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SURGERY

Guan-Din Method

A Novel Surgical Technique for Selective Thoracic Fusion to Maximize the Rate of Selective Thoracic Fusion and Compensatory Correction

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Study Design. Retrospective radiographical review.

Objective. To evaluate the outcome of selective thoracic fusion (STF) by using the Guan-Din method for the treatment of major thoracic compensatory lumbar (MTCL) curves.

Summary of Background Data. Performing STF for MTCL curves is to minimize the loss of lumbar motion and the risk of lumbar degeneration or pain. Surgical treatment of MTCL curves aims to maximize the rate of STF for MTCL curves while optimizing instrumental thoracic and compensatory lumbar correction. The Guan-Din method has been demonstrated to be able to enhance the lumbar curve's capacity for spontaneous correction and broaden the current curve criteria of MTCL curves for STF.

Methods. Between 2004 and 2010, 510 consecutive surgically treated MTCL curves were reviewed. Of these MTCL curves, who met the criteria of lumbar side bending Cobb 35° or less and without global thoracic hyperkyphosis and/or thoracolumbar kyphosis (T10–L2 ≤20°), were treated with STF using the Guan-Din method. Radiographs were analyzed before surgery, immediately after surgery, and at the most recent follow-up (range, 2–8 yr).

Results. Curve types of 510 MTCL curves according to Lenke system were as follows: 1A (n = 91), 2A (n = 74), 3A (n = 6), 4A (n = 2), 1B (n = 93), 2B (n = 34), 3B (n = 8), 4B (n = 5), 1C (n = 84), 2C (n = 26), 3C (n = 72), and 4C (n = 15). Of the 510 MTCL curves, 458 (90%) curves were treated with STF. A mean 73% thoracic correction and 63% lumbar correction was obtained at the most recent follow-up. Of the 197 surgically treated MTCL curves with a lumbar C modifier, 148 (75%) curves that contained 57 Lenke 1C and 2C curves and 40 Lenke 3C and 4C curves that did not meet Lenke curve criteria for STF, were successfully treated with STF. A mean 67% thoracic correction and 57% lumbar correction was obtained at the most recent follow-up. The rate of STF and the magnitude of correction of MTCL curves in this study were significantly greater than those in all other reports. No significant change in global coronal and sagittal imbalance was observed.

Conclusion. The rate of STF and the compensatory correction of MTCL curves could be maximized by using the Guan-Din method as the method for STF.

Key words: Guan-Din method, major thoracic compensatory lumbar curve, selective thoracic fusion.

Level of Evidence: 4

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Despite the continuous evolution in the surgical treatment of idiopathic scoliosis, the goals of surgery have remained the same. It is desirable to obtain solid fusion while providing safe and optimal coronal correction, sagittal alignment, and axial derotation. Fusing the smallest number of spinal segments possible while achieving these goals is also desirable to preserve the maximum number of motion segments both above and below the fused spinal segments. This philosophy holds true when treating major thoracic compensatory lumbar (MTCL) curves, where the goal is to perform selective thoracic fusion (STF), while leaving the lumbar spine unfused, in those cases amenable to this technique. Ideally, after STF, the unfused lumbar curve will spontaneously accommodate to the corrected position of the thoracic curve, achieving the ultimate goal of a balanced spine, with the fusion mass centered over the pelvis and a maximum number of unfused lumbar spinal segments remaining.

Surgical treatment of MTCL curves aims to maximize the rate of STF for MTCL curves while optimizing instrumented thoracic and spontaneous lumbar correction. We developed the Guan-Din method as the method for STF.[1,2] The method facilitates 3-dimensional control of the corrective forces for the thoracic curve to enhance the lumbar curve's capacity for spontaneous correction[1] and can broaden the current curve criteria for STF.[2] This approach was originated from an ancient Chinese methodology Guan-Din method, which

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means initiating the correction on the top, and then letting the corrective forces cascade down to correct the rest of the body spontaneously. The meaning is exactly the same as the effect on the compensatory lumbar (CL) curve by STF using this method to enhance the lumbar curve's capacity for spontaneous correction. Therefore, we use the original term, that is, the Guan-Din method as the name for description of this methodology. This study was conducted to demonstrate that the method is an effective alternative method for STF to achieve the goal of surgical treatment of MTCL curves.

MATERIALS AND METHODS

Definitions

MTCL curve: A scoliosis has a major thoracic curve and a CL curve.

Curve: The spine deviates from the midline with a Cobb angle more than 10°.

MT curve: The thoracic curve with the largest Cobb measurement and the least flexibility among all curves of a scoliosis. The apex of which is located between the cephalad border of T5 vertebral body and the cephalad border of T12 vertebral body.

CL curve: A CL curve that is adjacent to the MT curve. The CL curve's Cobb measurement is less than that of MT curve and the CL curve's flexibility is larger than that of the MT curve. The apex of CL is located between cephalad border of T12 vertebral body and caudal border of L4 vertebral body.

Between 2004 and 2010, 510 consecutive patients with MTCL curves had been treated surgically by 1 of us (K.W.C.). An MTCL curve was treated with STF using the Guan-Din method if CL curve's side bending Cobb 35° or less and without thoracolumbar kyphosis (T10–L2 ≤20°) and/or global thoracic hyperkyphosis.

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 the 510 MTCL curves. Standing long-cassette coronal and lateral radiographs from the preoperative period, immediately postoperative, 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 classification system of Lenke *et al.*[3] MTCL curves meeting (or not meeting) 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 apical vertebral translation (AVT), apical vertebral rotation (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. 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. When averaging the translational measurement (coronal and sagittal balance), we used absolute values so that the positive and negative values did not cancel each other out. Measures of preoperative and postoperative balance were compared. In the sagittal plane, thoracolumbar kyphosis (if the Cobb angle between T10 and L2 was more than 20°) and global thoracic hyperkyphosis were noted. Each postoperative radiograph was assessed for the evidence of 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 that obtained at the various postoperative time points using a mixed model analysis of variance. Specific comparisons of radiographical criteria were performed by analysis of covariance. Pairwise comparisons of the radiographical data were performed by using the Fisher exact test. Statistical significance was set at $P < 0.05$.

Surgical Techniques

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 1A). After the pedicle screw was positioned, a prebent rod was connected to the pedicle screws on the convex side (Figure 1B). 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. While this was being performed, pedicle screws on the lower and upper segment of the thoracic curve at the convex side were locked tightly (Figure 1C). 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. 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 1D). 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 1E). 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

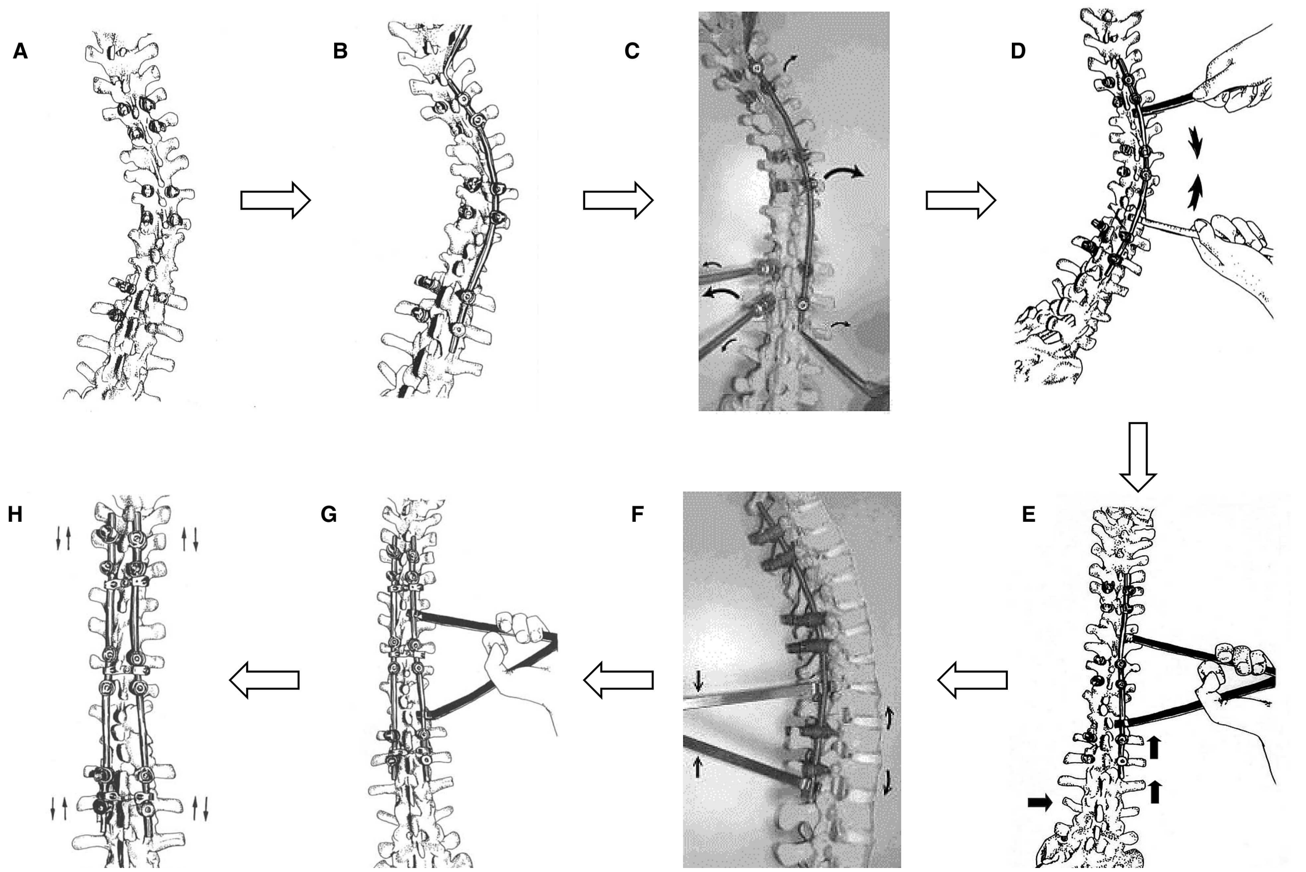

Figure 1. The Guan-Din method for selective thoracic fusion. (**A**) Insertion of 6 groups of pedicle screws. (**B**) A prebent rod was connected to the pedicle screws on the convex side. (**C**) The convex rod was secured tightly to the apical pedicle screws. While derotating the apex of the thoracic curve by derotating the convex rod with hexangular wrenchs and derotating the concave pedicle screws on the lower and upper segments of the thoracic curve with screw drivers in the opposite direction, the convex pedicle screws on the lower and upper segments of the thoracic curve were locked lightly to the convex rod. This procedure freezes the detorque for the thoracic curve in the curve and initiates the detorque for the lumbar curve and the proximal thoracic curve. (**D**) Two long *in situ* benders above and below the apical pedicle screws to generate corrective force in the coronal plane. (**E**) The thoracic curve was corrected, and the upper end vertebra of the lumbar curve was pulled up, thereby shifting the lumbar curve to the midline. (**F**) Further 2 long *in situ* benders at thoracolumbar junction to correct or prevent junctional kyphosis. (**G**) A prebent concave rod was secured to the concave screws to support and maintain the correction. (**H**) After connecting both rods by links, the *in situ* benders were released and removed.

prevent junctional kyphosis with separate application of lordotic corrective force *via* cantilever bending (Figure 1F). 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 1G). 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 (Figure 1H). The *in situ* benders were not removed until the corrected curvature was rigidly fixed.

The use of the Guan-Din method, 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 1 C, E, F) were used to control the corrective forces for the thoracic curve to guide the force which was beneficial to spontaneous correction of lumbar curve into the lumbar curve and to freeze the force which was detrimental to spontaneous correction of lumbar curve within the thoracic curve. Thoracic deformities were corrected in straightforward manner, without detrimental effect on the lumbar spine and to enhance the lumbar curve's capacity for spontaneous correction.

RESULTS

Of the 510 surgically treated MTCL curves, 417 were females and 93 were males. The mean age was 16.4 years (range, 13.8–20.5 yr). Curve types according to Lenke system were as follows: 1A (n = 91), 2A (n = 74), 3A (n = 6), 4A (n = 2), 1B (n = 93), 2B (n = 34), 3B (n = 8), 4B (n = 5), 1C (n = 84), 2C (n = 26), 3C (n = 72), and 4C (n = 15).

Four hundred fifty-eight (90%) of the 510 surgically treated MTCL curves were treated with STF. The mean duration of radiographical follow-up was 4.3 years (range, 2–8). The 458 MTCL curves included 90 (99%) of 91 Lenke 1A, 74 (100%) of 74 Lenke 2A, 6 (100%) of 6 Lenke 3A, 2 (100%) of 2 Lenke 4A; 92 (99%) of 93 Lenke 1B, 33 (97%) of 34 Lenke 2B, 8 (100%) of 8 Lenke 3B, 5 (100%) of 5 Lenke 4B; and

TABLE 1. Lenke Classification of 510 Surgically Treated MTCL Curves and (No., %) of Each Type of Curves Treated With STF

	Lenke 1	Lenke 2	Lenke 3	Lenke 4	Total
A	91 (90, 99)	74 (74, 100)	6 (6, 100)	2 (2, 100)	173 (172, 99)
B	93 (92, 99)	34 (33, 97)	8 (8, 100)	5 (5, 100)	140 (138, 99)
C	84 (82, 98)	26 (26, 100)	72 (35, 49)	15 (5, 33)	197 (148, 75)
Total	268 (264, 99)	134 (133, 99)	86 (49, 60)	22 (12, 55)	510 (458, 90)

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 curves treated with STF.
MTCL indicates major thoracic compensatory lumbar; STF, selective thoracic fusion.

82 (98%) of 84 Lenke 1C, 26 (100%) of 26 Lenke 2C, 49 (60%) of 86 Lenke 3C, and 12 (55%) of 22 Lenke 4C curves (Table 1).

The average preoperative MT curve was 64°. This decreased to 33° on side bending (flexibility: 48%). The MT curve was corrected to an average 14° shortly after surgery, to 17°, at the most recent follow-up (correction: 73%).

The average preoperative lumbar curve was 41°. This decreased to 12° upon side bending (flexibility: 71%). The CL flexibility was not less than that of the MT curve in any patient. The CL curve had corrected to an average 17°, shortly after surgery, and to 15° at the most recent follow-up (correction: 63%). No patient undergoing STF have required extension of the fusion to the lumbar spine.

Of the 313 MTCL curves with a lumbar A or B modifier, 310 (99%) were treated with STF. Those curves' radiographical data were shown in Table 2.

Of the 197 MTCL curves with a lumbar C modifier, 148 (75%) curves were treated with STF. For the 148 cases type C curves, the mean preoperative thoracic curve was 69 ± 12.8°, decreased to 43 ± 9.9° on side bending, and had corrected to 19 ± 8.7° shortly after surgery and to 23 ± 11.1°

TABLE 2. Radiographical Data for 458 of 510 Surgically Treated MTCL Curves Treated With STF

		Thoracic (Instrumented)			Lumbar (Spontaneous)			Balance		
Curves (No.)	Deformity	Pre	Final	Correction	Pre	Final	Correction	Pre	Final	Correction
Lenke 1, 2, 3, 4 with a lumbar A modifier (n = 172)	Cobb (°)	58	12	79%*	26	7	73%*			
	AVT (mm)	51	13	38*	7.9	4.1	3.8*			
	AVR (N-M grade)	1.9	1.7	0.2	1.4	1.1	0.3			
	Coronal balance (mm)							11	9	2
	Sagittal balance (mm)							1	−1	2
Lenke 1, 2, 3, 4 with a lumbar B modifier (n = 138)	Cobb (°)	67	14	79%*	43	13	70%*			
	AVT (mm)	53	18	35*	16.1	7.1	9*			
	AVR (N-M grade)	2.1	1.8	0.3	1.9	1.7	0.2			
	Coronal balance (mm)							13	14	1
	Sagittal balance (mm)							1	−2	3
Lenke 1, 2, 3, 4 with a lumbar C modifier (n = 148)	Cobb (°)	69	23	67%*	58	25	57%*			
	AVT (mm)	56	21	35*	48	21	27*			
	AVR (N-M grade)	2.5	1.9	0.6*	2.4	1.8	0.6*			
	Coronal balance (mm)							15	13	2
	Sagittal balance (mm)							−3	1	4

Data represent mean values.
*Statistically significant change ($P < 0.05$) relative to the preoperative value.
MTCL indicates major thoracic compensatory lumbar; pre, preoperative; STF, selective thoracic fusion; AVT, apical vertebral translation; AVR, apical vertebral rotation; N-M, Nash-Moe; n, number.

at the most recent follow-up, for a mean 67% correction. The preoperative lumbar curve averaged 58° ± 8.1°, to 26 ± 9° on side bending and had corrected to an average of 28 ± 4.8° immediately after surgery and to 25 ± 7.6° at latest follow-up, for a mean 57% spontaneous lumbar correction. MT and CL Cobb improvement was evident in every patient who underwent selective MT fusion, and true correction of thoracic and lumbar AVT was consistent. The preoperative AVT-CL averaged 48 mm. AVT-CL improved to an average 23 mm immediately after surgery, and to 21 mm (range: 8–30 mm) at final follow-up with a mean correction of 27 mm (range: 8–34 mm). Lumbar apical vertebral translation improved in all patients, and in 101 of the 150 patients led to a change in the lumbar modifier grade (C to A in 28 patients, C to B in 73 patients). AVT-MT improved from preoperative 56 mm to 21 mm at final follow-up with a mean correction of 35 mm. Apical vertebral rotation-CL exhibited either improved or unchanged but never aggravated after surgery or at later follow-up. The average preoperative AVR-CL was 2.4 Nash-Moe grade. This decreased to 1.8 at final follow-up. The average AVR-MT improved from preoperation 2.5 Nash-Moe grade to 1.9 at the latest follow-up (Table 2).

No significant change in the global sagittal was observed after surgery. The average global sagittal balance was −3 mm (range: −27 to 24 mm) before surgery, and 1 mm (range: −24 to 26 mm) at the latest follow-up. The mean global coronal balance was 15 mm before surgery (range: −42 to 26 mm) and 13 mm (range: −43 to 21 mm) at the latest follow up. It was improved after surgery but there was not a significant improvement (Table 2). There are 11 patients with coronal balance more than 2 cm before operation and 8 patients with coronal balance more than 2 cm after operation.

Of the 148 MTCL curves with C lumbar modifier, 40 were Lenke 3C and 4C curves and 108 were Lenke 1C and 2C curves. According to the Lenke guidelines, Lenke 3 and 4C curves were not recommended for STF because the lumbar curve is structural (side bending Cobb ≥ 25°). In this study, it was found that the 40 Lenke 3 and 4C curves with the Cobb magnitude of residual lumbar curve on side bending between 25° and 35° could be successfully treated with STF by using the Guan-Din method (Figure 2).

According to Lenke guidelines, for Lenke 1C or 2C curves to be successfully treated by STF, the MT/CL ratio of Cobb measurements, AVT, and AVR should be 1.2 or more. Among the 108 curves, there were 57 Lenke 1C and 2C curves, that were not recommended for STF according to Lenke guidelines, could be successfully treated by STF using the Guan-Din method (Figure 3). Among the 57 Lenke 1C and 2C curves, there were 37 Lenke 1C or 2C curves with the MT/CL ratio of Cobb measurement less than 1.2 (mean: 1.07, range: 1.0–1.2). Twenty-nine of the 57 Lenke 1C or 2C curves had an MT/CL ratio of AVT less than 1.2 (mean: 1.1, range: 1.0–1.2). Thirty-three of the 57 Lenke 1C or 2C curves had an MT/CL ratio of AVR less than 1.2 (mean: 1.0, range: 0.8–1.2).

DISCUSSION

Certain curve patterns leave little doubt concerning the ability to preserve lumbar motion. Those curves with only a thoracic deformity (King-Moe III, V and Lenke 1A, 2A) have long been treated with the distal level of fusion, generally a level or 2 proximal to the stable vertebra. This rarely results in a fusion distal to L2. On the contrary, there are curve patterns that routinely require fusion to L3 or L4. When the primary curve is in the lumbar or thoracolumbar region, lumbar fusion is unavoidable if surgical correction is undertaken. The debate regarding the inclusion of the lumbar spine in the fusion has always focused on those curves with both a MT and a CL component.

Our definition of MTCL curves is that a idiopathic scoliosis has a larger thoracic curve and a smaller lumbar curve that is more flexible than the larger thoracic curve. According to Lenke description of Lenke 1, 2, and 3 curves,[3] of these curves

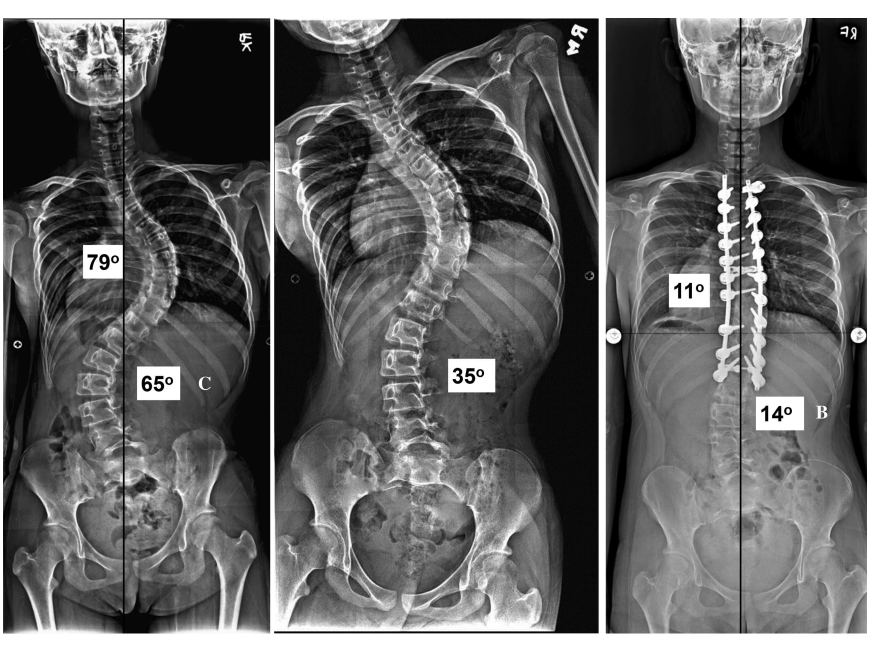

Figure 2. An 18-year-old female with a Lenke 3C curve that met the study criteria was successfully treated by Guan-Din method.

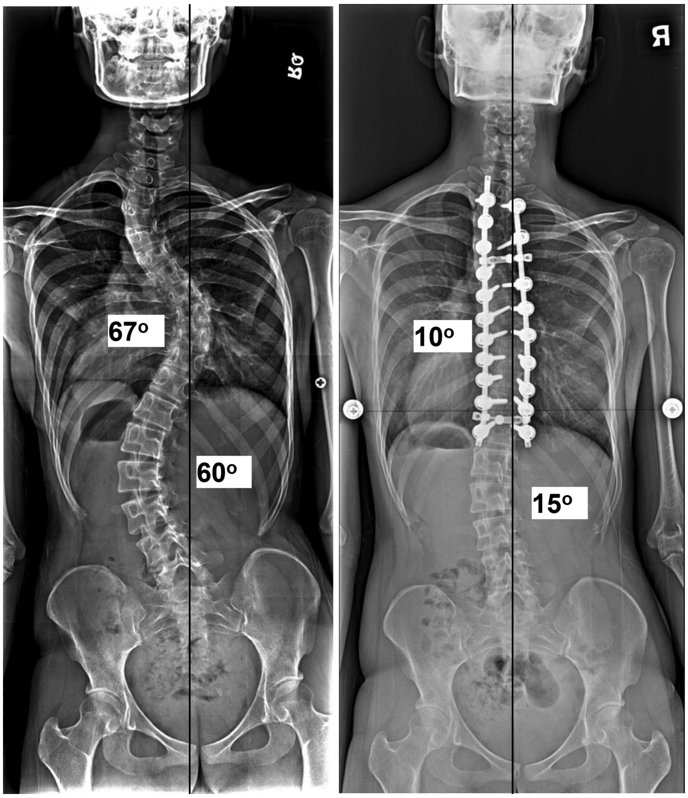

Figure 3. A 17-year-old female with a Lenke 2C curve. The T/L ratio of Cobb. AVT and AVR of the curve were 1.1, 1.0, and 0.8, respectively, which did not meet Lenke curve criteria for STF. However, the curve could be successfully treated with STF using Guan-Din method. AVT indicates apical vertebral translation; AVR, apical vertebral rotation; STF, selective thoracic fusion; T/L, thoracic/lumbar.

the thoracic curve is the major curve and the lumbar curve is the minor curve. The major curve is larger than the minor curve and the minor lumbar curve is always more flexible than the major thoracic curve. Therefore, according to the description by Lenke, Lenke 1, 2, and 3 curves and our definition of MTCL curves, MTCL curves include Lenke 1, 2, and 3 curves. As for Lenke 4 curves, according to the description by Lenke,[3] either the thoracic curve or the lumbar curve can be the major curve. Therefore, a portion of Lenke 4 curves is included in MTCL curves and MTCL curves include Lenke 1, 2, 3, and a portion of Lenke 4 curves. Lenke *et al*[3,5] proposed that Lenke 1 and 2 curves should not be treated with STF if the curves do not meet Lenke curve criteria for STF. They also thought that Lenke 3 and 4 curves should not be treated with STF because the lumbar curve was structural. Multiple studies have demonstrated the negative long-term risks of extending a scoliosis spinal fusion into the lumbar spine.[6–11] Reducing the number of fused levels maximizes spinal flexibility and distributes stress across more distal lumbar motion segments.[12] Theoretically, this 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.[13–20] Sparing the lumbar spine from fusion should be a goal whenever practical and STF should be considered for all MTCL curves. However, substantial variation in the rate of STF existed especially for MTCL curves with a lumbar C modifier. The rate of STF for Lenke 1C curve was in the range from 6% to 67%.[21]

We developed the Guan-Din method as the technique for STF.[1,2] 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.[1] 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*[22] discussed 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,[18,22–24] and induces deformity in the coronal and sagittal planes, thereby reducing the lumbar curve's ability to compensate for thoracic curve correction. Thus, the 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 1C). 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 CL AVR was either improved or unchanged. 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 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 1E). 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 1F). 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 method 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 CL curve was significant. True spontaneous correction of the lumbar curve with significant improvement in AVT was consistent. We found that the results from this series were significantly superior to all other studies[15,16,18,20,25–30] reporting on STF for Lenke 1C and 2C curves, King II curves or PUMC[31] IIb, IIc curves (Table 3). Compared with other series, the MT in this series obtains the best correction (C = 67%) and is the most overcorrected (correction/flexibility = 1.7), and it is echoed with optimal

TABLE 3. Summary Radiographical Data of Publications That Deal With the Issue of Selective Thoracic Fusion for Lenke 1C and 2C Curves, King II Curves, PUMC* IIb, IIc Curves, or MTCL Curves With a Lumbar C Modifier

		MT					CL				
		Cobb					Cobb				
	No. of Pts.	Preop (°)	Latest (°)	Flexibility (%)	Correction (%)	C/F	Preop (°)	Latest (°)	Flexibility (%)	Correction (%)	C/F
Richards[20]	24	61	32	36	48	1.3	49	36	73	27	0.4
Dobbs *et al*[16] (ASF)	16	62	33	50	47	0.9	45	27	44	41	0.9
Edwards *et al*[15] (PSF)	26	62	42	41	32	0.8	50	32	68	33	0.5
Edwards *et al*[15] (ASF)	15	56	32	40	43	1.1	44	27	66	39	0.6
Schulte *et al*[25] (ASF)	16	66	41	37	55	1.5	49	17	65	50	0.8
Lenke *et al*[18] (ASF)	7	65	27	34	59	1.7	42	21	71	50	0.7
Lenke *et al*[18] (PSF)	10	67	49	40	27	0.7	53	37	66	30	0.5
Suk *et al*[26] (PSF)	122	50	17	51	67	1.3	33	14	114	60	0.6
Yu *et al*[27] (PSF)	17	57	22	44	60	0.8	35	15	82	64	0.8
Dobbs *et al*[28] (PSF)	32	64	51	53	33	0.6	49	37	49	24	0.5
Kalen and Conklin[29]	58	52	13	33	25	0.8	32	22	75	31	0.4
Yong *et al*[30]	24	53	25	58	53	0.9	44	25	73	42	0.6
Dobbs *et al*[28] (PSF)	34	62	40	52	44	0.8	45	28	47	39	0.7
Chang *et al* (PSF)	148	69	23	38	**67**	**1.7**	58	25	55	**57**	**1.04**

Data represent mean values. The boldface values are the data in this study series.

**From PUMC.[31]*

MT indicates main thoracic curve; CL, compensatory lumbar curve; PSF, posterior spinal fusion; ASF, anterior spinal fusion; C/F, correction/flexibility; preop, preoperative; Pts, patients; flexibility = (preoperative angle − bending angle)/(preoperative angle × 100%); correction = (preoperative angle − postoperative angle)/preoperative angle × 100%.

correction of the lumbar curve (C = 57%). This series is the only one that the lumbar curve's capacity for spontaneous correction is enhanced (correction/flexibility = 1.04). 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), that is, correction/flexibility more than 1. Such a finding has not previously been reported. The quality of spontaneous correction of lumbar curves for MTCL curves treated by STF is crucial to the quality of life of the patient with MTCL. There is reason to think that lumbar degeneration will be less problematic if optimal spontaneous lumbar correction can be obtained.[32] The instrumented thoracic and CL correction could be maximized by using the Guan-Din method as the method for STF.

We also have demonstrated that this method can broaden the current curve criteria for STF to have more MTCL curves to be treated with STF.[2] In this study, of 510 surgically treated consecutive MTCL curves, 458 (90%) curves treated with STF. The rate of STF in this study was significantly greater

TABLE 4. Comparison of Authors' Consecutive Surgically Treated MTCL Curves Treated With STF

	Lenke 1	Lenke 2	Lenke 3	Lenke 4	Total
Lenke *et al*[3]	126 (114, 90)	56 (50, 89)	58 (2, 3)	8 (2, 25)	248 (228, 74)
Puno *et al*[33]	96 (81, 84)	16 (?)	26 (9, 35)	2 (0, 0)	124 (90, 73)
Chang *et al*	268 (264, 99)	134 (33, 99)	86 (49, 60)	22 (12, 55)	510 (458, 90)

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 curves treated with STF.

STF indicates selective thoracic fusion; MTCL, major thoracic compensatory lumbar.

than that in other reports[3,33] (Table 4). By using the Guan-Din method for STF, Lenke 1C and 2C curves could be treated with STF without any limitation and Lenke 3C and 4C curves could be treated with STF if lumbar side bending Cobb 35° or less, thus maximizing the number of Lenke 1C, 2C, 3C, and 4C curves to be treated with STF. Of the 197 MTCL curves with lumbar C modifier, 148 (75%) curves that contained 57 consecutive Lenke 1C and 2C curves and 40 Lenke 3C and 4C curves, which were not recommended for STF according to Lenke curve criteria or structural criteria, were successfully treated with STF using the Guan-Din method. The rate of STF for Lenke 1C curve was 98% in this study *versus* 68% in report of Newton *et al*[21] Lumbar motion is important for function during the patient's remaining decades of life. The rate of STF for MTCL curves could be maximized by using the Guan-Din method as the method for STF.

Why did we choose 35° as a cutoff point in this study? We have demonstrated that the Guan-Din method can enhance the lumbar curve's capacity for spontaneous correction.[1] We think that the residual lumbar curve on side bending represents the original lumbar curve's capacity for spontaneous correction and the lumbar curve can be at least corrected to the same Cobb magnitude of the residual lumbar curve on side bending, if not better. A residual lumbar curve of 35° after STF is acceptable to us. In our previous study,[2] 17 consecutive Lenke 3C and 4C curves with a magnitude of residual lumbar curve's Cobb on side bending less than 35° could be successfully treated with STF by using the Guan-Din method while optimizing correction. That is the reason we chose 35° as a cutoff point in this study.

Thoracolumbar kyphosis before surgery may also drive a surgeon to perform a more distal fusion in patients who might otherwise have been candidates for STF. The Lenke classification criterion states that if the T10–L2 kyphosis measures 20° or more, the thoracolumbar/lumbar region is considered "structural" and fusion is suggested across these levels.[3,5] Global thoracic hyperkyphosis might also require correction by instrumentation distally to L2 or L3 in some cases. In this study, 1 Lenke 1A, 1 Lenke 1B, 2 Lenke 1 C, 1 Lenke 2B, and 3 Lenke 3C curves had a global thoracic hyperkyphosis and all the kyphosis extended into the lumbar spine and require correction by instrumentation distal to L2 or L3. The sagittal plane deserves equal attention compared with the coronal plane because sagittal alignment determines the regions of a scoliosis to be included in an arthrodesis too, and the distal level of fusion must be appropriate for the deformity in both planes.

In our studies, postoperative radiography showed that lumbar AVR was either improved or unchanged but never aggravated, and therefore, couple aggravation of the lumbar curve or postoperative decompensation did not occur. Our results demonstrated that forceful and direct rotation of the thoracic apical vertebra and low-end vertebrae of the thoracic curve in the opposite direction by the Guan-Din method, reinforced with pressing the rib hump and twisting the pelvis in the opposite direction (this supplementary maneuver is only for curves with a lumbar C modifier, not for curves with a lumbar A or B modifier to avoid too much detorque for the lumbar curve resulting in postoperative adding-on) and locking the relative position on the convex rod (Figure 1C),

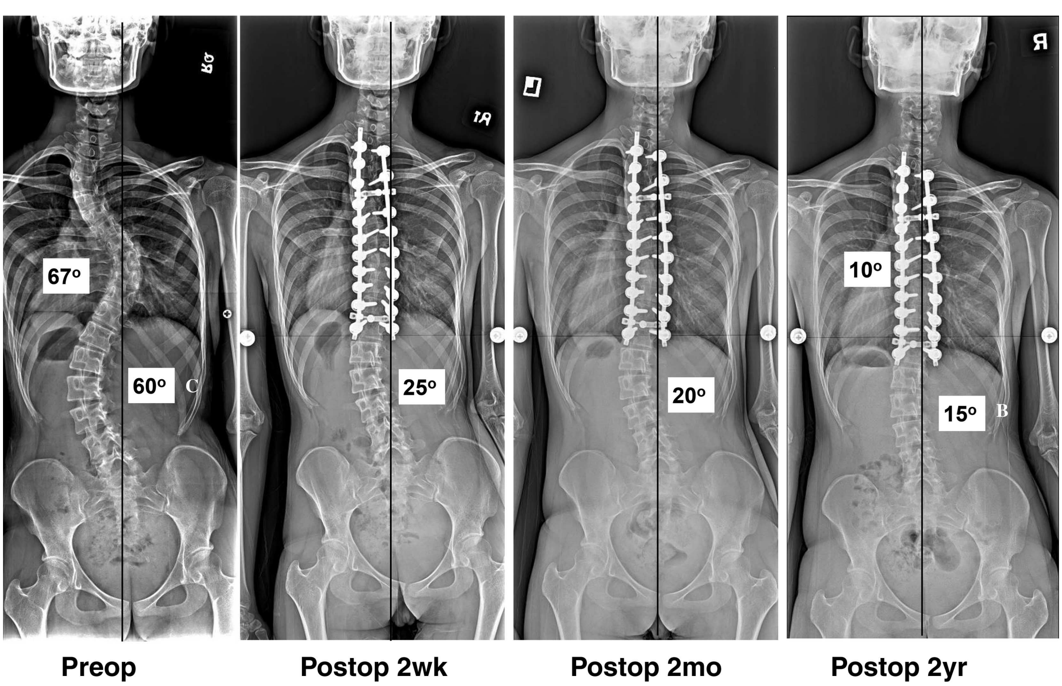

Figure 4. Preoperative, 2-week postoperative, 2-month postoperative, and 2-year postoperative standing radiographs demonstrate the spontaneous lumbar curve correction in Cobb magnitude, AVT, and balance is dynamic and actually improved from the immediately postoperative radiograph (25°, C, 21 mm) to 2 years of follow-up postoperative radiograph (15°, B, 4 mm). AVT indicates apical vertebral translation; preop, preoperative, postop, postoperative.

was an effective method to prevent transmission of thoracic detorque to the lumbar curve and initiate detorque for the lumbar curve as well as the thoracic apical vertebra. We think that this technique holds the key for successful STF and should be executed exactly. The lowest 2 instrumented vertebra should have bicortical fixations with fixed head screws so as to provide powerful derotation force for the lumbar curve when undergoing this technique.

In addition, our methodology has not only an immediate, but also a continuous and persistent positive influence on the capacity for spontaneous correction and compensation of the lumbar spine. For most of the curves, the spontaneous lumbar curve correction was dynamic and actually improved from the immediate postoperative radiograph to 2 years follow-up postoperative radiograph (Figure 4). The capacity for correction and compensation increased with time, suggesting that coordination of the corrective forces may also be enhanced over time.

As description of the meaning of the Guan-Din method at the beginning of the text, the method initiates the correction on the top, and let the corrective forces cascade down. Using the Guan-Din method for STF, it is crucial that the distal level of instrumentation and fusion is the "head" of the lumbar curve so that the force which enhances the lumbar curve's capacity for spontaneous correction can initiate correction of the "head" of the lumbar curve and be transmitted through the "head" into the lumbar curve. The proximal end vertebra of the lumbar curve, which also was the distal end vertebra of the thoracic curve, was considered to be the head of the lumbar curve and was designated as the distal level of instrumentation and fusion, and so to have the most number of unfused motion segments to spontaneously adjust after STF procedure. In general, among major thoracic compensatory C modifier lumbar curves, the curves with the distal level of instrumentation located at the proximal end vertebra of the lumbar curve as well as the first rotated vertebra of lumbar curve, the lumbar spontaneous correction and compensation after STF by the Guan-Din method would be the best. We realize that Cobb angles may be corrected quite impressively but what the patients more preferably notice will be the balance of their trunks. There was improvement in coronal balance but there was not a significant improvement. We think that this is a short coming of this technique. These details are based on our experience and must be noted to avoid being misled.

CONCLUSION

The Guan-Din method for STF can enhance the lumbar curve's capacity for spontaneous correction and broaden the current curve criteria of MTCL curves for STF. Of 510 surgically treated MTCL curves, 458 (90%) curves were treated with STF using the Guan-Din method and obtained instrumented thoracic correction of 73% and spontaneous lumbar correction of 63%. Of the 197 surgically treated MTCL curves with lumbar C modifier, 148 (75%) curves that contained 57 Lenke 1C and 2C curves and 40 Lenke 3C and 4C curves, that did not meet Lenke curve criteria for STF, were successfully treated with STF and obtained instrumented thoracic correction of 67% and spontaneous lumbar correction of 57%. The rate of STF and magnitude of correction of MTCL curves were significantly greater than those in all other reports. Surgical treatment of MTCL curves aims to maximize the number of MTCL curves to be treated with STF while optimizing instrumented thoracic and spontaneous lumbar correction. The goal can be achieved by using the Guan-Din method as the method for STF.

➢ Key Points

- The Guan-Din method for STF can enhance the lumbar curve's capacity for spontaneous correction and broaden the current curve criteria for STF.
- Of 510 surgically treated MTCL curves, 458 (90%) curves were treated with STF using the Guan-Din method and obtained instrumented thoracic correction of 73% and spontaneous lumbar correction of 63%.
- Of the 197 surgically treated MTCL curves with a lumbar C modifier, 148 (75%) curves that contained 57 Lenke 1C and 2C curves and 40 Lenke 3C and 4C curves that did not meet Lenke curve criteria for STF, were successfully treated with STF and obtained instrumented thoracic correction of 67% and spontaneous lumbar correction of 57%.
- The rate of STF and the magnitude of correction of MTCL curves in this study were significantly greater than those in all other reports.
- Surgical treatment of MTCL curves aims to maximize the number of MTCL curves to be treated with STF while optimizing instrumented thoracic and spontaneous lumbar correction. The goal can be achieved by using the Guan-Din method as the method for STF.

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