in all patients.

Another issue central to that of decompensation is selection of the appropriate fusion level. The concept of fusion to the neutral and stable vertebra is one that has evolved over time. In earlier writings, authors generally agreed that the fusion should include the entire major curve. Some supported the concept of extending the fusion to 1 or 2 vertebrae below the curve. Harrington[23] stressed the importance of ending the fusion at a level

that was centered over the sacrum, thus creating a stable base. Moe,[24,25] and Tambornino et al[26] recognized the importance of extending the fusion to include all the vertebra rotated toward the convexity, and stopping at the neutrally rotated vertebra. Goldstein[27,28] noted that fusion should often be extended one vertebra beyond the neutral vertebra to prevent future "adding on" of the curve after brace removal. However, Lenke et al[29] reported their previous experience with posterior instrumentation and fusion of thoracic curves with segmental spinal instrumentation, demonstrating that the safest correction and balance is obtained when stopping at the stable vertebra. Failure to adhere to this leads to a risk of decompensation, which occurred at a rate of 22% in one study.[4] King et al[12,30] identified the stable vertebra as the appropriate area to end a fusion. The goal of surgery is to achieve a balanced spine with the fusion mass centered over the pelvis. When fusion is carried out to the stable vertebra, a balance and stable outcome can be expected. This has emerged as a basic principle of scoliosis management.[17,18,25,28,31–33] In this study, we used the stable vertebra as the safest distal fusion point.

In addition, the methodology had not only immediate but also continuous and persistent positive influence on the capacity for spontaneous correction and compensation of lumbar spine. For some of the curves, the spontaneous lumbar curve correction was dynamic and actually improved
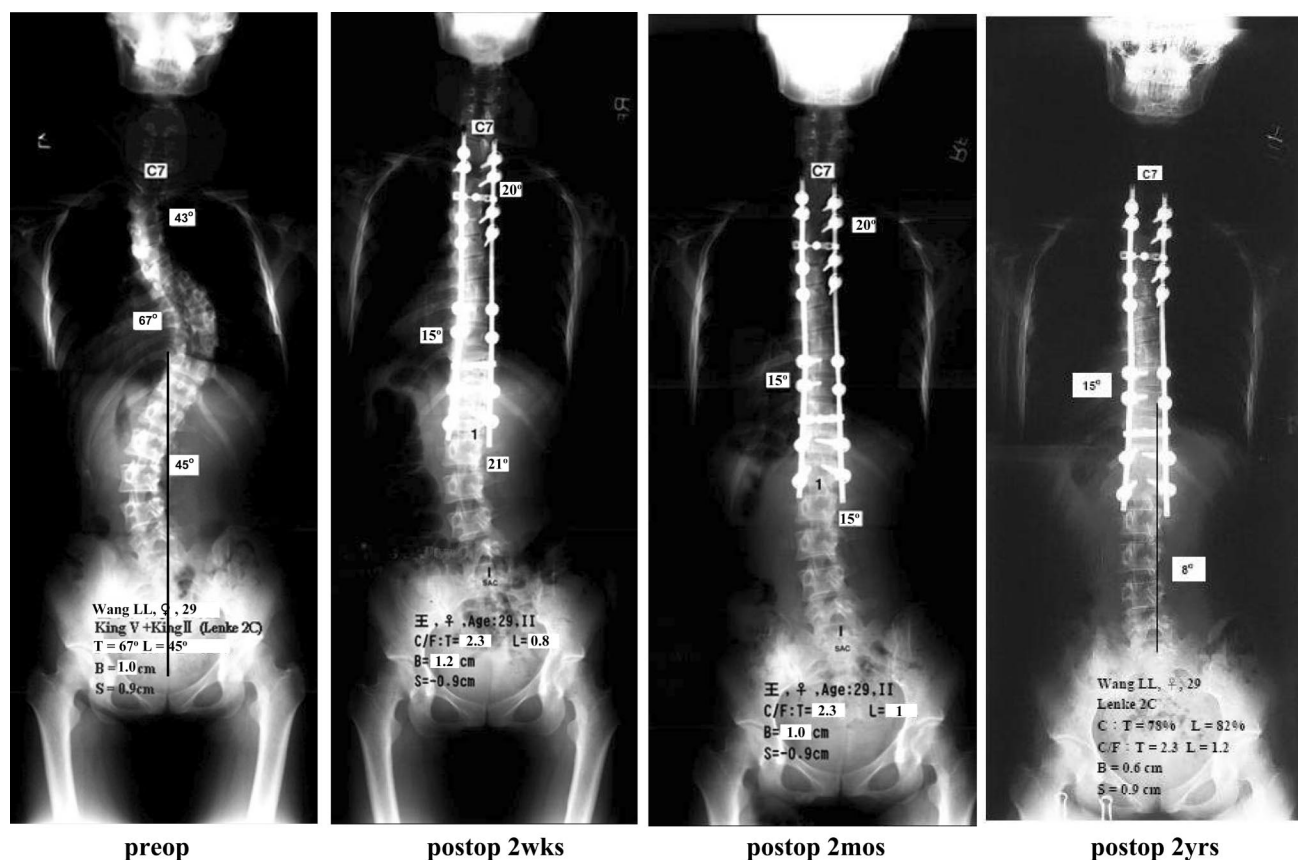

Figure 5. Standing radiographs preoperative, 2 weeks postoperative, 2 months postoperative, and 2 years postoperative demonstrate the spontaneous lumbar curve correction in Cobb magnitude, and AVT was dynamic and actually improved from the immediately postoperative radiograph (21°, C) to 2 years follow-up postoperative radiograph (8°, B).

Table 3. Summary Radiographic Data of Publications That Deal With the Issue of Selective Thoracic Fusion for Major Thoracic-Compensatory "C" Modifier Lumbar Curve, King II Curve, or PUMC IIb, IIc Curve Idiopathic Scoliosis

	No. of Patients	MT Cobb Preoperative (°)	MT Cobb Latest (°)	MT Flexibility (%)	MT Correction (%)	MT C/F	CL Cobb Preoperative (°)	CL Cobb Latest (°)	CL Flexibility (%)	CL Correction (%)	CL C/F
Richards[1]	24	61	32	36	48	1.3	49	36	73	27	0.4
Dobbs[40]	16	62	33	50	47	0.9	45	27	44	41	0.9
Edwards[41] (PSF)	26	62	42	41	32	0.8	50	32	68	33	0.5
Edwards[41] (ASF)	15	56	32	40	43	1.1	44	27	66	39	0.6
Schulte[42] (ASF)	16	66	41	37	55	1.5	49	17	65	50	0.8
Lenke[43] (ASF)	7	65	27	34	59	1.7	42	21	71	50	0.7
Lenke[43] (PSF)	10	67	49	40	27	0.7	53	37	66	30	0.5
Suk[44] (PSF)	122	50	17	51	67	1.3	33	14	114	60	0.6
Yu[45] (PSF)	17	57	22	44	60	1.4	35	15	82	64	0.8
Dobbs[46] (PSF)	32	64	51	53	33	0.6	49	37	49	24	0.5
Dobbs[46] (PSF)	34	62	40	52	44	0.8	45	28	47	39	0.7
Chang (current study) (PSF)	37	63	11	35	83	2.4	47	9	63	81	1.2

Mean values are shown.
Flexibility = preoperative angle − bending angle/preoperative angle × 100%. Correction = preoperative angle − postoperative angle/preoperative angle × 100%.
MT indicates main thoracic curve; CL, compensatory lumbar curve; PSF, posterior spinal fusion; ASF, anterior spinal fusion; C/F, correction/flexibility.

from the immediate postoperative radiograph to 2 years follow-up postoperative radiograph (Figure 5). The capacity for correction and compensation increased with time, suggesting that coordination of the corrective forces may also be enhanced over time.

Thoracolumbar kyphosis before surgery may also drive a surgeon to perform a more distal fusion in patients who might otherwise have been candidates for selective fusion. The Lenke classification criterion states that if the T10–L2 kyphosis measures >20°, the thoracolumbar/lumbar region is considered "structural" and fusion is suggested across these levels. In our study, no patient had a preoperative junctional kyphosis >20° or developed a postoperative junctional kyphosis.

Surgeons began using pedicle screws for thoracic scoliosis in 1988. Posterior spine fusion with thoracic pedicle screws has also been demonstrated to provide superior curve correction and improved sagittal control as compared with posterior spine fusion with hooks, while also saving fusion levels and avoiding the morbidity of an anterior approach to the thoracic spine.[9,33–39] In spite of this, no prior study has directly evaluated the efficacy of a technique to enhance the ability of spontaneous correction and compensation of the lumbar curve in Lenke 1C and 2C curve patterns. In the present series, we evaluated the results of 37 patients with Lenke Type 1C or 2C IS treated with CBT by using the pedicle screws for their 3-dimensional controllability in conjunction with the rods for their deformability. We found that the results from this series were significantly superior to all other reports[1,40–46] (Table 3). Compared with other series, the MT in this series obtains the best correction (C = 83%) and is the most overcorrected (C/F = 2.4), and it is echoed with the best correction of the lumbar curve (C = 81%). This series is the only one that the lumbar curve's capacity for spontaneous correction is enhanced (C/F =

1.2). The screws are immediately stable in all directions after insertion and offer rigid anchorage, which facilities 3-dimensional manipulation of vertebrae and controllability of corrective forces for MT. Hooks or wires do not have these characteristics and cannot be used to enhance the ability of spontaneous correction and compensation of lumbar curve.

In treatment of major thoracic-compensatory C modifier lumbar curves, CBT allows for 3-dimensional controllability of the corrective forces and facilitates maximal selective instrumentation-assisted thoracic correction and spontaneous lumbar curve correction.

■ Key Points

● In theory, since the lumbar curve is nonstructural and compensatory, the greater the degree of thoracic correction achieved, the greater the extent of spontaneous lumbar curve correction/compensation. However, current fusion techniques used in selective thoracic fusion involve undercorrection of the thoracic curve.
● Cantilevel bending technique facilitates control of 3-dimensional corrective forces, thereby maximizing selective instrumentation-assisted thoracic correction and enhancing the capacity for spontaneous correction of lumbar curve.
● Compared with other series, the thoracic curve in this series obtains the best correction (C = 83%) and is the most overcorrected (C/F = 2.4), and it is echoed with the best correction of the lumbar curve (C = 81%). This series is the only one that the lumbar curve's capacity for spontaneous correction is enhanced (C/F = 1.2).

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