Spine

SPINE Volume 39, Number 22, pp 1850-1859
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DEFORMITY

Could Structural and Noncompensatory Lenke 3 and 4C Lumbar Curves Be Nonstructural and Compensatory?

Lenke 1, 2, 3, and 4 Curve Types Were Similar and Could Be Considered Collectively as a Single Indication for Selective Thoracic Fusion

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Study Design. Retrospective radiographical review.

Objective. To demonstrate that the structural and noncompensatory Lenke 3 and 4C lumbar curves could be nonstructural and compensatory.

Summary of Background Data. Historically, Lenke 3 and 4C curves were not recommended for selective thoracic fusion (STF) because the lumbar curve was considered structural and noncompensatory. However, consecutive series of Lenke 3 and 4C curves suggest successful treatment with STF.

Methods. Between 2001 and 2004, 2005 and 2008, and 2010 and 2012, 3 consecutive series of 108, 134, and 78 surgically treated Lenke 1, 2, 3, and 4C curves were reviewed, respectively. The coronal curve criteria for the curves treated with STF during each period were lumbar side bending Cobb angle less than 25° and meeting the Lenke ratio criteria, lumbar side bending Cobb angle 35° or less, and lumbar side bending Cobb angle 45° or less, respectively. The sagittal curve criteria for STF during each period was absence of junctional thoracolumbar kyphosis 20° or more between T10 and L2. The technique used for STF was the Guan-Din method. Radiographs of all the curves treated with STF were analyzed before and after surgery.

Results. Optimal instrumented thoracic and compensatory lumbar correction was obtained for all Lenke 1, 2, 3, and 4C curves treated with STF in each period. As the coronal criteria for STF were broadened, the extent of feasibility of STF was expanded and the rate of STF increased. Although Cobb angle, apical vertebral translation, and apical vertebral rotation magnitudes of Lenke 3 and 4C curves were larger and more severe than those of Lenke 1 and 2C curves, optimal compensatory correction could still be obtained for Lenke 3 and 4C curves.

Conclusion. The structural and noncompensatory Lenke 3 and 4C lumbar curves were proven to be nonstructural and compensatory. Lenke 1, 2, 3, and 4C curves have similar natures and similar responses to the same technique (Guan-Din method) used for STF and could be considered collectively as a single indication for STF. The extent of feasibility of STF could be expanded from Lenke 1 and 2 curves to Lenke 1, 2, 3, and 4 curves.

Key words: compensatory curve, Guan-Din method, noncompensatory curve, nonstructural curve, selective thoracic fusion, structural curve.

Level of Evidence: 2

Spine 2014;39:1850–1859

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Acknowledgment date: March 5, 2014. First revision date: May 25, 2014. Second revision date: June 23, 2014. Acceptance date: June 25, 2014.

The manuscript submitted does not contain information about medical device(s)/drug(s).

No funds were received in support of this work.

No relevant financial activities outside the submitted work.

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DOI: 10.1097/BRS.0000000000000535

Currently, the Lenke classification system[1] is a widely accepted, treatment-oriented organization for thoracic and thoracolumbar/lumbar adolescent idiopathic scoliosis (AIS) deformities and is the most widely used method to describe curve patterns. For Lenke 1, 2, 3, and 4 curves, there are major, structural thoracic curves and minor lumbar curves, which can be either nonstructural or structural. According to Lenke guideline for selective thoracic fusion (STF),[1,2] Lenke 1 and 2C curves could be treated with STF because the lumbar curves of which were considered nonstructural and compensatory; and Lenke 3 and 4C curves should not be treated with STF because the lumbar curves of which were considered structural and noncompensatory (*i.e.*, side bending Cobb angle measurement ≥25°).

This study was conducted to demonstrate that structural and noncompensatory Lenke 3 and 4C lumbar curves could be nonstructural and compensatory, and could spontaneously accommodate well to the corrected position of the major thoracic curves. Lenke 3 and 4C curves, as well as Lenke 1 and 2C curves, can be treated with STF following the same surgical guideline, and could be considered collectively with the Lenke 1, 2, 3, and 4 curves as a single indication for STF.

MATERIALS AND METHODS

The Guan-Din method[3] was used as the technique for STF. Between 2001 and 2004, the criteria for Lenke 1, 2, 3, and 4C curves treated with STF were based on the guideline proposed by Lenke.[1,2] Of the 108 consecutive surgically treated Lenke 1, 2, 3, and 4C curves, 37 (34%) Lenke 1 and 2C curves in which the lumbar curve bent to less than 25°, the thoracic: lumbar ratio of Cobb angle, apical vertebral translation (AVT), and apical vertebral rotation (AVR) were all more than 1.2 (coronal curve criteria for STF) and lacked junctional thoracolumbar kyphosis 20° or more between T10 and L2 (sagittal curve criteria for STF) were treated with STF (Figure 1). Between 2005 and 2008, the coronal criteria for STF were broadened to lumbar side bending Cobb angle (LSBC) 35° or less, and the sagittal criteria remained the same (*i.e.*, without T10–L2 ≥20°). Of the 134 consecutive surgically treated Lenke 1, 2, 3, and 4C curves, 96 (72%, 72 Lenke 1 and 2C curves and 24 Lenke 3 and 4C curves) were treated with STF (Figure 2). Between 2010 and 2012, the coronal criteria for STF were further broadened to LSBC 45° or less, and the sagittal criteria remained the same. Of the 78 consecutive surgically treated Lenke 1, 2, 3, and 4C curves, 62 (79%, 41 Lenke 1 and 2C curves and 21 Lenke 3 and 4C curves) were treated with STF (Figure 3).

Radiographical Evaluation

Preoperative long-cassette standing upright coronal and lateral radiographs, as well as right and left supine best-effort side-bending coronal radiographs, were independently reviewed for those curves treated with STF during each of the 3 periods. Standing long-cassette coronal and lateral radiographs from the preoperative period and the most recent follow-up were evaluated to determine changes in radiographical characteristics. Radiographical follow-up was a minimum of 2 years. Coronal and sagittal curves were measured using the Cobb method. Curve types were classified according to the Lenke classification system.[1] The curves meeting the Lenke curve or structural criteria for STF were recorded. Curve flexibility and correction were calculated and recorded.

Additional criteria measured from the standing coronal radiograph included AVT and AVR. AVT for the thoracic curve was measured relative to the coronal C7 plumb line. AVT for the lumbar curve was measured relative to the center sacral vertical line, which should bisect the cephalad aspect of the sacrum and be perpendicular to the true horizontal position.[1] AVR for curves was assessed according to the system devised by Nash and Moe.[4]

Global coronal and sagittal balance were determined by measuring the horizontal distance from a vertical line extending from the center of the C7 vertebral body relative to the center sacral vertical line and posterior-superior corner of S1.[5] When averaging the translational measurement (coronal and sagittal balance), absolute values were used so that the positive and negative values did not cancel each other out. Measurements of preoperative and postoperative balance were compared. In the sagittal plane, the presence of thoracolumbar kyphosis (*i.e.*, Cobb angle >20° between T10 and L2) was noted. Each postoperative radiograph was assessed for implant failure, loss of fixation, and nonunion.

Statistical Analysis

Descriptive statistical analysis was performed for each dependent variable by comparing the preoperative radiographical data with data obtained at various postoperative time points using a mixed model analysis of variance. Specific

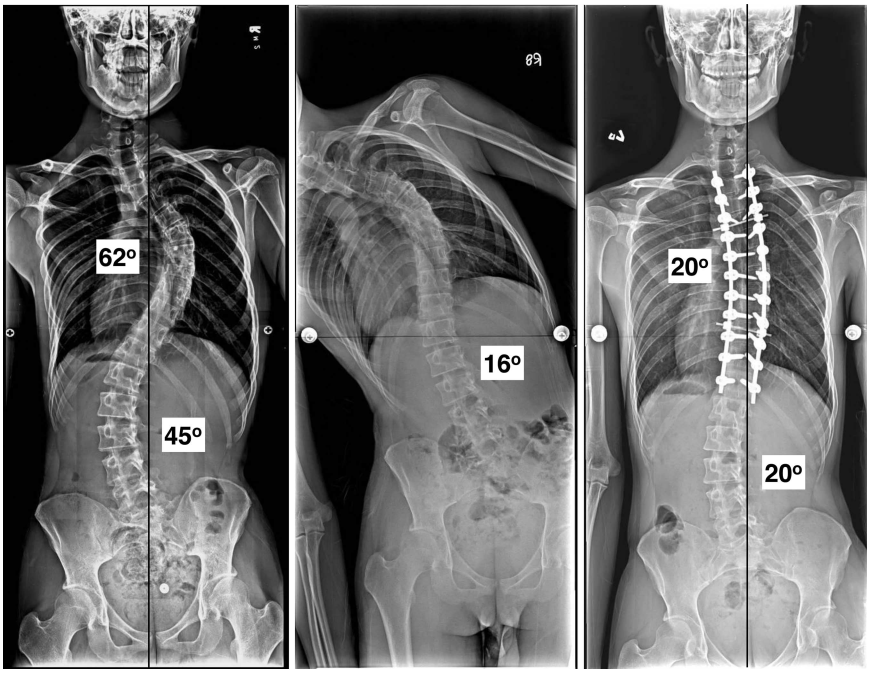

Figure 1. A Lenke 1C curve met LSBC less than 25°, thoracic: lumbar ratio of Cobb angle, AVT, and AVR more than 1.2 (coronal curve criteria) and without T10–L2 20° or more (sagittal curve criteria) and was successfully treated with STF in the period 2001 to 2004.

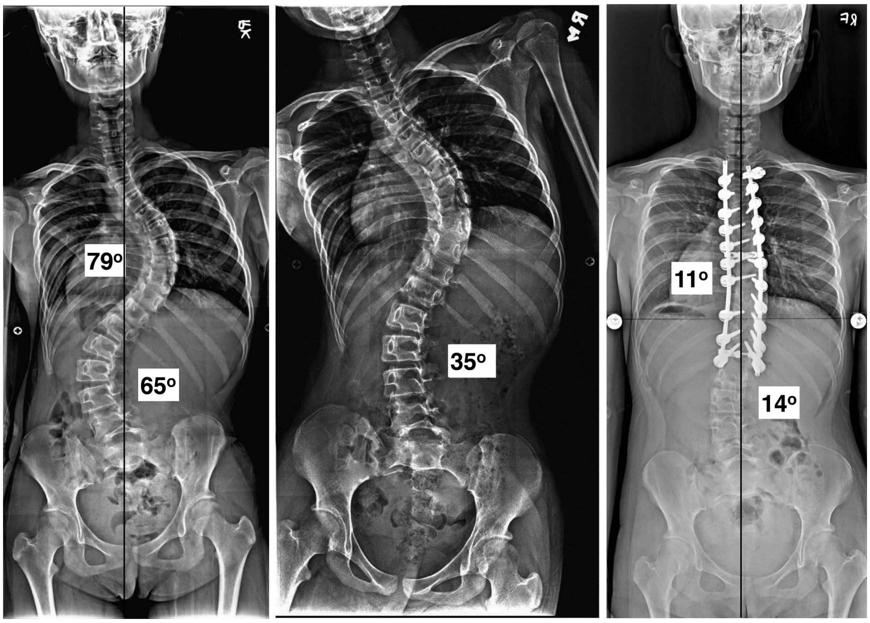

Figure 2. A Lenke 3C curve met lumbar side bending Cobb angle 35° or less (coronal curve criteria) and without T10–L2 20° or more (sagittal curve criteria) and was successfully treated with STF in the period 2005 to 2008.

comparisons of the radiographical criteria were performed by analysis of covariance. Pair-wise comparisons of the radiographical data were performed by using the Fisher exact test. Statistical significance was set at $P < 0.05$.

Guan-Din Method

The technique is described and shown in Figure 4 (A–H). The use of the Guan-Din method,[3] using pedicle screws for 3-dimensional controllability in conjunction with rods for deformability, facilitated 3-dimensional control of corrective forces for the thoracic curve. The implant pattern, purchase points and 3 important procedures (Figure 4C, E, F) were used to control the corrective forces for the thoracic curve to guide and initiate the force that was beneficial to spontaneous correction of lumbar curve into the lumbar curve to enhance the lumbar curve's capacity for spontaneous correction.[5,6]

RESULTS

The number of surgically treated Lenke 1, 2, 3, and 4C curves, and the number and percentage of each type of curve treated with STF during each period are shown in Table 1. Of the 37 Lenke 1 and 2C curves treated with STF between 2001 and 2004, 34 were females. The mean age was 17.3 years. Of the 96 Lenke 1, 2, 3, and 4C curves treated with STF between 2005 and 2008, 84 were females. The mean age was 16.7 years. Of the 62 Lenke 1, 2, 3, and 4C curves treated

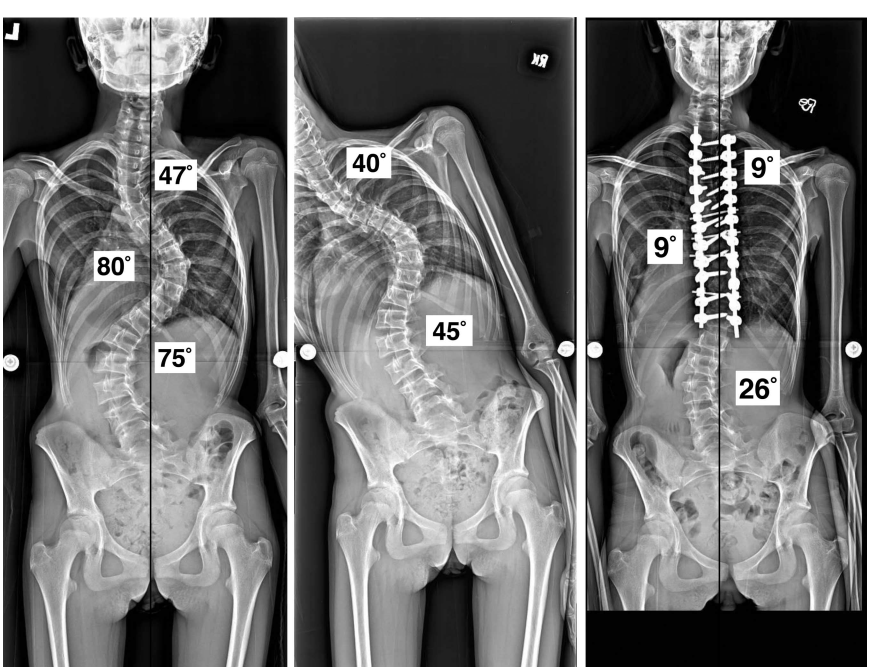

Figure 3. A Lenke 4C curves with lumbar side bending Cobb angle 45° or less (coronal curve criteria) and without T10–L2 20° or more (sagittal curve criteria) and was successfully treated with STF in the period 2010 to 2012.

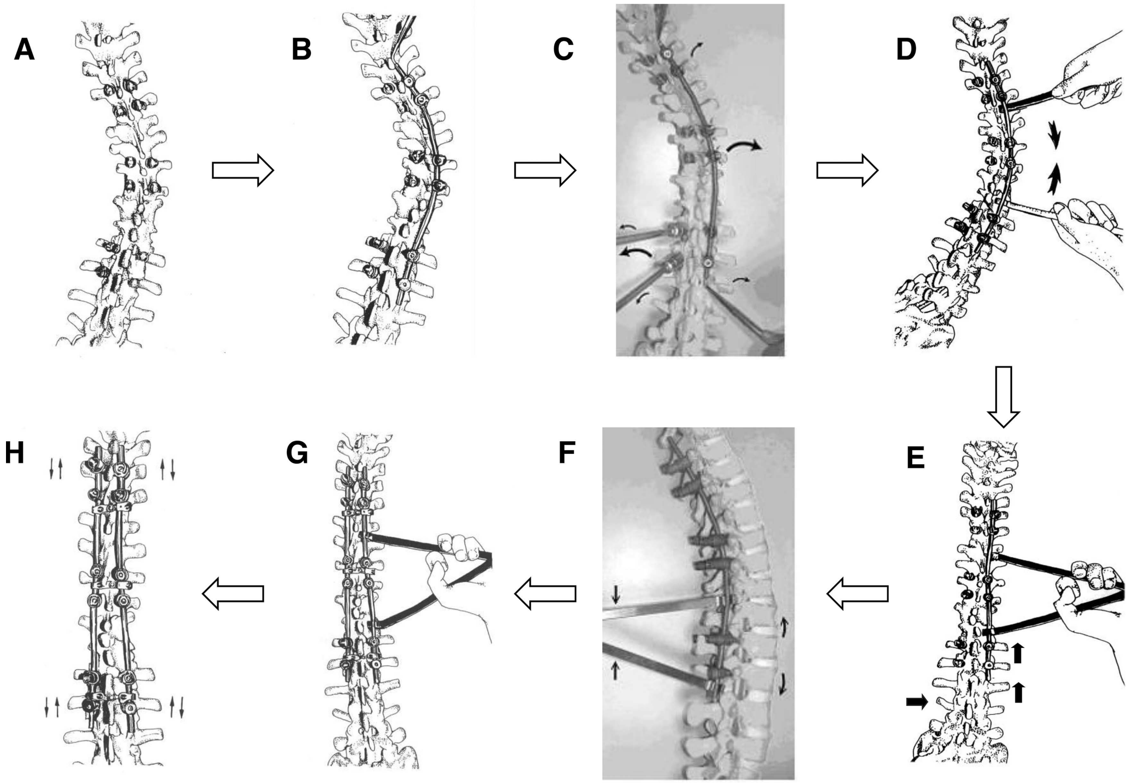

Figure 4. The Guan-Din method for selective thoracic fusion. **A**, In patients undergoing surgical correction, 6 groups of pedicle screws were inserted on the upper, apical, and lower segments on both sides of the thoracic curve. **B**, After the pedicle screw was positioned, a prebent rod was connected to the pedicle screws on the convex side. **C**, 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. For curves with a lumbar C modifier, this can be reinforced with pressing the rib hump and twisting the pelvis in the opposite direction. Although 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 initiates corrective torsion for the lumbar curve or the proximal thoracic curve at the lower and upper segment of thoracic curve. **D**, 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. **E**, 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. **F**, If necessary, 2 additional 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. **G**, 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. **H**, After connecting both rods by transverse links and finely adjusting the end vertebrae according to the intraoperative posteroanterior radiographs to balance the body and shoulder, the lever arms were released. The *in situ* benders were not removed until the corrected curvature was rigidly fixed.

with STF between 2010 and 2012, 55 were females. The mean age was 18.1 years. The duration of radiographical follow-up of the Lenke 1, 2, 3, and 4C curves treated with STF was 2 years or more. As the coronal criteria for STF was broadened from meeting the Lenke ratio criteria and LSBC less than 25° to LSBC 35° or less in the period 2005 to 2008, the rate of STF increased from 57% to 96% for Lenke 1C, from 56% to 100% for Lenke 2C (Lenke 1 and 2C curves that did not meet the Lenke ratio criteria were included additionally for STF), from 0% to 41% for Lenke 3C, and from 0% to 36% for Lenke 4C (Lenke 3 and 4C curves with LSBC between 25° and 35° were included additionally for STF). As the coronal criteria for STF was broadened from LSBC 35° or less to LSBC 45° or less in the period 2010 to 2012, the rate of STF for Lenke 3 and 4C increased further from 41% to 61% and from 36% to 50%, respectively (Lenke 3 and 4C curves with LSBC between 35° and 45° were included additionally for STF).

Radiographical data for the Lenke curves treated with STF between 2001 and 2004, 2005 and 2008, and 2010 and 2012 are shown in Table 2. For 37 Lenke 1 and 2 curves treated with STF between 2001 and 2004, a mean 83% instrumented thoracic correction, 81% spontaneous lumbar correction, and true correction of thoracic and lumbar AVT were obtained. No significant change in global sagittal and coronal balance was observed. For 24 Lenke 3 and 4C curves treated with STF between 2005 and 2008, a mean 67% instrumented thoracic and 53% spontaneous lumbar

TABLE 1. Period, Coronal, and Sagittal Curve Criteria for STF; No. of Surgically Treated Lenke 1, 2, 3, and 4C Curves; and (No., %) of Each Type of Curve Treated With STF During Each Period

Period	Curve Criteria for STF: Coronal Criteria	Curve Criteria for STF: Sagittal Criteria	Lenke 1C	Lenke 2C	Lenke 3C	Lenke 4C	Total
2001–2004	LSBC <25° T/L ratio of Cobb angle, AVT, and AVR >1.2	Without T10–L2 ≥20°	40 (23, 57%)	25 (14, 56%)	36 (0, 0%)	7 (0, 0%)	108 (37, 34%)
2005–2008	LSBC ≤35°	Without T10–L2 ≥20°	57 (55, 96%)	17 (17, 100%)	49 (20, 41%)	11 (4, 36%)	134 (96, 72%)
2010–2012	LSBC ≤45°	Without T10–L2 ≥20°	32 (31, 97%)	10 (10, 100%)	28 (17, 61%)	8 (4, 50%)	78 (62, 79%)

The value outside parenthesis indicates the surgically treated number of each Lenke curve type.
The value inside parenthesis indicates the number and percentage of each type of curve treated with STF.
STF indicates selective thoracic fusion; T, thoracic; L, lumbar; AVT, apical vertebral translation; AVR, apical vertebra rotation; LSBC, lumbar side bending Cobb angle.

correction and significant correction of thoracic and lumbar AVT and AVR were obtained. No significant change in global sagittal and coronal balance was observed. For 21 Lenke 3 and 4C curves treated with STF between 2010 and 2012, a mean 65% thoracic and 50% lumbar correction and significant correction of thoracic and lumbar AVT and AVR were achieved. No significant change in global sagittal and coronal balance was observed. By successfully pushing the limits on avoiding fusion of structural lumbar curves repeatedly in this study, the structural lumbar Lenke 3 and 4C curves were demonstrated to be nonstructural and compensatory. Radiographical data for the 150 Lenke 1 and 2C curves and 45 Lenke 3 and 4C curves for all 3 time periods are shown in Table 3. Although the lumbar Cobb angle, AVT, and AVR magnitude of the Lenke 3 and 4C curves were larger and more severe than that of the Lenke 1 and 2C curves, optimal lumbar compensatory correction could be obtained for Lenke 3 and 4C curves. No additional osteotomy/thoracoplasty was used for correction in any patient. No patient undergoing STF required extension of the fusion to the lumbar spine.

DISCUSSION

In 2001, Lenke *et al*[1] described a new surgical classification system for AIS that specifically quantified the structural aspects of regional scoliotic curves based on the relative curve magnitude, flexibility, and position, as well as the sagittal profile. The system classified AIS into 6 types. For Lenke type 1, 2, 3, and 4 curves, the thoracic curve is the major and largest curve, which is always structural (*i.e.*, side-bending Cobb angle measurement ≥ 25°), and the lumbar curve is a minor, smaller curve. If the lumbar curve is nonstructural (*i.e.*, side-bending Cobb angle measurement <25°) and has thoracolumbar kyphosis less than +20°, the curve is categorized as a Lenke 1 or 2 curve. If the lumbar curve is structural and has a side-bending Cobb angle measurement 25° or more or a thoracolumbar kyphosis +20° or more, the curve is classified as a Lenke type 3 (double major curve) or type 4 (triple major curve). On the basis of this classification, spinal arthrodesis that includes only the major curve and structural minor curve is proposed. 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), STF is recommended. The more challenging curves in which the lumbar apical vertebra is completely translated from the midline (lumbar modifier C) may also be treated with STF, but the potential for subsequent decompensation is high. In this consecutive study series, C curve patterns were selected as the study group because these patterns are more challenging for STF. According to the Lenke guidelines, for Lenke 1C or 2C curves to be successfully treated by STF, the thoracic: lumbar ratio of Cobb angle, AVT, and AVR should be 1.2 or more. Lenke 3 and 4C curves were not recommended for STF because the lumbar curve is structural (*i.e.*, side-bending Cobb angle ≥ 25°). Therefore, the extent feasibility of STF include Lenke 1 and 2C curves only and the rate of STF for Lenke 1C curves were only 49%[7] because of the limitation of the Lenke ratio criteria.

Multiple studies have demonstrated the negative long-term risks of extending a scoliosis spinal fusion into the lumbar spine.[8–13] Reducing the number of fused levels maximizes spinal flexibility and distributes stress across more distal lumbar motion segments.[14] Theoretically, this strategy may diminish the long-term risk of disc degeneration at adjacent distal levels. Therefore, it is clear why many studies have focused on the topic of STF.[15–22] Maximizing the extent of feasibility of STF and the rate of STF to spare the lumbar spine from fusion should be a goal whenever practical, and STF should be considered for all Lenke 1, 2, 3, and 4 curves.

The Guan-Din method was developed as a technique for STF.[3] The method uses the pedicle screws for their 3-dimensional controllability in conjunction with the rods for their deformability, thereby maximizing selective instrumentation-assisted thoracic correction and enhancing the capacity for spontaneous correction of the lumbar curve.[5] 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. A report by Thompson *et al*[23] discussed

TABLE 2. Period (No. Lenke Curve Type Treated With STF During the Period), Coronal and Sagittal Criteria for STF, and Radiographical Data for Curves Treated With STF During Each Period

Period (No., Type of Curve)	Criteria for STF		Deformity	Thoracic (Instrumented)			Lumbar (Spontaneous)			Balance		
	Coronal Criteria	Sagittal Criteria		Preop	Final	Correction	Preop	Final	Correction	Preop	Final	Correction
2001–2004 (23 1C, 14 2C)	LSBC <25° T/L ratio of Cobb angle. AVT. AVR > 1.2	Without T10–L2 ≥20°	Cobb angle (0°)	63	11	83%*	47	9	81%*			
			AVT (mm)	51	15	36*	29	18	11*			
			AVR (N-M grade)	2.1	1.9	0.2	1.3	1.1	0.2			
			Coronal balance (mm)							11	12	−1
			Sagittal balance (mm)							16	14	2
2005–2008 (20 3C, 4 4C)	LSBC ≤35°	Without T10–L2 ≥20°	Cobb angle (0°)	72	24	67%*	60	28	53%*			
			AVT (mm)	58	22	36*	47	22	25*			
			AVR (N–M grade)	2.6	2.1	0.5*	2.5	2.0	0.5*			
			Coronal balance (mm)							13	11	2
			Sagittal balance (mm)							−2	1	3
2010–2012 (17 3C, 4 4C)	LSBC ≤45°	Without T10–L2 ≥20°	Cobb angle (0°)	79	28	65%*	68	34	50%*			
			AVT (mm)	59	22	37*	49	27	22*			
			AVR (N-M grade)	2.7	2.1	0.6*	2.7	2.0	0.7*			
			Coronal balance (mm)							16	14	2
			Sagittal balance (mm)							−4	−1	3

Data represent mean values.

**Statistically significant change ($P < 0.05$) relative to the preoperative value.*

Preop indicates preoperative; STF, selective thoracic fusion; AVT, apical vertebral translation; AVR, apical vertebral rotation; N-M, Nash-Moe; No, number; LSBC, lumbar side-bending Cobb angle.

TABLE 3. Radiographical Data for Total Number of Lenke 1 and 2C and 3 and 4C Curves Treated With STF for All Time Periods

Curve Type (No.)	Deformity	Thoracic (Instrumented)			Lumbar (Spontaneous)			Balance		
		Preop	Final	Correction	Preop	Final	Correction	Preop	Final	Correction
Lenke 1 and 2C (150)	Cobb angle (0°)	65	18	72%*	51	18	65%*			
	AVT (mm)	53	16	37*	41	20	21*			
	AVR (N-M grade)	2.2	2.0	0.2	1.9	1.4	0.5*			
	Coronal balance (mm)							12	10	2
	Sagittal balance (mm)							5	3	2
Lenke 3 and 4C (45)	Cobb angle (0°)	75	26	65%*	64	31	52%*			
	AVT (mm)	58	22	36*	48	24	24*			
	AVR (N-M grade)	2.6	2.1	0.5*	2.6	2.0	0.6*			
	Coronal balance (mm)							14	12	2
	Sagittal balance (mm)							−3	0	3

Data represent mean values.

**Statistically significant change ($P < 0.05$) relative to the preoperative value.*

Preop indicates preoperative; STF, selective thoracic fusion; AVT, apical vertebral translation; AVR, apical vertebral rotation; N-M, Nash-Moe; No, number.

the potential for 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, aggravating torsional deformity of the lumbar spine,[20,23–25] and induces deformity in the coronal and sagittal planes, thereby reducing the lumbar curve's ability to compensate for thoracic curve correction. Thus, detorque for the thoracic curve needed to be frozen in the instrumented thoracic curve and not allowed to transmit to the lumbar spine. In this study, 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 and locking the relative position on the convex rod (Figure 4C). The Guan-Din method tries to initiate correction of the lumbar curve by derotation at the distal end vertebra of the thoracic curve, which is also the proximal end vertebra of the lumbar curve, in the same direction as the lumbar detorque. The postoperative lumbar AVR was either improved or unchanged. No aggravation of torsional deformity of lumbar curve occurred (Table 2), thus demonstrating the effectiveness of the method in freezing thoracic apical detorque. In the coronal plane, the method lifts up the convex lower thoracic spine and subsequently pulls up the concavity of the upper lumbar curve, thereby translating it to the midline (Figure 4E). In the sagittal plane, the corrective force for prevention and/or correction of junctional kyphosis could be easily provided by the method during corrective procedures (Figure 4F). All these thoracic corrective forces were either forced or guided to the same direction as required for correction of the lumbar curve. Through co-operation and co-ordination, 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 method would not impair but could enhance the capacity for spontaneous correction and compensation of the lumbar spine.

Our results demonstrate that compensatory correction of the C modifier lumbar curve of Lenke 1, 2, 3, and 4C curves was significant. True and significant correction of the lumbar curve with significant improvement in Cobb angle and AVT was consistent in patients of each period. In the period 2001 to 2004, 37 consecutive Lenke 1 and 2C curves, which met the Lenke ratio criteria and without T10–L2 more than 20°, were treated with STF using the Guan-Din method. The results from this series (the last third row of Table 4) were far superior to all other studies[17,18,20,22,26–30] reporting on STF for Lenke 1C and 2C curves, King II curves (Table 4). Compared with other series, the major thoracic curve in this series obtained the best correction (83%), and it was echoed with the best correction (81%) of the lumbar curve and the lumbar curve's capacity for compensatory correction was 2.8 times of that in Lenke series[20] (83% *vs.* 30%). The results demonstrated that the Guan-Din method could enhance the lumbar curve's capacity for compensatory correction and encouraged and initiated us to broaden the curve criteria for STF in the following periods to have more curves treatable with STF. In the next period 2005 to 2008, 24 consecutive Lenke 3 and 4C curves with LSBC 35° or less and without T10–L2 more than 20° and 21 consecutive Lenke 3 and 4C curves with LSBC 45° or less and without T10–L2 more than 20° in the following period 2010 to 2012 were treated with STF using the Guan-Din method. We found no similar series could be compared with because all other studies reported on STF for Lenke 1 and 2C, or King II curves, whose curve magnitude was significantly less than that of these Lenke 3 and 4C curves (the last 2 rows in Table 4). Even so, comparing with other series, the compensatory lumbar correction of those Lenke 3 and 4C curves in the periods of 2005 to

TABLE 4. Summary Radiographical Data of Publications That Deal With the Issue of Selective Thoracic Fusion for Lenke 1C and 2C Curves, King II Curves, or Lenke 3 and 4C Curves

		Thoracic Curve			Lumbar Curve		
		Cobb Angle		Correction (%)	Cobb Angle		Correction (%)
	No. of Pts	Preop (°)	Latest (°)		Preop (°)	Latest (°)	
Richards[22]	24	61	32	48	49	36	27
Dobbs *et al*[18] (ASF)	16	62	33	47	45	27	41
Edwards *et al*[17] (PSF)	26	62	42	32	50	32	33
Edwards *et al*[17] (ASF)	15	56	32	43	44	27	39
Schulte *et al*[26] (ASF)	16	66	41	55	49	17	50
Lenke *et al*[20] (ASF)	7	65	27	59	42	21	50
Lenke *et al*[20] (PSF)	10	67	49	27	53	37	30
Suk *et al*[27] (PSF)	122	50	17	67	33	14	60
Dobbs *et al*[28] (PSF)	32	64	51	33	49	37	24
Kalen and Conklin[29]	58	52	13	25	32	22	31
Yong *et al*[30]	24	53	25	53	44	25	42
Dobbs *et al*[28] (PSF)	34	62	40	44	45	28	39
Chang *et al* (PSF)	**37**	**63**	**11**	**83**	**45**	**9**	**81**
Chang *et al* (PSF)	**24**	**72**	**24**	**67**	**60**	**28**	**53**
Chang *et al* (PSF)	**21**	**79**	**28**	**65**	**68**	**34**	**50**

Data represent mean values.
The boldface values are the data in this study series.
PSF indicates posterior spinal fusion; ASF, anterior spinal fusion; preop, preoperative; Pts, patients.

2008 and 2010 to 2012 was superior to most of other studies (Table 4).

In the period 2001 to 2004, Lenke 1, 2, 3, and 4C curves treated with STF were according to Lenke guideline for STF; that is, Lenke 1 and 2C curves could be treated with STF if they met the Lenke ratio criteria for STF (T/L ratio of Cobb angle, AVT and AVR > 1.2) and without T10–L2 more than 20°, and Lenke 3 and 4C curves should not be treated with STF because the lumbar curve was structural and noncompensatory. Therefore, in the period 2001 to 2004, only Lenke 1 and 2C curves met the Lenke ratio criteria and without T10–L2 more than 20° were treated with STF and all Lenke 3 and 4C curves were treated with nonselective fusion of both curves, and so the rate of STF for Lenke 1, 2, 3, 4C curves were 57%, 56%, 0%, and 0%, respectively. In the period 2005 to 2008, the criteria for STF was broadened to LSBC 35° or less and without T10–L2 more than 20°. Therefore, Lenke 1 and 2C curves could nearly all be treated with STF because the LSBC of all Lenke 1 and 2 curves were less than 25° and Lenke 1 and 2 curves that did not meet the Lenke ratio criteria were released from the limitation to be treated with STF additionally, and Lenke 3 and 4C curves with LSBC 35° or less could be treated with STF additionally. The rate of STF for Lenke 1, 2, 3, and 4C curves increased to 96%, 100%, 41%, and 36%, respectively. In the period 2010 to 2012, the criteria for STF were further broadened to LSBC 45° or less and without T10–L2 20° or more. Therefore, Lenke 3 and 4C curves with LSBC less than 35° to LSBC 45° or less could be treated with STF additionally, and the rate of STF for Lenke 3 and 4C curves increased to 61% and 50% further. The extent

TABLE 5. Comparing Extent of Feasibility of STF and Rate of STF for Lenke 1, 2, 3, and 4C Curves Following the Fusion Criteria of the Lenke System and the Guan-Din Method

Lenke Curve Type	Lenke 1C, 2C	Lenke 3C, 4C
Extent of feasibility of STF following the fusion criteria of Lenke system		
Extent of feasibility of STF following the fusion criteria of the Guan-Din method		
Rate of STF following the fusion criteria of Lenke system	57%	0%
Rate of STF following the fusion criteria of the Guan-Din method	97%	47%

STF indicates selective thoracic fusion.

of feasibility of STF was expanded and the rate of STF was maximized (Table 5).

It is generally accepted that the fate of the lumbar curve of the surgically treated Lenke 1, 2, 3, and 4 curves is dependent upon its nature. The treatment-oriented Lenke classification systems for AIS are based on radiographical analysis to determine the nature of the lumbar curve (*e.g.*, flexibility, thoracic/lumbar ratio of Cobb angle, AVT, and AVR) and determine whether the lumbar curve is structural or compensatory and whether arthrodesis should be considered. The nature of the lumbar curve is the most important aspect of the Lenke classification system. According to the analysis, a scoliosis with a major thoracic curve and a minor lumbar curve can be classified into 4 distinct curve types (Lenke 1, 2, 3, and 4). Lenke 1 and 2C curves could be treated with STF because the lumbar curves of which were considered nonstructural and compensatory and Lenke 3 and 4C curves should not be treated with STF because the lumbar curves of which were considered structural and noncompensatory. We discovered that the surgical and instrumentation technique used for STF represents another important factor that can change that decides the fate of the lumbar curve. We found that structural and noncompensatory Lenke 3 and 4C lumbar curve could be nonstructural and compensatory if the Guan-Din method was used as the technique for STF. Lenke 3 and 4C curves, as well as Lenke 1 and 2C curves could be successfully treated with STF and demonstrated that Lenke 1, 2, 3, and 4 curves were similar, responded similarly to STF using the same technique (Guan-Din method) according to the same surgical guidelines, and could be considered collectively as a single indication for a STF that greatly assists the surgeon in planning operative intervention.

Because the surgical technique for STF can change the nature of curves and the lumbar curve's capacity for compensatory correction, the Lenke guideline for STF should be followed for curves treated with the surgical technique proposed by Lenke *et al*.[1,3,20,21] To our knowledge, the surgical technique would be avoidance of overcorrection and derotation for the thoracic curve, and the surgical strategy of which is to not diminish rather than to enhance the lumbar curve's capacity for compensatory correction, which is the surgical strategy of the Guan-Din method for STF.

This study was a retrospective radiographical study and functional outcomes were not within the scope of this study. However, lack of functional outcomes is a limitation of this article and future studies would be necessary to improve the level of evidence of these finding.

CONCLUSION

By successfully pushing the limits on avoiding fusion of the structural lumbar curve, the structural and noncompensatory Lenke 3 and 4C lumbar curves were proven to be nonstructural and compensatory. The lumbar curve's capacity for compensatory correction can be enhanced by the surgical technique used for STF. Lenke 1, 2, 3, and 4 curves were demonstrated to have similar natures and similar responses to the same technique used for STF (Guan-Din method), and could be considered collectively as a single indication for STF. The extent of feasibility of STF was expanded from Lenke 1 and 2 curves to Lenke 1, 2, 3, and 4 curves.

➢ Key Points

- ❑ Twenty-four consecutive Lenke 3 and 4C curves with LSBC 35° or less and 21 consecutive Lenke 3 and 4C curves with LSBC 45° or less were successful treated with STF using the Guan-Din technique.
- ❑ The 45 Lenke 3 and 4C lumbar curves that are defined as structural and noncompensatory by the Lenke system were proven to be nonstructural and compensatory.
- ❑ Although the Cobb angle, AVT, and AVR magnitude of Lenke 3 and 4C lumbar curves are larger and more severe than Lenke 1 and 2C lumbar curves, optimal compensatory correction could be obtained.
- ❑ The capacity of the lumbar curve for compensatory correction can be enhanced by the Guan-Din method used for STF.
- ❑ Lenke 1, 2, 3, and 4 curves were demonstrated to have similar nature and response to the same technique (Guan-Din method) used for STF and could be considered collectively as a single indication for STF.
- ❑ The extent of feasibility of STF could be expanded from Lenke 1 and 2 curves to Lenke 1, 2, 3, and 4 curves.

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