The selection of fusion levels in thoracic idiopathic scoliosis

HA King, JH Moe, DS Bradford and RB Winter
J. Bone Joint Surg. Am. 65:1302-1313, 1983.

The Selection of Fusion Levels in Thoracic Idiopathic Scoliosis

BY HOWARD A. KING, M.D.*, JOHN H. MOE, M.D.†, DAVID S. BRADFORD, M.D.†, AND ROBERT B. WINTER, M.D.†, MINNEAPOLIS, MINNESOTA

From the Twin Cities Scoliosis Center, Minneapolis and St. Paul

ABSTRACT: **From the material and data reviewed in our study of 405 patients, it appears that postoperative correction of the thoracic spine approximately equals the correction noted on preoperative side-bending roentgenograms. Selective thoracic fusion can be safely performed on a Type-II curve of less than 80 degrees, but care must be taken to use the vertebra that is neutral and stable so that the lower level of the fusion is centered over the sacrum. The lumbar curve spontaneously corrects to balance the thoracic curve when selective thoracic fusion is performed and the lower level of fusion is properly selected. In Type-III, IV, and V thoracic curves the lower level of fusion should be centered over the sacrum to achieve a balanced, stable spine.**

The selection of the fusion level in thoracic and in combined thoracic and lumbar‡ idiopathic scoliosis has been an area of controversy. There have been several suggested techniques for selection of the fusion area[1,4-6,8,12-14,19-21], but the superiority of any one method over another has not been established. The consensus of most authors, however, has been that the fusion area in a thoracic pattern must include all vertebrae within the measured curve[1,3,17,18]. Some authors have suggested that the fusion should extend from above the curve to two vertebrae below the curve as a general guide[7,8]. Others have stressed the necessity of fusion from the superior neutrally rotated vertebra to the inferior neutrally rotated vertebra[4-6,12-14]. Still others have discussed selecting the vertebrae on both ends of the curve that are parallel to one another after a turnbuckle cast has been applied[9,10,17]. In combined thoracic and lumbar curves in which both curves are of equal or nearly equal magnitude, most authors have suggested fusion of both curves[6-8,16,17]. For twenty-five years, Moe has stressed the importance of accurate curve measurement and analysis of levels of rotation, as well as the use of preoperative supine side-bending roentgenograms to determine the degree of a flexible lumbar curve, and has advocated fusion of the thoracic curve from the superior neutrally rotated vertebra to the inferior neutrally rotated vertebra[12,13]. In patients with a combined thoracic and lumbar curve in whom the correction of the lumbar curve on side-bending is equal to or greater than that of the thoracic curve, he has advocated selective fusion of only the thoracic curve[12-14]. The policy of the Twin Cities Scoliosis Center is to follow these guidelines in determining fusion levels in patients with double thoracic or lumbar and thoracic scoliosis.

The purpose of this paper is to review the experience of the Twin Cities Scoliosis Center in managing thoracic and double thoracic and lumbar curves, and to determine: (1) the effects of selective thoracic fusion in combined thoracic and lumbar curves; (2) a reliable method to aid in selecting patients for this procedure; and (3) if possible, the most precise means for selecting the fusion area.

Material and Methods

We reviewed the clinical charts and roentgenograms of the patients who had surgical treatment for idiopathic thoracic scoliosis or combined thoracic and lumbar scoliosis at Fairview Hospital in Minneapolis and Gillette Children's Hospital in St. Paul over the thirty-year period from 1947 to 1977. All of the procedures were performed or supervised by members of the staff of the Twin Cities Scoliosis Center. Patients with a single lumbar or thoracolumbar curve and patients with associated mental retardation, neuromuscular disease, or spondylolisthesis were excluded from the series, as were patients who had undergone spine fusion without Harrington instrumentation.

To be included in the series, a patient had to have been twenty-five years old or younger at the time of surgery, and a preoperative standing anteroposterior or posteroanterior roentgenogram and a complete set of preoperative supine side-bending roentgenograms had to be available. The patients had all undergone posterior spine fusion with Harrington instrumentation, and had to have a minimum follow-up of two years.

A total of 405 patients, forty-four (10.9 per cent) male and 361 (89.1 per cent) female, met these criteria. They ranged in age from ten to twenty-five years (average, 14.8 years) at the time of surgery. The length of follow-up ranged from two to 12.9 years, with an average of 4.0 years, and the age at the last follow-up ranged from 12.5 to 29.8 years, with an average of 16.5 years.

* Department of Orthopedic Surgery, Children's Orthopedic Hospital and Medical Center, P.O. Box C5371, Seattle, Washington 98105.

† Department of Orthopedic Surgery, University of Minnesota, Twin Cities Scoliosis Center, 606 24th Avenue South, Minneapolis, Minnesota 55454.

‡ The Scoliosis Research Society accepts *double primary* as proper terminology, but for clarity in differentiating double thoracic and double primary thoracic and lumbar curves, we have used the term *combined* for double primary thoracic and lumbar curves.

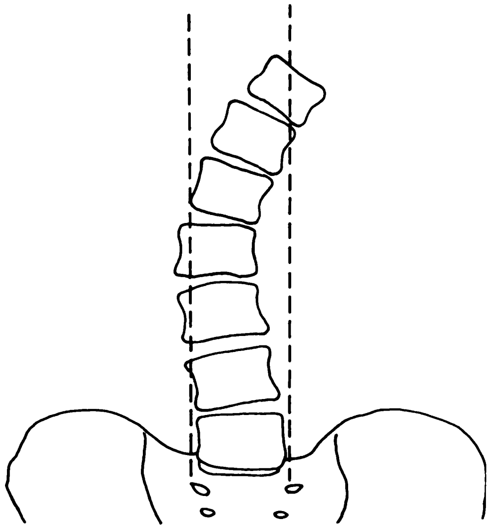

FIG. 1

The stable zone of Harrington, defined by parallel lines drawn through the lumbosacral facets. The vertebral bodies within the lines are in the stable zone.

The levels of fusion and instrumentation were recorded from the charts and roentgenograms. The roentgenograms were reviewed using the Cobb method, paying particular attention to vertebral rotation. The stable zone of Harrington was measured by two vertical lines drawn through the lumbosacral facets, as Harrington[8,15] has stated that the lower level of fusion should fall within this zone (Fig. 1). As our study progressed it became apparent that a more accurate determination could be gained by a single line drawn through the center of the sacrum perpendicular to the iliac crests, which we designated the central sacral line (Fig. 2-A). When a limb-length discrepancy is present, the pelvis should be leveled with an appropriate lift under the short limb. The central vertical line must always be based on a horizontal pelvis. The vertebra that is bisected or most closely bisected by this line is determined and is recorded as being the stable vertebra (Fig. 2-B).

TABLE I

CURVE PATTERNS

	Criteria	No. of Patients in the Present Series
Type I	S-shaped curve in which both thoracic curve and lumbar curve cross midline Lumbar curve larger than thoracic curve on standing roentgenogram Flexibility index a negative value (thoracic curve ⩾ lumbar curve on standing roentgenogram, but more flexible on side-bending)	52 (12.9%)
Type II	S-shaped curve in which thoracic curve and lumbar curve cross midline Thoracic curve ⩾ lumbar curve Flexibility index ⩾ 0	132 (32.6%)
Type III	Thoracic curve in which lumbar curve does not cross midline (so-called overhang)	133 (32.8%)
Type IV	Long thoracic curve in which L5 is centered over sacrum but L4 tilts into long thoracic curve	37 (9.2%)
Type V	Double thoracic curve with T1 tilted into convexity of upper curve Upper curve structural on side-bending	47 (11.6%)
Miscellaneous		4 (1.0%)

The degree of curvature on the preoperative and postoperative roentgenograms was measured and recorded. The percentages of correction on the preoperative supine side-bending and postoperative standing roentgenograms were compared with the preoperative standing roentgenogram.

The percentage of flexibility of the thoracic and lumbar curves on maximum lateral bending was determined, and the percentage of correction of the thoracic curve was then subtracted from the percentage of correction of the lumbar

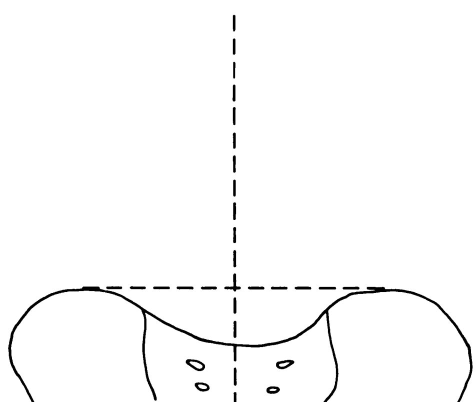

FIG. 2-A

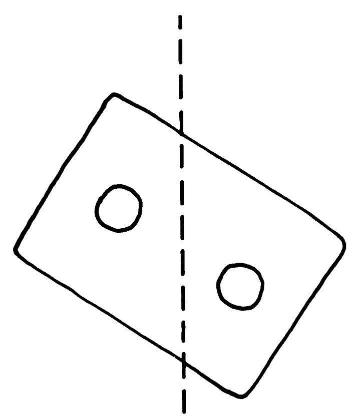

FIG. 2-B

Figs. 2-A and 2-B: Center sacral line.
Fig. 2-A: The line is drawn perpendicular to the level iliac crests and through the center of the sacrum.
Fig. 2-B: The vertebra that is most closely bisected by the line is the stable vertebra.

curve. This difference was designated the *flexibility index* and was applied to the statistical data to evaluate the results of selective fusion.

A subdivision of the basic curve types that were previously delineated by Ponseti and Friedman, and further described by Moe[11], was made to help to facilitate the se-

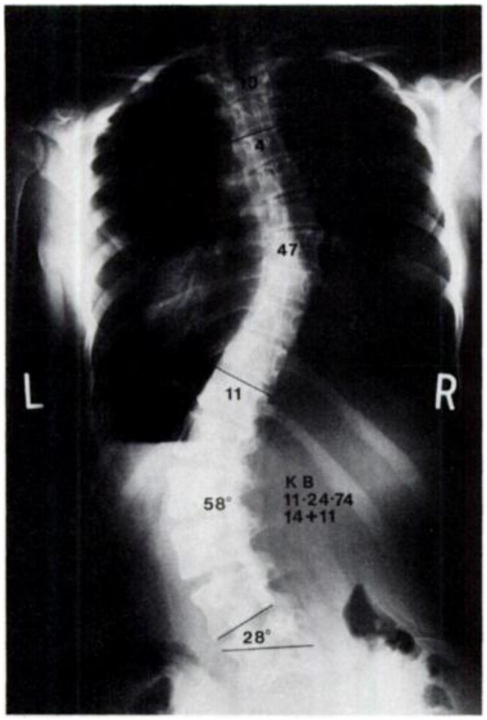

FIG. 3-A

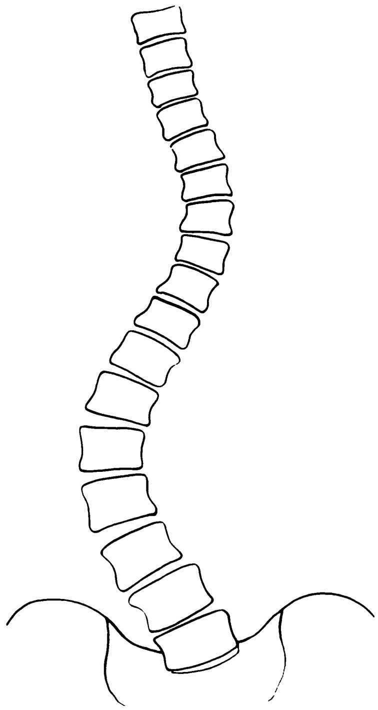

FIG. 3-B

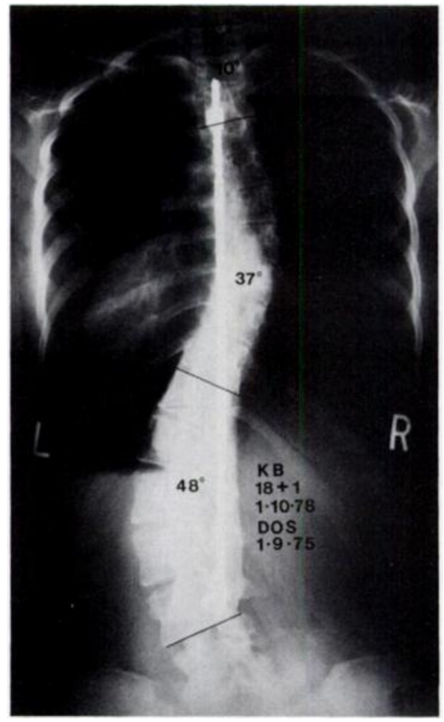

FIG. 3-C

Figs. 3-A, 3-B, and 3-C: Type I.
Fig. 3-A: The right thoracic curve, from the fourth to the eleventh thoracic vertebra, measures 47 degrees. The left lumbar curve, from the eleventh thoracic to the fourth lumbar vertebra, measures 58 degrees.
Fig. 3-B: Schematic representation.
Fig. 3-C: Three years after Harrington instrumentation and fusion of both curves.

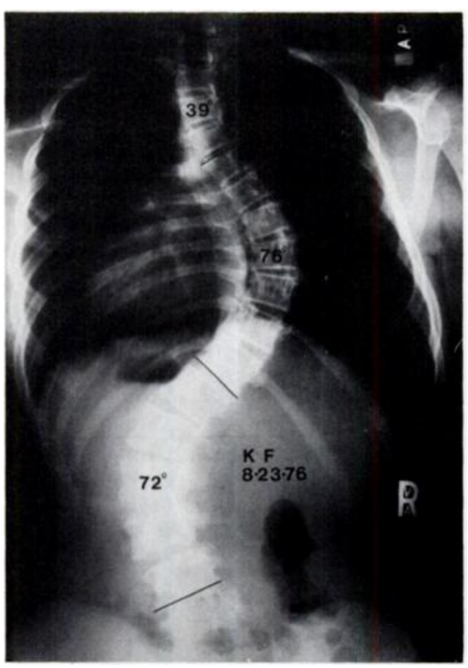

FIG. 4-A

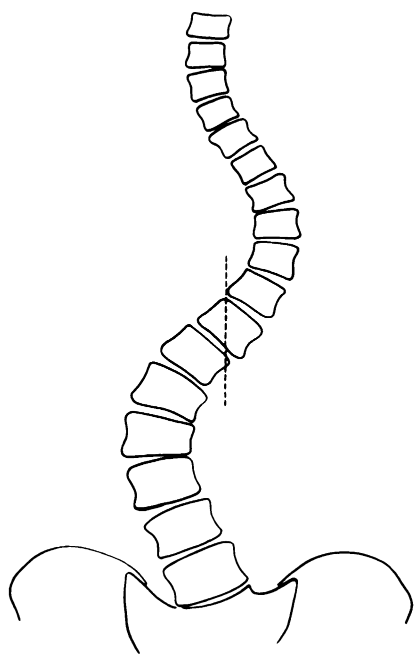

FIG. 4-B

Figs. 4-A and 4-B: Type II.
Fig. 4-A: The right thoracic curve, from the fifth to the eleventh thoracic vertebra, measures 76 degrees. The left lumbar curve, from the twelfth thoracic to the fourth lumbar vertebra, measures 72 degrees. The flexibility index is zero.
Fig. 4-B: Schematic representation.

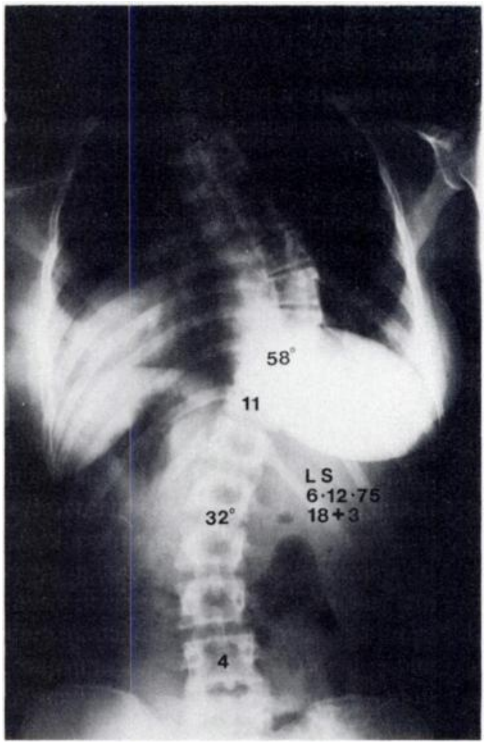

FIG. 5-A

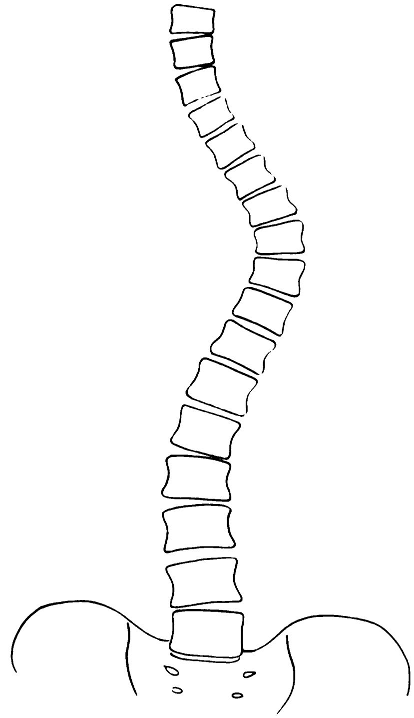

FIG. 5-B

Figs. 5-A and 5-B: Type III.
Fig. 5-A: The right thoracic curve, from the fifth to the eleventh thoracic vertebra, measures 58 degrees. The left lumbar curve, from the eleventh thoracic to the fourth lumbar vertebra, measures 32 degrees.
Fig. 5-B: Schematic representation.

lection of the fusion areas (Table I). The combined thoracic and lumbar curves were subdivided based on the magnitude of the curves in degrees and the degree of flexibility of the lumbar spine. The major thoracic curves were divided into two categories depending on the configurations of the thoracic and lumbar curves. Double thoracic curves were placed in a separate category.

Combined thoracic and lumbar curves were s-shaped curves in which both curves crossed a line drawn vertically from the middle of the sacrum. The double curves were then divided into Types I and II. Those in which the lumbar curve was larger than the thoracic curve by 3 degrees or more as determined on a roentgenogram made with the patient standing and those with a negative flexibility index (the thoracic curve more flexible than the lumbar curve on the supine side-bending roentgenograms) were classified as Type I (Figs. 3-A, 3-B, and 3-C). Combined thoracic and lumbar curves in which the thoracic curve was equal to or larger than the lumbar curve and the flexibility index was zero or more were classified as Type II (Figs. 4-A and 4-B).

Thoracic curves were subdivided according to the basic pattern of the thoracic and compensatory curves. The lumbar curves did not cross the midline. Lumbar curves with a plumbline directly centered over the sacrum were classified as Type III (Figs. 5-A and 5-B). In Type-IV curves, the fifth lumbar vertebra was centered over the sacrum and the fourth lumbar vertebra was tilted into the long thoracic curve. The main difference between Type-III curves and Type-IV curves was the length of the thoracic curve and the pattern of the compensatory lumbar curve (Figs. 6-A and 6-B).

A fifth category for double thoracic curves was included in the series. In Type-V curves, the first thoracic vertebra was tilted into the upper thoracic curve (called a positive first-thoracic tilt) and the first rib was elevated on the convexity of the thoracic curve (Figs. 7-A, 7-B, and 7-C).

The data were then evaluated, looking specifically at age at the time of surgery, degree of curvature, curve patterns, vertebral rotation, flexibility index, stable vertebra, and final result of treatment. The data were statistically evaluated for significance. The patient's final result was considered satisfactory if the spine was balanced, the head was centered over the sacrum, and there was no evidence of progression of the curve at follow-up.

Results

The data were reviewed to determine the number of patients in each group and the percentage of the series that they represented (Table I). Four patients did not fit any of the five categories and were therefore excluded from the analysis. The average preoperative and postoperative curves for the five groups were calculated and were compared with the preoperative side-bending correction and the flexibility index (Table II).

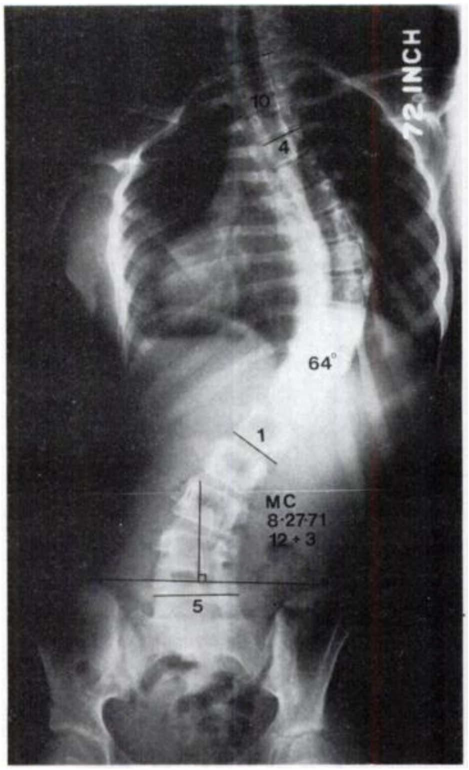

FIG. 6-A

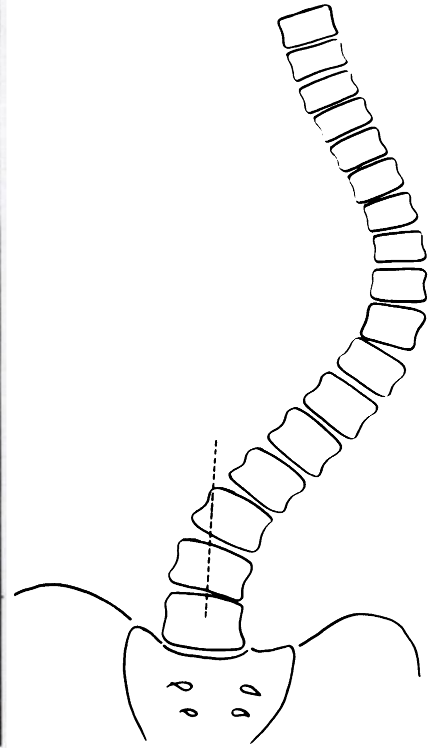

FIG. 6-B

Figs. 6-A and 6-B: Type IV.

Fig. 6-A: The right thoracic curve, from the fourth thoracic to the first lumbar vertebra, measures 64 degrees. The left lumbar curve, from the first to the fifth lumbar vertebra, measures 24 degrees.

Fig. 6-B: Schematic representation.

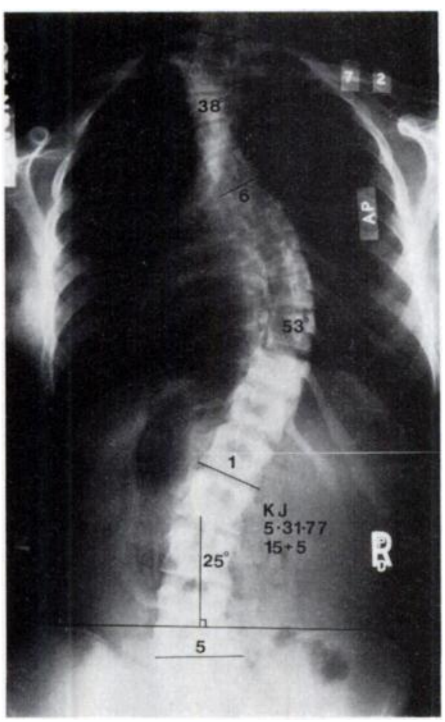

FIG. 7-A

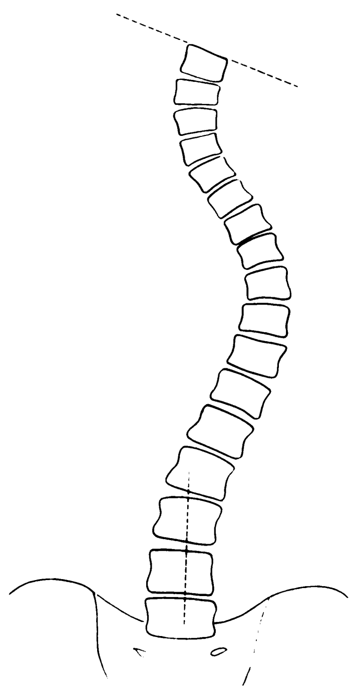

FIG. 7-B

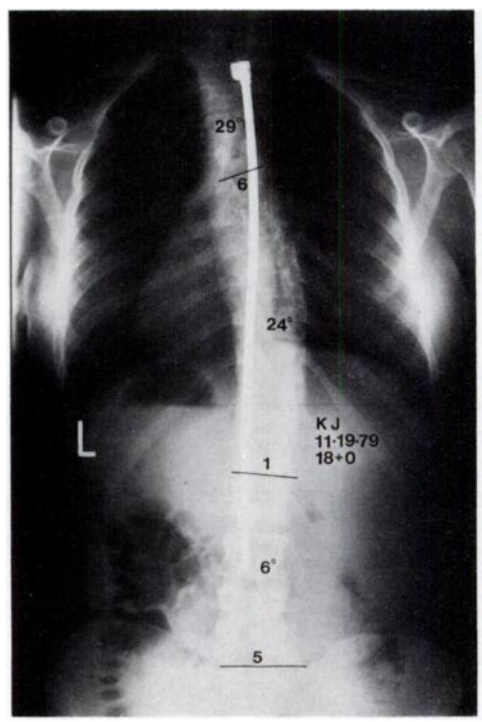

FIG. 7-C

Figs. 7-A, 7-B, and 7-C: Type V.

Fig. 7-A: The left upper thoracic curve, from the first to the sixth thoracic vertebra, measures 38 degrees; the right thoracic curve, from the sixth thoracic to the first lumbar vertebra, measures 53 degrees; and the left lumbar curve, from the first to the fifth lumbar vertebra, measures 25 degrees. The first thoracic vertebra is tilted into the concavity of the upper thoracic curve, and the left first rib is elevated.

Fig. 7-B: Schematic representation.

Fig. 7-C: Two and one-half years after Harrington instrumentation and fusion of both thoracic curves.

TABLE II

AVERAGE VALUES FOR THE PRESENT SERIES*

	Preop. Curve (Degrees)	Correction on Side-Bending		Flexibility Index	Postop. Curve (Degrees)	Postop. Correction		Age at Operation (Yrs.)
		Degrees	Per Cent			Degrees	Per Cent	
Type I								
Thoracic	49.4 ± 10.7	21.4 ± 8.3	45.0 ± 17.9	14.8 ± 19.3	29.4 ± 9.3	20.0 ± 7.7	40.5 ± 13.4	15.5
Lumbar	58.5 ± 11.1	34.0 ± 9.0	58.0 ± 17.5		30.3 ± 10.2	28.2 ± 10.7	48.2 ± 14.7	
Type II								
Thoracic	59.2 ± 12.5	23.7 ± 8.5	41.4 ± 16.4	33.1 ± 25.1	35.3 ± 10.8	23.9 ± 8.2	40.6 ± 12.2	14.6
Lumbar	47.5 ± 11.7	33.4 ± 8.5	74.5 ± 27.3		30.7 ± 10.2	16.8 ± 8.8	34.8 ± 17.4	
Type III								
Thoracic	55.0 ± 13.9	26.3 ± 9.7	49.1 ± 17.7	48.3 ± 29.9	31.1 ± 11.0	23.9 ± 10.7	43.0 ± 15.4	14.3
Lumbar	33.4 ± 10.7	31.4 ± 10.6	97.3 ± 29.4		19.7 ± 8.8	13.7 ± 10.1	37.1 ± 42.5	
Type IV								
Thoracic	63.3 ± 16.6	29.4 ± 10.8	48.3 ± 18.3	59.1 ± 30.8	30.3 ± 12.1	33.0 ± 9.5	53.1 ± 11.7	15.5
Lumbar	32.4 ± 10.3	33.5 ± 10.0	107.4 ± 29.2		12.7 ± 8.5	19.7 ± 6.1	63.5 ± 17.3	
Type V								
Thoracic	52.5 ± 10.8	25.8 ± 8.2	50.8 ± 17.2	54.0 ± 36.5	30.5 ± 8.5	22.0 ± 8.7	41.4 ± 12.5	14.3
Lumbar	27.9 ± 9.9	27.7 ± 8.8	104.8 ± 34.0		15.8 ± 9.1	12.2 ± 7.8	42.6 ± 27.1	

* Mean and standard deviation.

Type-I Curves

Fifty-two patients with Type-I curves underwent spine fusion and Harrington instrumentation. In fifty of these patients the lumbar curve was larger than the thoracic curve as measured on the preoperative roentgenogram. In two patients the thoracic curve was larger than the lumbar curve, and both had a negative flexibility index (thoracic curve more flexible than lumbar curve).

Both of the patients with a negative flexibility index had fusion of both curves which resulted in a balanced stable spine. In one patient the lumbar curve was 3 degrees larger than the thoracic curve, but the lumbar curve was more flexible on side-bending (flexibility index, 54). This patient was the only one who underwent a selective thoracic fusion. The lower level of fusion was beyond both the neutral vertebra and the stable vertebra. At follow-up the lumbar curve was 2 degrees larger than the thoracic curve, the patient's body was well balanced, and there was no evidence of progression. We have considered 30 or more to be a significant difference in measurement, taking into account roentgenographic and measurement technique.

The remaining patients, who underwent fusion of both curves, showed no evidence of progression above or below the fusion. No fusion was carried to below the fourth lumbar vertebra.

For the thoracic curves, correction on preoperative side-bending roentgenograms averaged 21.4 ± 8.3 degrees (45 per cent). The postoperative correction averaged 20.0 ± 7.7 degrees (40.5 per cent). The lumbar curves averaged 34.0 ± 9.0 degrees on the preoperative side-bending roentgenograms and 28.2 ± 10.7 degrees (48.2 per cent correction) at the time of follow-up (Table II).

Type-II Curves

There were 132 patients in this category. Twenty-one patients underwent fusion of both the thoracic and the lumbar curve, and 111 patients had selective fusion of only the thoracic curve. No patient had fusion of less than the measured thoracic curve. The largest curve that was treated in the group with selective fusion measured 85 degrees. All twenty-one patients who had fusion of both curves had a balanced, stable spine at follow-up.

In forty-one patients the fusion extended inferiorly to the vertebra that was both neutral in rotation and stable. No patient in this group showed progression of the lumbar curve, and in no patient was the lumbar curve greater than the thoracic curve at follow-up. In twenty-seven patients the fusion was carried beyond the first neutral vertebra but stopped at the stable vertebra. In one patient in this group the lumbar curve was larger than the thoracic curve (by 7 degrees) at the last clinic visit. Both curves had stabilized and showed no signs of progression.

In forty-two patients the thoracic spine was fused beyond the neutral vertebra and beyond the stable vertebra. In this group, in twenty-four patients (57.1 per cent) the lumbar curve was larger than the thoracic curve, whereas in no patient was the lumbar curve larger than the thoracic curve before surgery. Two of these twenty-four patients required extension of the fusion for progression of the lumbar curve. Both spines had been fused beyond the stable vertebra. The second surgical procedure was performed because of progression of the lumbar curve, clinical decompensation, and loss of curve balance. The remaining twenty-two patients had not shown evidence of lumbar progression at follow-up. One spine was fused short of the neutral vertebra, but to the stable vertebra. This patient showed no evidence of progression at follow-up, and the thoracic and lumbar curves were balanced.

The correction of the thoracic curves averaged 23.7 ± 8.5 degrees (41.4 per cent) on the preoperative side-bending roentgenograms. The postoperative correction averaged 23.9 ± 8.2 degrees (40.6 per cent) at the time of follow-

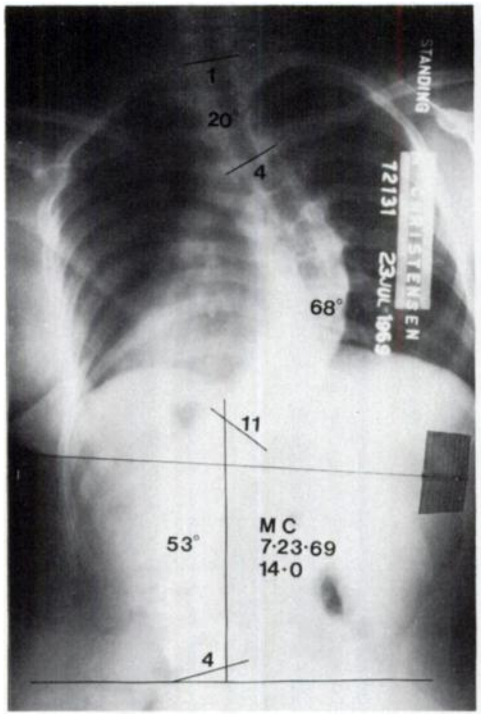

FIG. 8-A

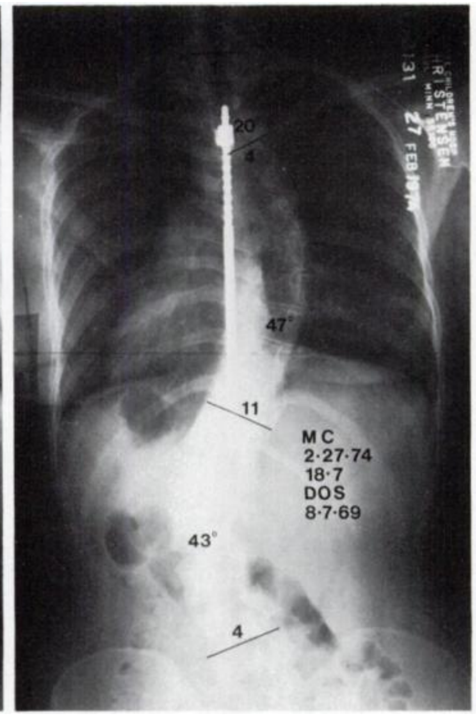

FIG. 8-B

Figs. 8-A and 8-B: This was a Type-II curve.

Fig. 8-A: Preoperative standing roentgenogram. The right thoracic curve, from the fourth to the eleventh thoracic vertebra, measures 68 degrees. The left lumbar curve, from the eleventh thoracic to the fourth lumbar vertebra, measures 53 degrees. The stable vertebra is the twelfth thoracic.

Fig. 8-B: The spine is well balanced after selective thoracic fusion to the stable vertebra.

up. The average correction for the lumbar curve at follow-up was 34.8 per cent on the last available roentgenogram. The average preoperative correction on side-bending was 74.5 per cent. Therefore correction was significantly less than on side-bending preoperatively, but this appeared to be more a mechanism of balancing the fused thoracic curve (Table II).

The data on the group of patients in whom the lumbar curve was greater than the thoracic curve at follow-up or who had an extended fusion for a progressive lumbar curve were evaluated according to age of the patient at surgery and preoperative flexibility index. The average age at the time of surgery was 15.0 years, compared with 14.6 years for the entire group (Group II). The flexibility index averaged 31, compared with 33.1 for the entire group.

Type-III Curves

There were 133 patients in this group who underwent Harrington instrumentation and spine fusion. All patients had fusion of the thoracic curve only. No patient in this group had a flexibility index of less than 16.

Sixty-three patients (47.4 per cent) had a fusion to the lower neutrally rotated vertebra but short of the stable vertebra. In forty-two (66 per cent) of those sixty-three patients, one or more vertebrae were added to the measured preoperative thoracic curve. No progression was noted in the lumbar curve, and no patient required extension of the fusion. The other twenty-one patients did not add additional levels to the measured thoracic curve, and their lumbar curves were stable at the time of follow-up. In thirty-four patients the lower portion of the fusion was extended beyond the lower neutrally rotated vertebra to the stable vertebra. None of these patients showed addition of levels to the curve or any progression of the curve in the unfused lumbar spine.

In thirty-two patients the lower level of the fusion ended at the vertebra that was both neutrally rotated and stable. None of these patients showed evidence of progression of the lumbar curve or added levels to the measured thoracic curve. In three patients the fusion stopped short of both the neutrally rotated vertebra and the stable vertebra. One of the three had addition of one vertebra to the measured thoracic curve, and the other two did not. In another patient the spine was fused beyond the neutral and stable vertebra and, as noted in the Type-II curves, the lumbar curve was greater than the thoracic curve (by 6 degrees) at follow-up. The curve appeared to be stable. However, in the hospital record the patient was noted to have mild decompensation of the spine. No patient required extension of the fusion into the lumbar spine after the initial thoracic fusion.

The correction of the thoracic curve averaged 26.3 degrees (49.1 per cent) on the preoperative side-bending roentgenograms. Postoperatively the correction averaged 23.9 ± 10.7 degrees (43.0 per cent). The average correction of the lumbar curve on preoperative side-bending roentgenograms was 97.3 per cent and the average postoperative correction was 37.1 per cent. This demonstrates the flexibility of the lumbar curve and shows that the lumbar curve tends to correct to balance the fused thoracic segment.

The average age at the time of surgery of the patients in whom levels were added to the measured curve after thoracic fusion was 15.7 years. The average age at the time of surgery of all of the patients in Group III was 14.3 years (Table II).

Type-IV Curves

Thirty-seven patients in this category had Harrington instrumentation and fusion of the thoracic curve. In seven patients the lower portion of the fusion was extended beyond the neutrally rotated vertebra but ended at the stable vertebra. All of these patients had a stable lumbar curve and none demonstrated added levels to the measured thoracic curve. In eight patients the lower portion of the fusion ended at the neutrally rotated and stable vertebra. None of these patients had vertebrae added to the measured curve and no patient demonstrated evidence of progression of the unfused lumbar curve.

In eighteen patients the lower level of the fusion ended at the neutrally rotated vertebra, but short of the stable vertebra. Of these patients, nine (50 per cent) had addition of one or more vertebrae to the measured curve. In one patient in this group the spine was fused to the first neutral vertebra, two vertebrae short of the stable vertebra, and a progressive lumbar curve developed that required extension of the fusion to the stable vertebra.

In three patients the fusion ended short of the neutral and stable vertebra, but they showed no addition of levels to the measured thoracic curve or progression of the lumbar curve. One spine was fused to the stable vertebra but short of the neutrally rotated vertebra. The final result was satisfactory.

The correction of the thoracic curve averaged 29.4 ± 10.8 degrees (48.3 per cent) on preoperative side-bending roentgenograms. The average correction on the follow-up roentgenograms was 33.0 ± 9.5 degrees (53.1 per cent). The average preoperative correction of the lumbar curve on side-bending was 107.4 per cent and the average postoperative correction was 63.5 per cent (Table II).

The average age at the time of surgery of the patients in whom the curve was fused short of the stable vertebra and who had added levels to the measured curve was 18.0 years. The one patient whose lumbar curve progressed, requiring extension of the fusion, was 12.0 years old at the time of surgery.

No patient in whom the spine was fused to the stable vertebra demonstrated addition of levels to the thoracic curve or required extension of the fusion for progression of the lumbar curve.

Type-V Curves

Forty-seven patients with double thoracic curves underwent Harrington instrumentation and fusion. Twenty-four patients underwent fusion to the neutrally rotated and stable vertebra, with satisfactory results. Ten patients underwent fusion to the lower neutrally rotated vertebra but short of the stable vertebra. Seven of the ten had addition of one or more vertebrae to the measured thoracic curve on the postoperative roentgenograms. One of the seven patients had progression of the lumbar curve after fusion to the neutral vertebra but two levels short of the stable vertebra. The curve continued to progress, and eight years later the fusion was extended to the level of the stable vertebra.

Ten patients underwent fusion beyond the neutrally rotated vertebra to the stable vertebra. All of their curves were balanced, and there was no evidence of addition of levels to the thoracic curve or progression of the lumbar curve. Three spines were fused short of the neutral vertebra, but the fusion was done to the stable vertebra. All three of these patients had satisfactory results without addition of vertebrae to the lumbar segment.

The correction of the thoracic curve averaged 25.8 ± 8.2 degrees (50.8 per cent) on the preoperative side-bending roentgenograms and 22.0 ± 8.7 degrees (41.4 per cent) on the follow-up roentgenograms. The correction of the lumbar curve in this group averaged 104.8 per cent on the preoperative side-bending roentgenograms and 42.6 per cent at follow-up (Table II).

The classification of a double thoracic pattern was based on a tilt of the first thoracic vertebra into the concavity of the upper curve (called a positive tilt). All forty-seven patients demonstrated this. The average correction of the upper curve on preoperative side-bending was 30 per cent. Six patients did not undergo fusion of the upper curve. Two of the six required a second procedure to extend the fusion to include a progressive upper-thoracic curve. One patient had increased shoulder elevation on the convex side, two were unchanged, and one patient had spontaneous improvement of shoulder balance. Of the forty-one patients in whom both curves were instrumented and fused, in only one was the shoulder line made worse. Seventeen were improved and twenty-two were unchanged. One patient who had instrumentation of the lower thoracic curve and fusion without similar correction of the upper thoracic curve had elevation of the shoulder on the convex side. The patient considered this satisfactory, and no further surgery was performed.

The average age at surgery of the patients who showed addition of measured levels to the lower thoracic curve after fusion short of the stable zone was 14.6 years. The one patient who showed progression of the lumbar curve after a short fusion, necessitating extension of the fusion, was 11.9 years old at the time of surgery.

Patients in Whom the Flexibility Index Was Fifteen or Less Preoperatively

A separate analysis was performed on the patients whose flexibility index was 15 or less on preoperative roentgenograms. This group was reviewed to determine the results in patients with a more structural lumbar curve. In the entire series, there were forty patients who had a flexibility index of 15 or less and in whom the thoracic curve was equal to or larger than the lumbar curve on the standing preoperative roentgenogram. All of these patients had Type-I or Type-II curves.

Twenty patients had fusion of both curves; all of the fusions were carried to the fourth lumbar level. No patient with a fusion of both curves had progression of either curve.

Twenty patients underwent fusion of the thoracic curve alone. Nine spines were fused to the neutrally rotated and stable vertebra. All of these nine patients had correction of both the lumbar curve and the thoracic curve and were well balanced at the last follow-up. No lumbar curve progressed and there was no addition of measured segments to the thoracic curve.

The remaining eleven spines were all fused beyond both the neutrally rotated and the stable vertebra. In this group, in five patients the lumbar curve was larger than the thoracic curve at follow-up. One of the five patients had continued progression of the lumbar curve that required extension of the fusion; the result was well balanced thoracic and lumbar curves.

Patients Who Required Extension of the Lower Level of Fusion

Four patients of the entire group — two patients with a Type-II curve and one patient each with a Type-IV and a Type-V curve — required a second operation to extend the level of fusion into the lumbar spine. These four patients (1.0 per cent of the series) had documented progression of the lumbar curve after fusion of the thoracic curve (Figs. 9-A through 9-D).

In both of the two patients with failures in the Type-II group, the lower level of the fusion extended beyond the neutral vertebra and the stable vertebra. In both of these patients the initial thoracic fusion extended into the lumbar curve. They required subsequent lengthening of the fusion to include the entire lumbar curve. One of the patients underwent a second procedure 2.5 years after the initial operation and the other, one year after the original procedure.

One patient in the Type-IV group had a short fusion. This patient had a fusion to the neutral vertebra; however, the neutral vertebra was short of the stable vertebra and the lumbar curve continued to progress, requiring extension of the fusion to the stable vertebra as calculated from the original standing roentgenogram (Figs. 9-A, 9-B, and 9-C). The second procedure was performed one year after the initial procedure. The long-term follow-up revealed that the patient had a satisfactory result with a stable, balanced spine (Fig. 9-D).

The patient with a Type-V curve had a fusion to the first neutrally rotated vertebra at the lower limit of the thoracic curve. However, this vertebra did not fall in the stable line. She had addition of levels to the measured thoracic curve, and eight years after initial surgery the fusion was extended to the stable vertebra. Balance was regained and the patient had a satisfactory result.

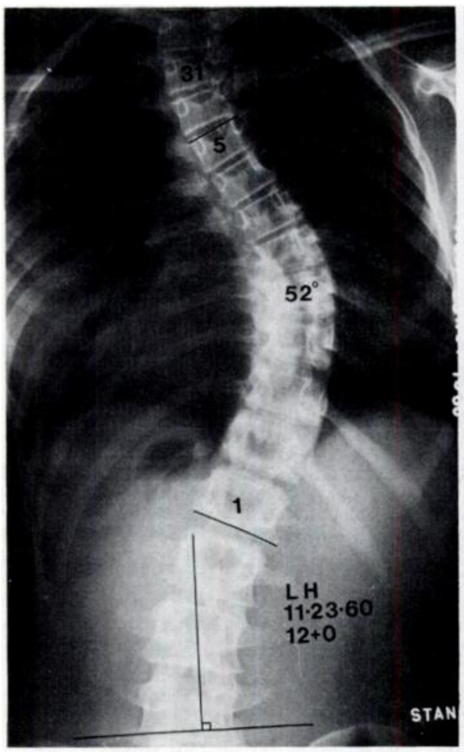

Fig. 9-A

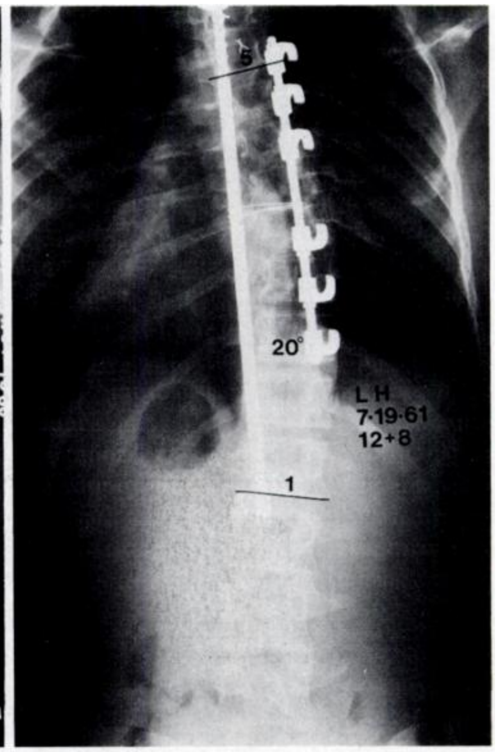

Fig. 9-B

Figs. 9-A through 9-D: A Type-IV curve.
Fig. 9-A: The right thoracic curve, from the fifth thoracic to the first lumbar vertebra, measures 52 degrees. The stable vertebra is the third lumbar vertebra.
Fig. 9-B: The spine was fused to the first lumbar vertebra, two levels short of the stable vertebra.

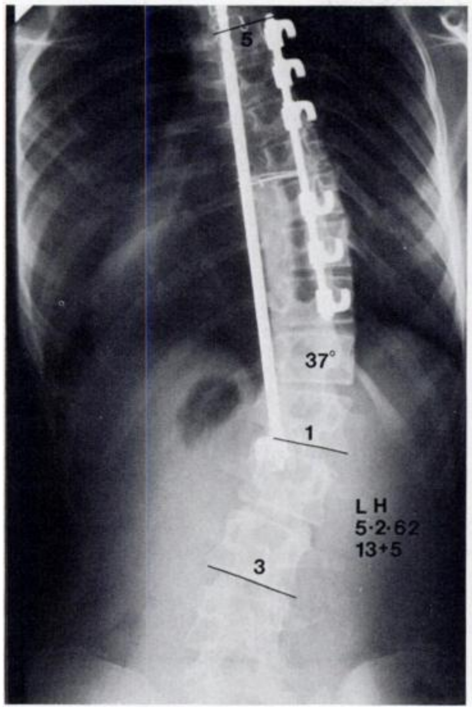

Fig. 9-C

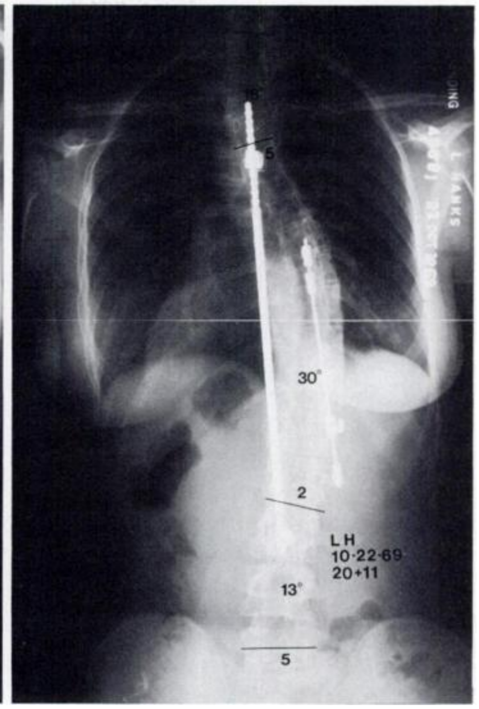

Fig. 9-D

Fig. 9-C: The curve progressed below the level of fusion.
Fig. 9-D: The fusion was extended to the stable vertebra and the result was satisfactory.

Comparison of Final Correction and Correction on Preoperative Side-Bending Roentgenograms

Table II details the magnitudes of the preoperative curves and of the final curves at follow-up. We compared the curve correction on preoperative supine side-bending roentgenograms with that on postoperative standing roentgenograms. The usefulness of the preoperative data available on each subject for predicting the postoperative results was examined by means of the matrix of correlations among preoperative and postoperative measurements. Predictive models for the outcome variables were tested by multiple regressive fits.

The model that we used proved to be the best predictive model for the postoperative correction compared with the preoperative supine side-bending correction in Types I, II, III, and V. This model explained approximately 50 per cent of the variability of the results. In Type IV the side-bending correction failed to show significant predictive value. Age at surgery showed no significant predictive power for estimating postoperative correction.

Postoperative correction of the lumbar curve could be predicted from preoperative side-bending roentgenograms, but not as successfully as for the thoracic curves. Correction of the lumbar curve on side-bending contributed significantly to the prediction in Types I, II, and III, but not in Type IV or Type V.

These results demonstrate that the average correction of the thoracic curve at follow-up approximately equals the preoperative correction on supine side-bending, especially in Types I through IV.

Discussion

The purpose of this study was to review the results of selective thoracic fusion in combined thoracic and lumbar curves. Moe has advocated this approach for many years and has gained vast experience in treating a large series of patients. Through this retrospective study, more exact guidelines for patient selection and levels of fusion have been developed.

The flexibility index has proved to be of value in differentiating Type-I, II, and III curves. The index compares the flexibility of the thoracic and lumbar curves. It does not, however, take into account the initial magnitudes of the curves. The index must therefore be correlated with the standing roentgenograms to determine the curve patterns accurately.

It is readily evident from the data that Moe's concept of selective thoracic fusion in Type-II curves is valid. Initial postoperative and long-term roentgenograms have shown that the lumbar curve spontaneously corrects to balance the corrected thoracic curve. The long-term results show that balance of the curves can be achieved and maintained. The proper selection of the lower level of fusion is critical if one hopes to obtain a balanced spine when performing a selective thoracic fusion. The advantages of the selective fusion are many. By avoiding a fusion of the lumbar spine, more mobility is maintained and the surgical exposure is reduced. The fate of the unfused segments below a long fusion into the lumbar spine is as yet unknown. The additional mobility may prove to be beneficial when forty, fifty, and sixty-year follow-ups are available.

In this series, only one Type-I curve was treated with a selective thoracic fusion. The fusion was extended beyond the stable vertebra. At follow-up the lumbar curve was 2 degrees larger than the thoracic curve, which was almost the same difference as preoperatively. The remaining patients had fusion of both curves, with the lower level of fusion extending to the fourth lumbar vertebra. There was no problem with decompensation or loss of balance in the lumbosacral curve. It appears that Type-I curves could be satisfactorily treated with fusion of both curves to the fourth lumbar vertebra. There does not appear to be a need or indication to fuse to the fifth lumbar vertebra in patients with idiopathic scoliosis. Our data are inadequate to allow us to recommend selective thoracic fusion in Type-I curves.

In Type II, 111 patients had a selective thoracic fusion. Two patients required a second procedure to correct a progressive lumbar curve. In twenty-five patients the lumbar curve was larger than the thoracic curve at follow-up. In these patients, the lower level of fusion selected was beyond the neutral and stable vertebra. Eighty-five patients, however, had a fusion to the stable vertebra: twenty-eight beyond the neutral vertebra to the stable vertebra, and fifty-seven to the vertebra that was both neutral and stable. In two of these patients the lumbar curve was larger than the thoracic curve at follow-up, but none required a second procedure for progression or loss of spinal balance.

It appears that Type-II curves can be managed successfully with a selective thoracic fusion. There are two important factors in selecting the lower level of fusion: vertebral rotation and the stable vertebra. In many patients the neutral vertebra and the vertebra bisected by the center sacral line are the same. From these data it appears that one can safely fuse to this level and gain a satisfactory result. When the neutral vertebra and the stable vertebra do not correspond, the data suggest that fusion to the stable vertebra will give the most reliable and satisfactory long-term result (Figs. 8-A and 8-B).

In 1930, Ferguson pointed out the necessity for centering the fusion mass over the sacrum. He thought that this would result in balanced and stable curves after surgery. This very provocative thought has received little attention in the literature. The data collected in our series support Ferguson's concept. The best results in all groups were achieved when the lower level of fusion was centered over the sacrum.

Our experience in Type-II curves with a flexibility index of 5 or less is limited. Three patients had fusion of both curves. Eight had selective thoracic fusion. In five of these eight the lumbar curve was greater than the thoracic curve at follow-up, and all five spines had been fused beyond the neutral and stable level. The remaining three spines were fused to the neutral and stable vertebra and the patients had satisfactory results, with balanced curves. It appears that selective thoracic fusion can be performed in this group of patients with structural lumbar curves if care is taken in selecting the lower level of fusion.

Twenty-one patients with Type-II curves had fusion of both the thoracic and the lumbar curve. These patients had similar curve patterns and flexibility indices when compared with the rest of the group. In retrospect, these patients could have been spared fusion of the lumbar spine. We cannot agree with those surgeons who advocate automatic fusion of both curves in patients with combined thoracic and lumbar curves. We still believe that additional mobility of the lumbar spine is beneficial for the short and long term.

Age did not appear to play a role in the progression of the lumbar curve, as suggested by some authors[4-6]. The Type-II patients in whom the lumbar curve was larger than the thoracic curve at follow-up had an average age at surgery of 15.0 years, compared with an average of 14.6 years for the entire group of Type-II curves. Selection of the lower level of fusion was the only variable that was associated with progression of the lumbar curve.

In the thoracic curve patterns of Types III, IV, and V, curve differentiation was found to be helpful. The Type-IV curve differs from Type III on the basis of the length of the curve. Because of its length, generally the fusion needs to be carried farther into the lumbar spine to avoid loss of balance and correction. It is important to recognize the Type-V curve, as failure to identify and treat the upper thoracic curve can lead to a disfigured shoulder line and loss of balance.

The selection of the lower level of fusion in Types III, IV, and V follows similar basic principles. The data on these groups were therefore analyzed together. The common error in selecting the fusion level was to fall short of centering the lower level of fusion over the sacrum. This resulted in additional levels being added to the thoracic curve. Of the 217 patients in all three groups, ninety-eight had fusion to the neutral vertebra but short of the stable vertebra. In this group, sixty-one patients (62 per cent of the ninety-eight) added levels to the measured preoperative thoracic curve. Two patients required additional surgery to correct a progressive lumbar curve. It is important to note that most of the patients who had added levels to the measured thoracic curve had an acceptable result clinically and roentgenographically. The measurement of levels added is used as a means to evaluate the data.

In the Type-III, IV, and V curves the neutral vertebra does not seem to be as reliable a guide for selecting the lower level of fusion as it is in the Type-II curves. Many of the thoracic curves are long and sweeping, with rotation stopping short of the end of the curve. In these curves it seems that fusion to the stable vertebra gives the most reliable results.

The average correction of the curves was calculated for all groups (Table II). When the final roentgenograms were correlated with the preoperative side-bending roentgenograms, it was apparent that the bending roentgenograms were an accurate prediction of the postoperative correction of the thoracic curve. The lumbar curves generally demonstrated much more correction on the preoperative roentgenograms than on the follow-up roentgenograms. It appears that the lumbar curve corrects to balance the thoracic curve. The side-bending roentgenograms were very helpful in establishing the indications for selective thoracic fusion in the Type-II curves.

It appears from this review that categorization of curve patterns and evaluation of preoperative roentgenograms, looking at vertebral rotation and the stable vertebra, are valuable aids in selecting proper levels for fusion. Our data support a plan for selecting fusion levels to minimize the length of fusion and yet obtain balanced, stable curves on long-term follow-up. Our current recommendations for selecting fusion levels in patients with thoracic idiopathic scoliosis are as follows:

Type I — fusion of both curves to the lower vertebra, but no lower than the fourth lumbar vertebra.

Type II — selective thoracic fusion to the lower vertebra that is both neutral and stable. When the neutral vertebra and the stable vertebra are not the same, the stable vertebra appears to be more reliable.

Type III — fusion to include the measured thoracic curve, with the lower level of fusion ending at the first vertebra that is most closely bisected by the center sacral line.

Type IV — fusion to include the measured thoracic curve, with the lower level of fusion ending at the first vertebra that is bisected by the center sacral line.

Type V — fusion of both thoracic curves. The lower level should include the vertebra that is most closely bisected by the center sacral line.

References

1. Butte, F. L.: Scoliosis Treated by the Wedging Jacket. Selection of the Area to Be Fused. J. Bone and Joint Surg., **20:** 1-22, Jan. 1938.
2. Cobb, J. R.: Outline for the Study of Scoliosis. *In* Instructional Course Lectures, The American Academy of Orthopaedic Surgeons. Vol. 5, pp. 261-275. Ann Arbor, J. W. Edwards, 1948.
3. Ferguson, A. B.: The Study and Treatment of Scoliosis. Southern Med. J., **23:** 116-120, 1930.
4. Goldstein, L. A.: The Surgical Management of Scoliosis. Clin. Orthop., **35:** 95-115, 1964.
5. Goldstein, L. A.: Surgical Management of Scoliosis. J. Bone and Joint Surg., **48-A:** 167-196, Jan. 1966.
6. Goldstein, L. A.: The Surgical Management of Scoliosis. Clin. Orthop., **77:** 32-56, 1971.
7. Harrington, P. R.: Treatment of Scoliosis. Correction and Internal Fixation by Spine Instrumentation. J. Bone and Joint Surg., **44-A:** 591-610, June 1962.
8. Harrington, P. R.: Technical Details in Relation to the Successful Use of Instrumentation in Scoliosis. Orthop. Clin. North America, **3:** 49-67, 1972.
9. Hibbs, R. A.: A Report of Fifty-nine Cases of Scoliosis Treated by the Fusion Operation. J. Bone and Joint Surg., **6:** 3-37, Jan. 1924.
10. Hibbs, R. A.; Risser, J. C.; and Ferguson, A. B.: Scoliosis Treated by the Fusion Operation. An End-Result Study of Three Hundred and Sixty Cases. J. Bone and Joint Surg., **13:** 91-104, 1931.
11. Moe, J. H.: A Critical Analysis of Methods of Fusion for Scoliosis. An Evaluation in Two Hundred and Sixty-six Patients. J. Bone and Joint Surg., **40-A:** 529-554, June 1958.
12. Moe, J. H.: Methods and Technique of Evaluating Idiopathic Scoliosis. *In* The American Academy of Orthopaedic Surgeons: Symposium on the Spine, pp. 196-240. St. Louis, C. V. Mosby, 1969.
13. Moe, J. H.: Methods of Correction and Surgical Techniques in Scoliosis. Orthop. Clin. North America, **3:** 17-48, 1972.
14. Moe, J. H.; Winter, R. B.; Bradford, D. S.; and Lonstein, J. E.: Scoliosis and Other Spinal Deformities. Philadelphia, W. B. Saunders, 1978.
15. Nash, C. L., Jr., and Moe, J. H.: A Study of Vertebral Rotation. J. Bone and Joint Surg., **51-A:** 223-229, March 1969.
16. Ponseti, I. V., and Friedman, Barry: Prognosis in Idiopathic Scoliosis. J. Bone and Joint Surg., **32-A:** 381-395, April 1950.
17. Risser, J. C.: Scoliosis: Past and Present. J. Bone and Joint Surg., **46-A:** 167-199, Jan. 1964.
18. Schmidt, A. C.: Fundamental Principles and Treatment of Scoliosis. *In* Instructional Course Lectures, The American Academy of Orthopaedic Surgeons. Vol. 16, pp. 184-212. St. Louis, C. V. Mosby, 1959.
19. Tambornino, J. M.; Armbrust, E. N.; and Moe, J. H.: Harrington Instrumentation in Correction of Scoliosis. A Comparison with Cast Correction. J. Bone and Joint Surg., **46-A:** 313-323, March 1964.
20. von Lackum, W. H., and Miller, J. P.: Critical Observations of the Results in the Operative Treatment of Scoliosis. J. Bone and Joint Surg., **31-A:** 102-106, Jan. 1949.
21. Woodward, H. R.; Chan, D. P. K.; Goldstein, L. A.; Devanny, J. R.; and Haake, P. W.: Selection of the Fusion Area in Thoracolumbar and Lumbar Curve Patterns: A Follow-up Report. Orthop. Trans., **4:** 38-39, 1980.