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The Selection of Fusion Levels Using Torsional Correction Techniques in the Surgical Treatment of Idiopathic Scoliosis

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Study Design. This is a retrospective, consecutive case series, with the index patient included.

Objectives. To evaluate the evolution and effectiveness of instrumentation techniques designed to untwist the scoliosis deformity.

Summary of Background Data. Three-dimensional studies of the idiopathic scoliosis deformity are consistent with the theory that the deformity or deformities evolve as an imperfect torsion or torsions.

Methods. From 1989 through 1995, 102 consecutive patients (84 females, 18 males) underwent surgery with increasing emphasis on torsional correction. One hundred patients (98%), with an average age of 14.3 years (range, 10.5–20.8 years), were observed for an average of 40 months (range, 24–81 months). The upper instrumented vertebra evolved to be the centered vertebra. The lower instrumented vertebra was chosen based on its ability to become horizontal on contralateral bend radiographs and was termed the caudal foundation vertebra. Because these techniques evolved over the first 3 years of the study period, a split analysis was performed to evaluate improvements in correction and correction maintenance over the course of the study.

Results. The average Cobb angle was 59° before surgery, 18° after surgery (69% correction), and 22° (63% correction) at latest follow-up. A comparison of the first half of the series with the second half showed no significant demographic differences. Curve correction was significantly improved for King–Moe IIB (thoracolumbar–lumbar curve only), King–Moe III, and King–Moe V curve types in the second half of the series. In the last 4 years, curve correction at latest follow-up for King–Moe IIB curves was 61% for the thoracic curve and 65% for the thoracolumbar–lumbar curve. King–Moe III curves had a 68% correction, and King–Moe V curves had a 50% high thoracic and a 72% thoracic curve correction. Thoracolumbar, lumbar, and King–Moe I curves averaged 81% correction of the thoracolumbar–lumbar curve. The angle of thoracic curve inclination improvement at 1 year was maintained at latest follow-up.

Conclusions. This method of selecting instrumentation levels while using torsional correction techniques is safe and reliable. The results were improved with the evolution of these techniques and appear to provide improved correction and correction maintenance compared with that of historical controls. [Key Words: idiopathic scoliosis, Isola instrumentation] **Spine 1999;24:1728–1739**

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Instrumented correction and stabilization of large scoliosis deformities were initially developed between 1949 and 1960 by Dr. Paul Harrington in response to inadequacies of the exiting scoliosis treatment methods.[24] Introduced commercially in 1960, the Harrington instrumentation system was the most widely used system for 25 years, and its results remain the standard by which other systems are compared.

By the early 1970s, the shortcomings of this one-planar, two-dimensional system were becoming apparent, particularly in its inability to control sagittal plane alignment, the need for postoperative casting, and significant loss of correction.

This led to the development of the two-planar, three-dimensional system of Luque (1974),[34] followed by the three-planar, three-dimensional system of Cotrel–Dubousset (1984),[17] which finally freed the patient from postoperative immobilization. These improvements were encouraging, but problems remained. Other systems were developed because of concerns about instrumentation bulk, complexity, connection strength, emerging reports of imbalance, and other issues. Of these, Isola instrumentation (AcroMed, Cleveland, OH) first introduced in a limited manner in early 1989, is unique because of its planned integration of hook, wire or cable, and screw anchors.[3,4]

Along with improvements in instrumentation design and application has come a better understanding of the three-dimensional nature of the scoliotic deformity.[5,17,18,20,37] From these studies, the concept of scoliosis as a series of one, two, or three torsions emerged and fit into instrumentation development.[6,7]

The purpose of this study was to analyze the results using posterior Isola instrumentation and fusion for the treatment of idiopathic scoliosis. In addition, guidelines were defined for the selection of fusion levels using torsional and countertorsional instrumentation concepts that evolved during the first 3 years of the study.

Materials and Methods

One hundred two patients (84 females, 18 males) were initially treated with posterior Isola instrumentation and arthrodesis from February 1989 through December 1995. This represented

89% of the 114 patients with idiopathic scoliosis who underwent surgery during this period. Cotrel–Dubousset instrumentation (CDI) was used in 2 patients of the 114 in 1989 and anterior Isola in 10 others from 1993 through 1995. All operative procedures were performed by the senior author. Inclusion criteria for this study involved a diagnosis of either juvenile or adolescent idiopathic scoliosis and age less than or equal to 20 years. One patient was lost to clinical follow-up, although telephone contact has been re-established. Another was lost to follow-up 20 months after surgery. The remaining 100 patients (98%) were available for clinical study for a minimum of 24 months after surgery, with an average follow-up of 39 months (range, 24–81 months). Data through 1-year follow-up were included for the patient lost at 20 months' follow-up.

The angle of trunk inclination (ATI)[14] was recorded on all patients before surgery, at 1 year after surgery, and at latest follow-up. Ordinal style function, pain, and appearance self-assessment forms were recorded before surgery beginning in 1992. All patients completed the self-assessment forms at latest follow-up. In addition, the newly developed Scoliosis Research Society (SRS) Outcomes Instrument[23,48] was provided to all patients; 84 (82%) responded.

Standing posteroanterior and lateral 36-in. scoliosis radiographs were obtained in all patients before surgery, after surgery, and at latest follow-up. Most had supine active right and left bend radiographs before surgery. Frontal curve magnitudes were recorded using the Cobb method.[15] The first step in radiographic analysis was to number the vertebra accurately. Kyphosis was measured from T2 to T12 and lordosis from T12 to S1, using the Cobb method.[15] Balance in the frontal plane was recorded as the offset of T1 from the central sacral line,[29] ±20 mm being normal.[42] Thoracic curves received King–Moe (KM)[29] classifications with the following modification: the KM II curve was subclassified into KM IIA or KM IIB, similar in concept to that originally described by Ibrahim.[26] In the study, KM IIB curves had two or more of the following characteristics: inflection vertebra offset from the medial sacral gravity reference line toward the convexity of the lower curve, inflection vertebra of T11 or higher, or presence of thoracolumbar junction kyphosis. Thoracolumbar junction kyphosis was defined as increased global extension of the most extended vertebra at the thoracolumbar junction, T11–L2 (*e.g.,* normal T12 extension, $-12 \pm 6°$) or abnormal posterior global translation of L1 (normal, $+2 \pm 14$ mm).[42]

King–Moe V curves were defined as those with an angulation of T1 toward the concavity of the high thoracic curve greater than or equal to 5°. Thoracolumbar curves were defined as those with an apex at the T12 body, T12–L1 disc, or L1 body, and lumbar curves as those with an apex at or below the L1–L2 disc space.[43,44]

Upper and lower instrumented level selection evolved over the first 3 years of the study period but were observed closely during the last 4 years. The upper instrumented level for KM V curves was usually T2, occasionally T3, in lower apex, high thoracic curves. The upper fusion level for all other curves was based on the centered vertebra, defined as the first vertebra cephalad to the upper end vertebra of the thoracic curve that is midway between the sides of the rib cage in a plane parallel to the global Y-axis.[45] High thoracic sagittal plane alignment was also considered and an additional one or two cephalad levels added, as necessary, to treat hyperkyphosis or hypokyphosis. In no instance was T1 instrumented and included in the fusion.

In choosing the lower instrumentation level, there were two general principles. First, never end the fusion above a kyphotic disc space, and second, always leave three or more distal motion segments.

The lower instrumented vertebra for KM IIA curves was the stable vertebra.[29] For KM III, IV, and V curves, the lower instrumented vertebra chosen was usually one below the lower end vertebra[24] and one above the stable vertebra.[2] The lower instrumented vertebra for KM IIB, KM I, thoracolumbar, and lumbar curves was based on the caudal foundation vertebra (CFV). The CFV was defined as the first vertebra at or above the lower end vertebra of the lumbar curve that would become centered over the sacrum after the application of torsional reduction loads. The CFV is based on two criteria: The immediately subjacent disc space wedging is reversed or at least neutralized on convex bending, and the vertebra below the CFV has 15° or less rotation in the transverse plan on convex bending.

To achieve the goal of preserving at least three distal motion segments bilateral lower instrumented vertebra pedicle screws were used with occasional destabilization of the lumbar spine by adding supplemental anterior 360° anulectomy and discectomy of the lowest three of four fused motion segments, filling the temporarily distracted interspace with large quantities of nonstructural autograft or autograft–allograft mixture bone.

Statistical Analysis. Descriptive statistics were calculated for all variables. In split analyses, patients were divided into two groups based on the year when surgeries were performed (*i.e.,* 1989 through 1991 and 1992 through 1995). Measurements on correction maintenance over the course of the study were assessed before surgery, after surgery, and at latest follow-up. Statistical significance of the difference in mean percentage of correction between two periods (*e.g.,* correction from before surgery to the latest follow-up) was tested using Student's *t* test. Appropriate transformations were made before the test was performed when a variable showed a skew distribution after visual investigation of the data or if the Shapiro–Wilk test resulted in a violation of normality assumption. Statistical significance was set at $P < 0.05$.

Techniques. All patients received cephalosporin prophylaxis during surgery and after surgery and underwent surgery on a well-padded Relton–Hall style frame.[38] Somatosensory evoked potential spinal cord monitoring was used in almost all cases to supplement the wake-up test[49] and clonus test.[25] The mean arterial pressure was maintained at approximately 70 mm Hg, and the patient's core body temperature maintained at 35.5 C to 37 C. Predonated autologous blood and intraoperative cell saving were used in most patients. Autologous iliac crest bone graft was used except in most patients undergoing convex thoracoplasty, in which autologous rib grafts alone were used.

Instrumentation consisted of the sequential, segmental application of corrective translational forces, angular moments, and torsions to the spine by hook, screw, or wire–cable anchors connected to anatomically contoured longitudinal members (rods) that were sequentially transversely connected, creating a stable frame (Figure 1).[3,4]

Bilateral transverse process–facet intrasegmental claws were used for the upper instrumented vertebra, providing upper instrumented vertebra position control. The only exception to this was for the double thoracic curve, where the convex facet hook was moved to the sublaminar position to minimize any lateral pullout tendency. At T12, L1, or L2 of single tho-

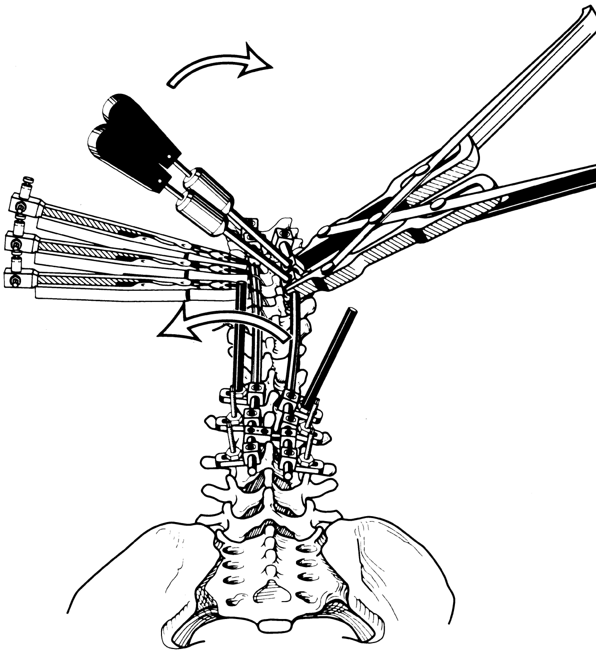

Figure 1. Model depicting application of corrective thoracic counterclockwise torsion and lumbar clockwise torsion. Not shown is the addition of stabilizing high thoracic stabilizing clockwise torsion to resist the continuation of the corrective thoracic counterclockwise torsion into the high thoracic spine. The corrective lumbar clockwise torsion may continue into the pelvis, but clinically transverse plane compensation occurs in the noninstrumented lumbar spine.

racic or double thoracic curves, the lower foundation sometimes consisted of three or four hooks, one or two down-going supralaminar hooks on the concave side and one or two up-going lamina hooks on the convex side. In most instances, however, instrumentation of the lowest instrumented vertebra consisted of two pedicle screws. This procedure was used for all double curves and thoracolumbar—lumbar curves (with a sole exception in 1989).

Thoracic spine concave anchors were sublaminar wires, subpars cables, or facet hooks. When computed tomographic studies showed that sublaminar wires were not providing derotation,[21,50] subpars wires or cables were used in most instances, unless the curves were very flexible, in which case used facet hooks were used. The convex thoracic instrumentation evolved to an intertransverse process apex claw. In the lumbar spine, the convex apex was always instrumented with pedicle screws. Initially, the concave side was instrumented with wires, but over time this changed to pedicle screws. In double curves, inflection hooks were gradually deleted, because the principal correction loads were applied at the apex. In double thoracic curves, a high thoracic convex up-going transverse process hook was placed two below the T2 (or T3) upper instrumented vertebra, typically at T4 or T5. This provided a rotation point and thus a moment arm about which the upper instrumented vertebra through its foundation, a transverse process lamina claw, could be rotated in the coronal plane. This resulted in the addition of a coronal plane counterclockwise angulation to the upper instrumented vertebra. A high thoracic concave transverse process down-going hook was placed on the inflection vertebra, usually T6, and occasionally on T7. From this anchor site, strong distraction could be added to the concave T2 facet hook, further improving T1 coronal plane angulation. After rod capture, a variety of instruments aided in the translational force and angular moment application. A typical double torsion instrumentation is shown (Figure 2). Although instrumentation construct and sequences have continued to evolve slowly, the principal evolution occurred in the first 3 years of the series and has been described elsewhere.[4,7,13] None of the patients was immobilized with a cast or brace after surgery.

Results

The patients' average age was 14 years, 4 months (range, 10 years, 6 months–20 years, 10 months). In addition to primary posterior instrumentation and fusion, four patients had anterior procedures, because of the size and stiffness of their curve. Three of these were sequential, and one was staged 1 week before the posterior procedure. The latter resulted in a prolonged hospital stay (24 days). Twenty patients had concomitant rib procedures. Six received concave rib osteotomy, seven had thoracoplasty, and seven had a combination of either concave and convex rib osteotomy (one patient) or concave osteotomy with convex thoracoplasty (six patients).

The average operative time was 341 minutes (range, 211–578 minutes). Average intraoperative blood loss was 950 mL (range, 200–3000 mL). The average hospital stay for patients undergoing a posterior procedure only was 8.5 days (range, 6–13 days). The average stay for patients undergoing anterior and posterior procedures was 16 days (range, 8–24 days).

King–Moe IIA

There were six patients with KM IIA curves. The average age was 14.4 years (range, 12.2–16.6 years), and follow-up averaged 57 months (range, 44–81 months). Radiographic and clinical analyses are shown in Table 1. The average thoracic curve correction in this group was 59% with an 8% loss at latest follow-up. The average lumbar curve correction was 40% with a 7% loss at latest follow-up. No patients were radiographically or clinically off balance at latest follow-up. The average lower end vertebra was T11.7, stable vertebra T12, and lower instrumented vertebra T12. The average length of fusion was 8.6 vertebral bodies and the upper instrumented vertebra averaged T4.5 (Table 2). Because no surgery was performed on KM IIA curves in the second half of the series, there could be no comparison between the two groups.

King–Moe IIB

There were 25 patients with KM IIB curves. The average age was 13.4 years (range, 10.5–18.75 years), and follow-up averaged 38 months (range, 24–81 months). Radiographic and clinical analyses are shown in Table 3. The average thoracic curve correction in this group was 63% with a 3% loss at latest follow-up. The average thoracolumbar–lumbar curve correction was 62% with a 2% loss at latest follow-up. Two patients were radiographically off balance at latest follow-up (21 mm and 23

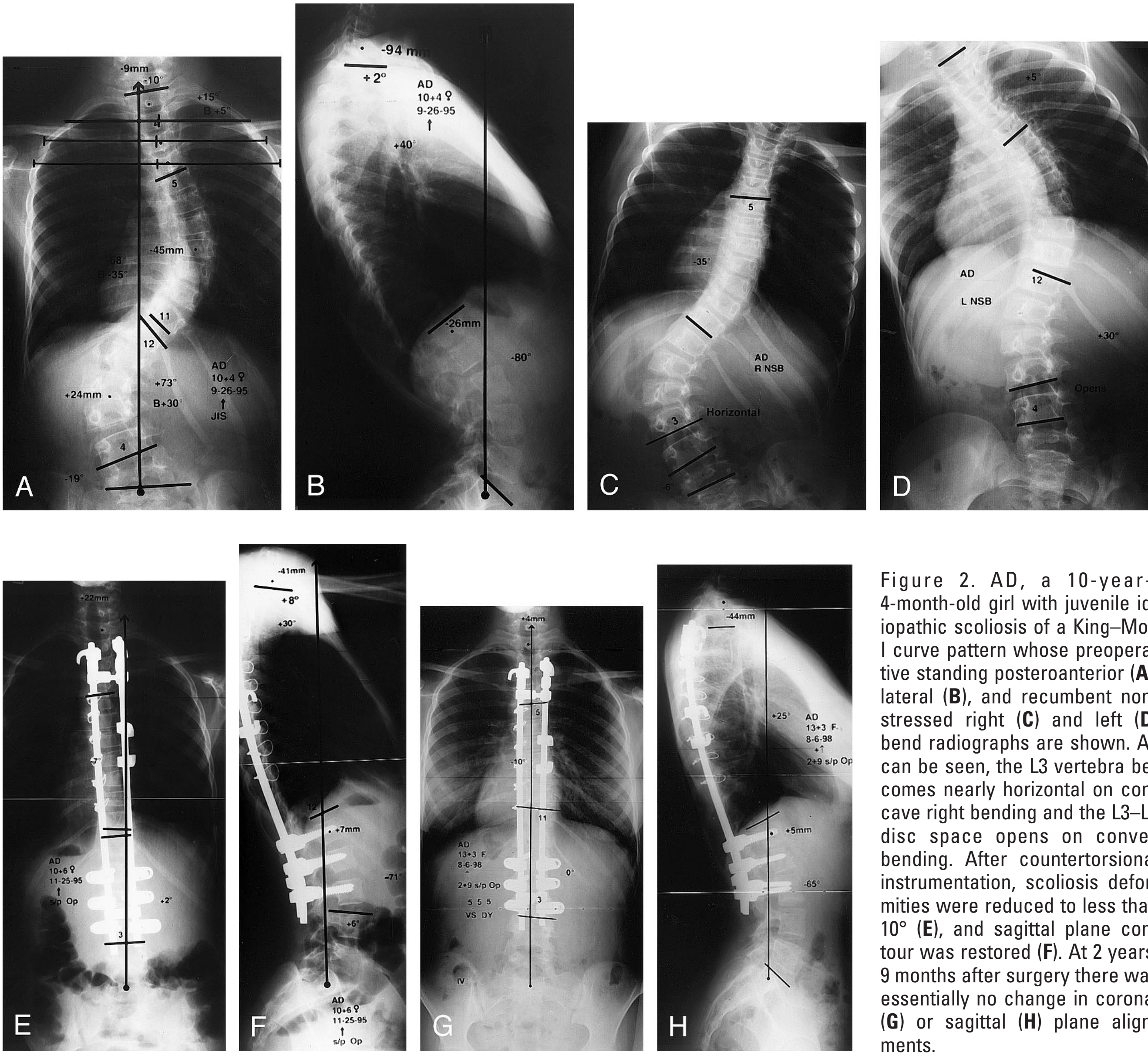

Figure 2. AD, a 10-year-, 4-month-old girl with juvenile idiopathic scoliosis of a King–Moe I curve pattern whose preoperative standing posteroanterior (**A**), lateral (**B**), and recumbent nonstressed right (**C**) and left (**D**) bend radiographs are shown. As can be seen, the L3 vertebra becomes nearly horizontal on concave right bending and the L3–L4 disc space opens on convex bending. After countertorsional instrumentation, scoliosis deformities were reduced to less than 10° (**E**), and sagittal plane contour was restored (**F**). At 2 years, 9 months after surgery there was essentially no change in coronal (**G**) or sagittal (**H**) plane alignments.

mm). However, neither patient was clinically off balance, and neither mentioned it. The average thoracolumbar–lumbar lower end vertebra was L3.5, stable thoracic vertebra T12, and lower instrumented vertebra L2. The average length of fusion was 11.4 vertebral bodies, and the average upper instrumentated vertebra T3.6 (Table 2).

Table 1. KM IIA Curves

Patient No.	Date	Preop Data				Postop			1 yr F/U				Last F/U				
		T1	T	TL/L	ATI-T	T1	T	TL/L	T1	T	TL/L	ATI-T	Months	T1	T	TL/L	ATI-T
1	12/27/89	0	75	53	20	X	27	29	12	36	32	10	46	0	31	31	12
2	7/13/89	11	50	31	13	X	19	15	X	X	X	X	81	0	30	21	7
3	7/20/89	0	55	44	13	0	30	25	11	34	30	13	44	11	36	30	11
4	3/29/90	0	57	39	16	0	21	22	10	23	25	15	63	0	18	19	14
5	6/28/90	9	85	45	24	20	40	35	3	46	34	24	49	5	48	38	20
6	7/25/91	4	53	38	14	7	20	24	X	X	X	X	70	8	20	20	4
Average		4	63	42	16.7	7	26	25	9	35	30	15.5	57	3	31	28	12.8

T1 = T1 mediolateral offset (mm) from the mid-sacral gravity reference line (Z axis); T = thoracic Cobb; TL/L = thoracolumbar/lumbar Cobb; ATI-T = angle of trunk inclination, thoracic; Preop = preoperative; Postop = postoperative; F/U = follow-up; X = missing data point.

Table 2. Upper Instrumented Vertebra (UIV), Lower End Vertebra (LEV), Stable Vertebra (SV), and Lower Instrumented Vertebra (LIV) by Curve Pattern

Curve Pattern	Period	n	UIV	LEV	SV	LIV
IIA	1989–1995	6	T4.5	11.7	T12	T12
IIB	1989–1995	25	T3.6	L3.5	T12	L2
	1989–1991		T3.3			
	1992–1995		T3.8			
III	1989–1995	26	T3.6	T11.7	L2	L1
	1989–1991		T3.5			
	1992–1995		T3.6			
IV	1989–1995	5	T5	L1	L4	L2.5
V	1989–1995	17	T2.7	T12.8	L2.5	L1.3
	1989–1991		T2.3			
	1992–1995		T2.9			
TL/L/KM I	1989–1995	20	T6.1	L3.5	NA	L3.3

Results of split analysis of the first 3 years *versus* the last 4 (Table 4) showed thoracolumbar–lumbar curve correction was significantly improved at 1 year (44% *vs.* 63%; $P < 0.01$) and at latest follow-up (42% *vs.* 65%). Thoracic curve correction and ATI were improved, but not significantly. The average lower instrumented vertebra changed from L1 in the first 3 years of the series to L2.4 in the last 4 years (Table 2).

King–Moe III

There were 26 patients with KM III curves. The average age was 14.2 years (range, 10.5–20.8 years) and follow-up averaged 38 months (range, 24–68 months). Radiographic and clinical analyses are shown in Table 5. The average thoracic curve correction in this group was 69%, with a 6% loss at latest follow-up. One patient was radiographically off balance at latest follow-up (30 mm). Her clinical examination, however, showed that she was well balanced in the coronal plane, and she did not have a sensation of leaning to the side. The average lower end vertebra was T11.7, stable vertebra L2, and lower instrumented vertebra L1. The average length of fusion was 10.5 vertebral bodies and the upper instrumented vertebra T3.6 (Table 2).

Table 3. KM IIB Curves

Patient No.	Date	Preop T1	Preop T	Preop TL/L	Preop ATI-T	Postop T1	Postop T	Postop TL/L	1 yr F/U T1	1 yr F/U T	1 yr F/U TL/L	1 yr F/U ATI-T	Last F/U Months	Last F/U T1	Last F/U T	Last F/U TL/L	Last F/U ATI-T
7	6/23/89	4	55	44	13	0	21	21	7	28	26	13	48	4	20	24	13
8	2/15/89	0	50	36	15	21	31	22	4	29	26	17	51	0	26	21	17
9	7/12/89	25	70	59	15	22	30	35	10	35	35	17	81	0	35	39	15
10	7/3/89	20	72	41	23	0	26	20	0	40	27	23	55	7	37	29	24
11	4/11/90	8	58	45	15	19	17	20	17	27	31	9	25	5	27	26	11
12	6/6/90	8	55	35	21	14	12	6	0	13	5	18	50	7	13	10	18
13	6/21/90	8	65	51	11	7	20	20	6	20	24	10	48	13	30	32	7
14	8/17/90	14	45	36	15	20	18	11	5	19	20	19	48	10	16	20	15
15	5/4/92	16	50	35	14	17	13	0	25	16	0	14	37	11	20	6	11
16	7/6/92	16	58	48	12	2	20	20	7	22	20	11	35	0	19	17	5
17	7/20/92	9	84	60	20	5	40	29	9	32	20	15	25	0	30	22	15
18	8/7/92	12	47	37	8	5	21	15	0	16	20	7	24	0	25	21	7
19	8/12/92	34	108	110	10	0	64	50	0	60	52	24	45	6	62	54	22
20	10/21/92	15	54	50	16	20	15	9	X	X	X	X	50	0	10	2	10
21	11/16/92	12	70	53	10	10	17	10	8	16	13	5	24	7	16	12	2
22	12/2/92	12	53	43	15	5	15	10	8	21	13	7	24	3	19	11	7
23	3/19/93	6	59	42	14	10	14	14	12	17	23	9	42	3	20	23	6
24	7/12/93	6	48	46	15	10	7	12	0	13	10	0	29	8	12	12	6
25	8/13/93	4	67	47	19	25	25	20	18	26	22	16	24	21	26	20	19
26	12/13/93	11	52	32	18	0	22	11	18	22	7	0	37	23	22	7	16
27	5/20/94	44	59	42	15	12	27	14	0	20	16	15	28	3	24	20	15
28	7/1/94	0	69	55	13	6	28	28	9	20	31	0	29	5	29	24	5
29	7/20/94	6	50	40	19	3	16	16	8	20	15	11	26	10	22	17	12
30	1/6/95	0	52	35	21	27	17	13	0	25	10	14	24	8	26	0	20
31	6/16/95	20	56	56	10	13	25	15	7	21	15	4	25	8	23	13	8
Average		12	60	47	15	11	22	17.6	7	24	20	11.8	38.0	6	24	19	12.1
1989–1991		11	59	43	16	13	22	19.4	6	26	24.3	15.8	50.8	6	26	25	15.0
1992–1995		13	61	49	14.5	10	23	16.8	8	23	17.9	9.6	30.6	7	24	17	10.5

See Table 1 for abbreviations.

Table 4. KM IIB Split Analysis

	Angle (°)	% Correction	
		1 yr	Latest
Preop Cobb thoracic			
1989–1991	59	56	56
1992–1995	61	62	61
Preop Cobb TL/L			
1989–1991	43	44*	42*
1992–1995	49	63*	65*
Preop ATI thoracic			
1989–1991	16	1	8
1992–1995	14.5	31	25

* $P < 0.01$.

Split analysis of the first 3 years *versus* the last 4 (Table 6) showed a significant improvement in thoracic curve correction at 1 year (59% *vs.* 70%; $P < 0.01$) and at latest follow-up, 57% *vs.* 68% ($P < 0.05$). The ATI correction was not significantly improved at 1 year (28% *vs.* 41%) but was at latest follow-up (19% *vs.* 50%; $P < 0.01$). The average lower instrumented vertebra was L1 in both study groups (Table 2).

King–Moe IV

There were five patients with KM IV curves. The average age was 15.0 years (range, 14.1–18.5 years) and follow-up averaged 43 months (range, 27–62 months). Radiographic and clinical analysis are shown in Table 7. The average thoracic curve correction in this group was 72% with a 4% loss at latest follow-up. No patients were radiographically or clinically off balance at latest follow-up. The average lower end vertebra was L1, stable vertebra L4, and lower instrumented vertebra L2.6 (Table 2). The average length of fusion was 10.6 vertebral bodies and the average upper instrumented vertebra T5. The number of patients with KM IV curves was too small to show any statistically relevant differences between the two groups.

King–Moe V

There were 18 patients with KM V curves. The average age was 14.5 years (range, 10.8–20.1 years), and fol-

Table 6. KM III Split Analysis

	Angle (°)	% Correction	
		1 yr	Latest
Preop Cobb			
1989–1991	58	59*	57†
1992–1995	63	70*	68†
Preop ATI			
1989–1991	17.5	28	19*
1992–1995	17.2	41	50*

* $P < 0.01$.
† $P < 0.05$.

Table 5. KM III Curves

Patient No.	Date	Preop T1	Preop T	Preop ATI-T	Postop T1	Postop T	1 yr F/U T1	1 yr F/U T	1 yr F/U ATI-T	Last F/U Months	Last F/U T1	Last F/U T	Last F/U ATI-T
32	7/3/89	17	60	23	0	18	0	34	17	37	0	26	19
33	8/10/89	20	55	12	22	22	0	29	11	46	18	30	13
34	8/23/89	25	42	8	10	13	18	19	7	54	0	27	7
35	9/6/89	5	55	17	10	24	5	23	17	47	5	20	15
36	9/7/89	43	74	26	13	20	5	30	11	53	30	30	13
37	3/22/89	5	53	15	6	30	13	30	15	46	0	25	15
38	4/11/90	32	64	22	11	35	9	30	23	24	14	35	24
39	6/8/90	20	76	23	0	25	7	26	18	61	7	23	20
40	11/2/90	8	57	18	22	5	5	5	0	68	11	10	6
41	6/5/91	25	61	13	4	25	9	19	10	30	7	17	10
42	9/18/91	0	44	15	0	11	25	22	10	55	11	35	13
43	4/29/92	3	62	22	7	22	5	20	12	41	7	20	10
44	5/27/92	15	55	15	3	10	11	16	8	38	3	16	8
45	5/28/92	5	53	15	32	14	5	17	10	26	4	16	9
46	7/22/92	41	78	20	0	23	5	27	12	29	4	24	14
47	3/24/93	0	63	9	17	15	0	22	5	30	12	12	5
48	6/2/93	32	70	19	8	30	8	35	12	25	14	32	13
49	7/29/93	23	60	11	0	14	11	18	7	24	15	24	5
50	8/18/93	15	54	22	15	21	2	10	12	48	8	18	13
51	10/1/93	25	66	24	0	17	7	21	19	49	4	25	17
52	12/10/93	19	68	20	19	14	11	10	9	23	18	19	11
53	1/5/94	9	70	17	10	21	12	15	8	25	5	20	5
54	4/4/94	11	56	13	6	20	16	18	6	24	0	17	4
55	6/20/94	23	60	16	6	16	7	16	12	24	0	20	11
56	10/2/95	5	57	22	17	12	11	13	6	26	17	13	6
57	10/23/95	38	74	24	0	16	8	20	13	24	0	18	10
Average		18	61	17.29	9	19	8.27	21	11.29	37.7	8.2	22	11.36
1989–1991		18	58	17.45	9	21	8.73	24	12.64	47.4	9.4	25	14.09
1992–1995		18	63	17.2	9	18	8	19	10.2	28	7	20	8.6

See Table 1 for abbreviations.

Table 7. KM IV Curves

Patient No.	Date	Preop T1	Preop T	Preop ATI-T	Postop T1	Postop T	1 yr F/U T1	1 yr F/U T	1 yr F/U ATI-T	Last F/U Months	Last F/U T1	Last F/U T	Last F/U ATI-T
58	6/14/89	12	54	12	23	15	5	8	0	55	5	9	5
59	7/7/89	0	60	12	12	27	19	35	11	53	20	27	7
60	7/6/92	46	50	16	11	0	7	0	9	62	24	9	6
61	7/16/92	30	63	15	0	16	15	13	16	38	5	23	15
62	5/21/93	24	56	20	24	20	20	27	11	27	10	28	10
Average		22	57	15.0	14	16	13	17	9.4	43	13	19	9.3

See Table 1 for abbreviations.

low-up averaged 34 months (range, 23–64 months). Radiographic and clinical analyses are shown in Table 8. The average high thoracic curve correction in this group was 48%, with a 2% loss at latest follow-up. The average thoracic curve correction was 70%, with a 3% loss at latest follow-up. No patients were radiographically or clinically off balance at latest follow-up. The average lower end vertebra was T12.8, stable vertebra L2.5, and lower instrumented vertebra L1.3. The average length of fusion was 11.8 vertebral bodies, and the upper instrumented vertebra averaged T2.7.

Split analysis of the first 3 years *versus* the last 4 (Table 9) showed significant improvement in high thoracic curve correction at latest follow-up (31% *vs.* 50%; $P < 0.05$). Thoracic curve correction was not significantly better at 1 year (55% *vs.* 69%) but was significantly better at latest follow-up (51% *vs.* 72%; $P < 0.01$). Thoracic ATI was improved, but there was not a significant difference in the improvement. The average lower instrumented vertebra was unchanged at L1.5 for the first 3 years and L1.3 for the second 4 years (Table 2).

Thoracolumbar, Lumbar, and King–Moe I

There were 19 patients with primary thoracolumbar, lumbar, and KM I curves. The average age was 14.3 years (range, 10.5–17.7 years), and follow-up averaged 43 months (range, 24–66 months). Radiographic and clinical analyses are shown in Table 10. The average thoracolumbar–lumbar curve correction was 81% with a 4% loss at latest follow-up. The average lower end vertebra was L3.5 and lower instrumented vertebra L3.1 (Table 2). The average length of fusion was 10.0 vertebral bodies and the average upper instrumented vertebra T6.1. At latest follow-up one patient was off balance by 26 mm and clinically off balance by 1 cm. She did not mention the imbalance. Another patient was off balance radiographically by 21 mm, but clinically she was well balanced. Only one patient had a fusion extending to L4;

Table 8. KM V Curves

Patient No.	Date	Preop T1	Preop HT	Preop T	Preop ATI-T	Postop T1	Postop HT	Postop T	1 yr F/U T1	1 yr F/U HT	1 yr F/U T	1 yr F/U ATI-T	Last F/U Months	Last F/U T1	Last F/U HT	Last F/U T	Last F/U ATI-T
63	3/31/89	29	37	55	11	23	27	25	17	26	28	8	50	0	31	30	10
64	4/27/90	25	52	64	13	8	34	26	5	37	30	4	64	5	37	30	4
65	10/20/90	0	71	134	22		55	65	10	50	64	20	46	17	50	68	20
66	10/23/91	6	34	49	9	27	17	13	19	17	13	2	49	6	19	19	6
67	3/16/92	18	33	51	10	30	25	7	9	22	13	1	29	3	29	9	1
68	3/23/92	22	45	59	13	49	8	9	0	10	11	5	26	6	6	11	7
69	4/1/92	16	50	76	22	10	32	34	9	35	33	16	39	0	30	29	18
70	9/18/92	8	57	70	14	2	22	20	0	15	21	4	25	0	15	10	
71	6/28/93	15	59	76	16	0	24	24	7	30	24	13	23	12	31	21	10
72	6/23/95	7	35	55	15	0	12	15	7	24	18	8	31	0	15	15	9
73	6/24/94	32	35	49	16	10	22	10	18	22	19	12	23	0	24	18	12
74	7/11/94	6	50	80	21	16	30	15	7	26	15	10	24	7	20	13	9
75	7/18/94	0	40	52	11	10	28	12	9	28	17	4	23	5	27	19	3
76	8/3/94	6	40	61	21	6	18	25	6	24	26	22	25	20	24	29	18
77	3/6/95	0	35	54	17	11	20	18	9	27	25	5	27	10	25	22	5
78	3/13/95	24	44	44	15	5	6	14	0	16	14	5	27	0	3	15	6
79	6/28/95	49	48	59	11	36	17	11	3	19	19	10	26	16	18	15	7
80	9/1/95	7	49	70	14	28	21	20	0	21	13	8	24	15	22	13	6
Average		15	46	64	15.3	16	23	20	8	26	22	9.2	34	7	26	21	9.8
1989–1991		15	49	76	13.8	19	33	32	13	33	34	8.5	52	7	34	37	10.0
1992–1995		15	44	61	15.9	15	20	17	6	24	19	9.5	27	7	22	17	9.7

HT = high thoracic Cobb. See Table 1 for other abbreviations.

Table 9. KM V Split Analysis

	Angle (°)	% Correction 1 yr	% Correction Latest
Preop HT Cobb			
1989–1991	49	33	31*
1992–1995	44	45	50*
Preop T Cobb			
1989–1991	76	55	51†
1992–1995	62	69	72†
Preop thoracic ATI			
1989–1991	13.8	38	28
1992–1995	16.0	41	40

* $P < 0.05$.
† $P < 0.01$.

Table 11. KM I, TL, and Lumbar Split Analysis

	Angle (°)	% Correction 1 yr	% Correction Latest
Preop T Cobb			
1989–1991	26	62	55
1991–1995	37	68	62
Preop TL/L Cobb			
1989–1991	50	74	72
1992–1995	54	81	81
Preop TL/L ATI			
1989–1991	11.6	71	76
1992–1995	17.1	73	80

she had a fully lumbarized S1, leaving her with three lumbar motion segments.

Analysis of the first 3 years *versus* the last 4 years (Table 11) showed no significant differences in preoperative curve, curve correction, ATI correction, or lower instrumented vertebra.

Kyphosis

For the purposes of analysis, patients were grouped before surgery into those with less than 20° kyphosis (hypokyphotic), between 20° and 40° (normokyphotic), and more than 40° (hyperkyphotic). Preoperative kyphosis and that at latest follow-up are noted in Table 12. Kyphosis could not be determined at latest follow-up in four patients.

Outcome Analysis

Beginning in 1992, 47 patients completed a Likert-style self-assessment evaluation before surgery and at latest follow-up (Appendix). The mean preoperative scores were function, 4.7; pain, 3.9; and appearance, 2.1 (highest possible, 5). The mean scores at latest follow-up were function, 4.6; pain, 4.1; and appearance, 4.1. No statistically significant difference was seen in function and pain. Appearance score was improved significantly ($P < 0.05$). The SRS Outcomes Instrument was completed after surgery at an average of 61 months (range, 24–99 months) by 82 patients. The mean overall score was 3.99 (highest possible, 5). The mean satisfaction score was 4.44. There were no statistically significant differences between the first and second groups in the series. Results are summarized in Table 13.

Complications

There were no deaths, neurologic deficits, or acute deep wound infections. There was one delayed deep wound infection diagnosed 12 months after surgery, which was associated with pseudarthrosis at the lowest instru-

Table 10. KM I, Thoracolumbar and Lumbar Curves

Patient No.	Date	Curve	Preop T1	Preop T	Preop TL/L	Preop ATI-TL/L	Postop T1	Postop T	Postop TL/L	1 yr F/U T1	1 yr F/U T	1 yr F/U TL/L	1 yr F/U ATI-TL/L	Last F/U Months	Last F/U T1	Last F/U T	Last F/U TL/L	Last F/U ATI-TL/L
81	3/28/90	L TL	20	0	40	8	19	5	5	6	14	10	3	47	5	12	11	2
82	6/1/90	L TL	8	31	45	8	11	10	5	7	17	10	1	51	11	14	11	0
83	6/14/90	L LUMBAR	30	26	54	17	21	13	11	5	22	15	9	49	9	18	18	9
84	7/13/90	L TL	0	33	57	13	26	0	20	22	24	22	7	49	11	25	25	6
85	8/6/90	L LUMBAR	35	21	50	6	13	5	5	4	9	8	9	45	3	8	5	0
86	12/12/90	KM I	56	43	59	10	9	5	11	9	5	19	0	66	9	0	20	2
87	6/6/91	R TL	13	31	48	18	7	15	13	0	0	10	0	48	14	11	11	0
88	8/7/91	R TL	14	19	47	13	0	11	14	5	0	13	6	44	5	X	13	6
89	5/4/92	KM I	30	38	40	8	16	24	4	18	24	8	7	41	21	23	9	0
90	5/29/92	L TL	25	23	45	10	44	7	0	17	12	4	0	28	8	11	4	0
91	7/15/92	L TL	10	28	52	18	8	0	8	10	0	8	0	49	7	0	12	4
92	7/27/92	L TL	23	25	46	18	10	10	4	0	0	9	4	24	8	10	7	5
93	1/22/93	L TL	43	0	49	20	14	0	5	19	0	5	11	25	26	X	10	13
94	7/8/93	KM I	48	45	71	26	33	19	13	0	29	16	9	51	9	17	25	7
95	10/18/93	KM I	23	34	49	20	3	16	10	4	17	6	5	51	2	18	7	0
96	7/3/95	KM I	17	50	60	5	7	18	15	9	21	17	0	25	9	21	16	0
97	8/16/95	KM I	26	45	55	20	33	23	23	12	20	20	6	X	X	X	X	X
98	8/28/95	KM I	10	50	55	10	22	16	15	20	14	17	0	24	0	11	5	0
99	11/20/95	KM I	5	68	73	10	20	7	2	9	6	3	X	33	3	9	2	0
Average			23	32	52	13.9	17	11	10	9	12	12	4.7	43	9	13	12	3.4
1989–1991			22	26	50	11.6	13	8	11	7	11	13	4.4	50	8	13	14	3.1
1992–1995			24	37	54	16.3	19	13	9	11	13	10	5.1	33	9	13	10	3.7

ATI = angle of trunk inclination, thoracolumbar/lumbar. See Table 1 for other abbreviations.

Table 12. Kyphosis

	No. of Patients	Preop		Postop		Last F/U	
		Ky	Lo	Ky	Lo	Ky	Lo
All patients	101	34	−63	24	−54	30	−54
Hypokyphotic							
All average	14	13	−54	18	−51	21	−57
Hypo at F/U	5	14	−53	18	−52	13	−54
Normo at F/U	9	13	−54	18	−51	25	−58
Hyperkyphotic							
All average	29	51	−68	29	−53	39	−53
Normo at F/U	18	49	−67	27	−52	31	−47
Hyper at F/U	11	54	−70	34	−57	52	−59
Normokyphotic							
All average	59	31	−62	24	−54	28	−55
Hypo at F/U	10	30	−61	20	−53	13	−55
Hyper at F/U	8	31	−60	27	−53	46	−52
Normo at F/U	37	30	−62	23	−55	27	−55

See Table 1 for abbreviations.

mented level (T11–T12). The infection was successfully treated with irrigation and débridement, implant removal, and closure over drains. Intraoperative cultures grew *Staphylococcus aureus*. The pseudarthrosis has remained asymptomatic, although some radiographic thoracolumbar junction kyphosis developed. Two other pseudarthroses occurred in the series. One was associated with loss of fixation and required multilevel osteotomy, reinstrumentation, and fusion at the same levels 35 months after surgery. The other patient with pseudarthrosis was asymptomatic and deferred further treatment. One patient who had thoracolumbar junctional kyphosis for which revision was recommended has declined treatment. All four of these patients had surgery in the first 3 years of the series when the instrumentation sequence was developing rapidly.

Four patients experienced late operative site pain,[8] requiring implant removal. One patient who had one L1 pedicle screw exposed medially to the canal was asymptomatic and declined implant removal.

■ Discussion

The introduction of Harrington instrumentation in 1960 revolutionized the operative management of idiopathic scoliosis.[24] It was the most commonly used instrumentation for 25 years and the standard by which subsequent instrumentations are compared. However, by the early 1970s its principal shortcoming, an inability to correct and maintain sagittal plane alignment, was becoming apparent.

Use of segmental spinal wiring with Luque instrumentation[34] obviated the need for postoperative immobilization and provided better sagittal plane control. However, axial–vertical translation and end vertebra angulation, especially the lower end vertebra, were poorly controlled, and transverse plane angular correction did not occur.[35] Cotrel–Dubousset instrumentation emerged in 1984, as the concept of scoliosis as a three-dimensional deformity developed.[17,20] It attempted to use derotation with a multiple hook and rod system as a primary means of correction in the coronal and sagittal planes.

In the late 1980s, other systems, such as Texas Scottish Rite Hospital (TSRH) instrumentation, were developed in an effort to improve on the CDI system.[10] At that time, Isola was developed.[3] Its implant components included a full integration of hooks, wires, and screw anchors, and the techniques involved anatomically contoured longitudinal members. Torsional–countertorsional load application, emphasizing mediolateral and anteroposterior apex translational loads and angular moments, was used to effect correction in all three planes.[4]

The problem of coronal plane imbalance with CDI and TSRH treatment of scoliotic curves, particularly KM II curves,[30,36,39,40] led not only to the use of a slightly modified form of the KM classification system, but also to the development of a new set of guidelines for the selection of instrumentation levels. The classification system is not specific for the instrumentation system. Also,

Table 13. SRS Outcomes Instrument

	Pain	Gen Self-Image	Self-Image at Surgery	Function at Surgery	General Function	Function–Activity	Satisfaction	Overall Average
1989–1991	4.27	4.20	3.40	2.85	4.22	4.48	4.44	4.08
1992–1995	4.11	4.19	3.12	2.60	4.05	4.32	4.44	3.93
All	4.18	4.20	3.23	2.70	4.12	4.38	4.44	3.99

the instrumentation system used does not have to be used to produce torsion–countertorsion loads. However, we believe that a torsion–countertorsion load results in better deformity correction. Also, we do not believe that torsional–countertorsional loading is limited to the implant system described. It is technique dependent, not instrument dependent.

As the concept of a torsion–countertorsion force couple system as a means of curve correction evolved, it became clear that KM IIB could usually best be instrumented into the compensatory thoracolumbar–lumbar curve. This curve typically has a regional apex, defined as the most laterally translated vertebra from a cord line joining the end vertebra centroids of L1, of L1–L2 disc space, or L2. This is typically one segment above the global apex, defined as the most laterally translated vertebra from the midsacral gravity reference line.[45]

In all but the stiffest curves, the vertebral body directly below the regional apex is the CFV and is usually one vertebral body above the lower end vertebra of the lower curve. By placing pedicle screw fixation in the CFV, the regional apex could be controlled. In the last 4 years of the study, application of torsion–countertorsion forces to the two curves achieved an improved percentage of correction, compared with that in previously reported with the use of hooks[12,19,29–32,40] and equivalent or better than other series using lumbar pedicle screws.[11,22,33] Additionally, instrumentation into the lumbar spine of these curves was accomplished without extension to L4 and with preservation of more lumbar motion segments than that previously reported with CDI.[11,30,32] This was accomplished without the problem of coronal plane imbalance.

As the result of an effort to gain better spine and trunk realignment, we have increasingly instrumented a portion of the thoracolumbar spine in KM IIB curves, with the average lower instrumented vertebra in the last 4 years being L2.4 compared with L1 for the first 3 years of the series. This has resulted in significant thoracolumbar curve correction (44% *vs.* 63%; $P < 0.01$); a correction that has been maintained. We believe this is important, because Connolly et al[16] reported a significant correlation between lower spine scores and larger residual secondary (thoracolumbar–lumbar) curve (Cobb) an average of 12 years after Harrington instrumentation.

Curve correction of KM III and KM IV curves in the last 4 years of the study was 68%. This appears to be an improvement over other series using other systems,[12,29,31,32,40] with the exception of Suk et al.[46] They were able to achieve equivalent corrections (70%) using thoracic pedicle screws.

To determine whether true torsional correction is occurring, preoperative and postoperative computed tomographic scans were obtained that included the apex vertebra on 22 patients and found the apex RAsag[1] corrected from $20.4 \pm 5.41°$ to $14.7 \pm 7.26°$ ($P < 0.001$).[21] In addition, rib hump index[1] improved from 0.391 ± 0.225 to 0.249 ± 0.234 ($P < 0.01$).[21] These patients underwent surgery midway through the series, before concave rib osteotomies were in use. Furthermore, it was found that sublaminar wires did not result in true derotation, whereas subpars wires and facet hooks did.

Curve correction for the high thoracic and thoracic component of KM V curves in the last 4 years of the study was 50% and 72%. This was an improvement in curve correction of this curve type over previous reports,[29,30,31] and we believe it was obtained by setting the cephalad foundation in the relatively stiff upper thoracic curve and then applying a torsion–countertorsion force couple to the two curves.[3,4]

The ATI correction obtained in the thoracolumbar–lumbar group was significantly better than that in any other group in the current series. This was because of a true derotation of the apex of the thoracolumbar–lumbar curve, which can be accomplished with pedicle screw fixation.[41] The curve corrections and correction maintenance obtained are an improvement over the use of posterior CDI or Harrington instrumentation[19,31] and are similar to corrections reported using anterior systems.[28,47]

With continued improvement in anterior thoracolumbar–lumbar surgical techniques, some patients in the thoracolumbar–lumbar group since 1993 have been treated anteriorly. Although this saves proximal motion segments and may save a distal motion segment, it may not provide optimal junctional realignment proximally[9] or distally.[27] Residual proximal junctional kyphosis and distal junctional tilt may be more important to long-term results than is currently realized.

This 7-year experience encompasses an evolution of thought regarding torsion–countertorsion force coupling as a means of scoliosis correction.[4,5] This evolution is demonstrated by the improvement in curve correction and correction maintenance seen in the split analysis of the first 3 and last 4 years of the study. This represents an improvement in ability to analyze the various rotational components of the curve types, select appropriate fusion levels, and use adequate instrumentation constructs to maximize correction.

In conclusion, we have found that Isola posterior instrumentation and fusion are a safe treatment for idiopathic scoliosis. In the last 4 years of the study, we were able to improve the percentage of correction and correction maintenance compared with that in previous reports using other instrumentation systems. This has been accomplished while saving lumbar motion segments, and no patient was left with less than three mobile lumbar motion segments.

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Appendix

Spine Patient: Overall Function, Pain, and Appearance Self Assessment

Circle the one number that best describes your current and recent function level:

5. Normal daily activity
4. Moderate daily activity
3. Limited daily activity
2. Rare daily activity
1. Bedridden, no activity

Circle the one number that best describes your current and recent pain level:

5. No pain at all
4. Mild intermittent pain
3. Moderate, but manageable
2. Moderate with severe intervals
1. Severe pain

Circle the one number that best describes the appearance of your trunk; defined as the human body except for the head and extremities.

5. Very good
4. Good
3. Fair
2. Poor
1. Very poor

Comment if you wish: