Idiopathic Scoliosis: New Instrumentation for Surgical Management

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Abstract

The surgeon can now choose from among a number of alternatives available for the safe and effective surgical treatment of the adolescent with progressive or severe idiopathic scoliosis. The authors analyze the wide array of posterior and anterior instrumentation systems that have evolved and discuss preoperative evaluation and planning, intraoperative considerations, and postoperative complications.

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Posterior spinal arthrodesis and instrumentation for the correction and stabilization of idiopathic scoliosis have been used with success for more than 35 years. Today, the surgeon has available a wide array of posterior instrumentation systems, among them the Harrington instrumentation with sublaminar wires, the Luque instrumentation, the Wisconsin segmental spinal system, the Cotrel-Dubousset (CD) instrumentation, the Texas Scottish Rite Hospital (TSRH) system, the Isola spine implant system, and the Moduloc posterior spinal system. Vertebral pedicle screws have been combined with posterior systems for selected indications, such as adult scoliosis and high-degree idiopathic curves, especially those with significant rotational deformity. Anterior instrumentation has also been developed to deal with select thoracolumbar curves and with rigid, difficult curves, including the Dwyer flexible cable and the Zielke threaded-rod ventral derotation spondylodesis, MOSS, and TSRH solid-rod anterior systems.

Regardless of the instrumentation chosen, the goal of surgical intervention in idiopathic scoliosis is correction of three-dimensional deformity, restoration of balance, fusion of a minimum of segments for preservation of spinal mobility, and prevention of curve progression.

The general indication for fusion in idiopathic scoliosis is a curve greater than 45 to 50 degrees at skeletal maturity or a curve greater than 40 to 45 degrees in a child with 1 to 2 years or more of growth remaining. Curves measuring less than 30 degrees at skeletal maturity tend not to progress regardless of the curve pattern. Thoracic curves that measure between 50 and 75 degrees at skeletal maturity progress almost 1 degree per year.[1] A patient with a thoracolumbar or lumbar curve of more than 40 degrees, especially with high degrees of rotation and translatory shift, has a greater risk of significant back pain as an adult and is generally a candidate for fusion.[2] If a child has significant growth remaining (Risser stage 0 or 1 or age 10 years or younger), both anterior and posterior fusion may be required to prevent rotational progression, the so-called crankshaft phenomenon.[3]

Preoperative Evaluation

History

In the initial intake history, essential questions must be asked: When and how was the scoliosis identified? Is there a family history? Has prior treatment been given? What is the menarchal status? Is there associated back pain (given that idiopathic scoliosis is a painless condition)?[4] Information relating to the respiratory and cardiovascular systems also should be obtained.

Physical Examination

The physical examination must be a complete musculoskeletal assessment, including a neurologic evaluation. Trunk asymmetry may be measured with a topographic contour system (e.g., moiré topography or ISIS) when such a system is available. Shoulder balance and waistline asymmetry should also be assessed. The thoracic, thoracolumbar, and lumbar angles of trunk rotation should be measured with an inclinometer.[5] Leg lengths must be accurately determined to investigate the possibility of nonstructural scoliosis. Leg-length measurements are also

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useful in predicting the potential trunk imbalance if fusion is later carried to L-4 or L-5.

Neurologic evaluation includes an assessment of motor strength of the upper and lower extremities and assessment of sensation, including skin, light touch, and deep tendon reflexes. It has been suggested that reflex abnormalities, such as absence of abdominal reflexes, may indicate intraspinal pathology, such as syringomyelia or hydromyelia.[6]

Radiologic Evaluation

Preoperative x-ray evaluation should include erect posteroanterior and lateral full-length radiographs, so that the overall alignment and balance of the entire spine can be evaluated. The flexibility of the curve or curves is determined with posteroanterior supine right- and left-side bending films. These bending films are then used to further define the structural and compensatory components of the curve in order to determine the fusion level and whether a posterior, anterior, or combined procedure is required. Additional imaging procedures, such as technetium bone scanning, magnetic resonance imaging, computed tomography (CT) scans, planar tomography, and metrizamide myelography, may be indicated when there is associated back pain or abnormal neurologic findings.[7]

Laboratory Evaluation

Preoperative evaluation also includes a complete blood cell count and urinalysis. Additional laboratory studies, such as prothrombin time; partial thromboplastin time; serum electrolyte, blood urea nitrogen, and serum creatinine determinations; and liver function tests may be required in some patients.

Preoperative pulmonary function tests often show a significant reduction in vital capacity and forced vital capacity.[8] A significant increase in residual volume is also found after both posterior and anterior spinal fusion. If there is restrictive pulmonary disease, preoperative aerobic exercise is recommended, and alterations in the anesthetic protocol may be required.[8] A vital capacity of less than 40% of predicted or a history of respiratory failure predicts a likelihood that postoperative assisted ventilation will be necessary.[9] In these cases, consultation by a pulmonary specialist and arterial blood gas analysis are indicated.

Preoperative Planning

Transfusion

Preoperative donation of 1 to 3 units of autologous blood is now routine at most institutions. Patients who are very young, weigh less than 100 lb, or are in poor health are often precluded from autologous donations by the criteria of the local blood bank or hospital program. Some centers are treating preoperatively with erythropoietin, but this technique is not yet available on a widespread basis. Directed donation of blood is an attractive alternative; however, the safety of directed-donation blood over routinely banked blood has not been established. Although safeguards are in place with routine screening of donated blood, significant risks remain. The American Association of Blood Banks and other agencies have recommended that informed consent be obtained prior to administration of blood products.[10]

Another important factor is to minimize the need for transfusion by patient positioning, acute hemodilution techniques, deliberate hypotensive anesthesia, and blood salvage.[9] However, blood salvage is most useful when blood loss is expected to exceed 2,000 ml.[11] To decrease intra-abdominal venous pressure, the patient is positioned prone on a padded frame, such as the Relton-Hall frame, or on longitudinal rolls, which allow the abdomen to hang free and suspend the patient along the lateral chest and pelvis.

Extent of Fusion

The selection of fusion levels for segmental posterior instrumentation requires further evaluation and definition, although it is generally accepted that fusion must be within the stable zone of Harrington, and that a fusion should never be ended in the apex of deformity in either the frontal or the sagittal plane.

Changing concepts in the selection of fusion levels are driven in part by attempts to apply concepts for distraction instrumentation to newer translational systems. King et al[12] identified five curve types based on standing posteroanterior and supine bending radiographs. Type 1 is a combined thoracic and lumbar curve in which the lumbar curve is larger or less flexible than the thoracic curve. Type 2 is a combined curve in which the thoracic curve is larger or less flexible than the lumbar curve. Type 3 is an isolated thoracic curve in which the lumbar curve does not cross the midline. Type 4 is a long thoracic curve that includes L-4. Type 5 is a double thoracic curve.

Based on their experience with 405 patients, King et al[12] recommended fusion of type 1 curves to include both measured curves but not to extend lower than L-4. Type 2 curves can be managed with a selective thoracic fusion distally to the stable vertebrae (the vertebrae most closely bisected by the central sacral line). Similarly, type 3, 4, and 5 curves are most stable when fused the extent of the measured curve to the stable vertebrae. In their study, the best results were generally obtained when the lower level of the fusion was centered over the sacrum. The desired postoperative correction of the thoracic curve was accurately predicted from the bending radiographs. Postoperative Risser casting was commonly employed.

The concept that lumbar curves improve with selective thoracic fusion was confirmed by Kalen and Conklin.[13] They performed selective thoracic fusion for King type 2 curves. The initial correction of both the lumbar and the thoracic curves averaged 38%. An average correction of 25% was maintained in the thoracic curves, while an average correction of 31% was maintained in the lumbar curves. A 31% correction in the thoracic hypokyphosis was observed, and the preoperative lumbar lordosis was also maintained at final follow-up. They concluded that selective thoracic fusion for type 2 curves is appropriate and effective.

Intraoperative Considerations

Spinal cord monitoring may be considered in conjunction with or as an alternative to the wake-up test. Somatosensory evoked potential (SSEP) monitoring is a widely used technique that involves stimulating a peripheral nerve in the lower extremities and recording the response proximal to the surgical area. This modality monitors primarily the dorsal column pathways. Acute alterations in the latency of the waveform or amplitude of the potential are indicative of impending or actual spinal cord injury. Motor evoked potential (MEP) monitoring more effectively reflects the function of the anterior motor pathways. The combined technique of simultaneous SSEP / MEP monitoring, available in some centers, may offer the most sensitive method of assessing the entire spinal cord with the minimum potential for false-negative results.[14] When monitoring indicates a significant abnormality, a wake-up test is done.[9]

Anesthesia considerations are important, especially when spinal cord monitoring is being done. Inhalation agents, such as halothane and isoflurane, and other drugs, such as benzodiazepine, may alter or depress the SSEP signal and should be limited when monitoring is being done. The recommended protocol includes nitrous oxide, narcotics, and muscle relaxants.

A posterior fusion is essential and includes a Moe facetectomy, decortication, and the use of autogenous iliac bone and / or allograft. Without a satisfactorily performed fusion, instrumentation of any kind will eventually fail or cut out.

Posterior Instrumentation

Harrington Instrumentation

Although the Harrington instrumentation has been supplanted by posterior segmental instrumentation systems, it may still be considered the standard to which other systems are compared. Dickson et al[15] evaluated 206 consecutive patients operated on for idiopathic scoliosis between 1961 and 1963 with the use of Harrington instrumentation. These patients were compared with 100 age- and sex-matched normal control subjects. The study patients had more back pain and fatigue symptoms than the control subjects, but their ability to perform activities of daily living was not significantly diminished. Eighty-eight percent of the patients stated that they would recommend the procedure, 11% had reservations, and 1% would not recommend the procedure to a patient with scoliosis.

The newer systems developed from the single Harrington distraction rod demonstrate the evolution, refinement, and improvement of posterior instrumentation (Table 1). The changes in the Harrington system include the addition of a compression rod on the convexity of the curve, transverse devices connecting the two rods, and the use of sublaminar wires with the distraction rod. Mielke et al[16] studied 302 patients treated with one-stage posterior spinal fusion between 1960 and 1984. No difference was seen between the four types of fixation used, as measured by the amount of correction obtained and maintained after a minimum of 2 years of postoperative surveillance. The pseudarthrosis rate was 3.1%. Diminished thoracic kyphosis was seen with the distraction rod and with the combination of the distraction and compression rods. The loss of thoracic kyphosis was less with the use of sublaminar wires; this finding continues to be corroborated.[16-18]

Thomson and Renshaw[19] reported the data on 66 patients who underwent posterior spinal fusion extending into the lumbar spine with Harrington distraction instrumentation. The total lumbar lordosis, sacral horizontal angle, and sagittal plane alignment remained relatively constant. The lordosis within the fusion levels decreased and the lordosis caudal to the fusion increased as the lower hook placement moved caudally.

Bassett et al[20] reviewed the data on 85 patients with primary thoracic curves who underwent fusion with the Harrington instrumentation to determine its effectiveness in correcting decompensation. Spinal balance was assessed by measuring the magnitude of spinal decompensation. Sixty-four percent of the patients with initially decompensated curves showed improvement.

Segmental Systems

Because of concerns about maintaining lumbar lordosis and restoring thoracic kyphosis, other posterior spinal instrumentation systems were developed.[21] Thompson et al[22] reviewed the data on 86 patients with idiopathic scoliosis

Table 1
Characteristics of Posterior Instrumentation Systems for Idiopathic Scoliosis

System	Rods	Cost*	Hooks: End Only	Hooks: Multiple Segmental	Sublaminar Wires or Spinous-Process Wires	Set Screws on Hooks	Screws	Distraction-System Effect	Translation / Derotation System Effect
Harrington	Ratcheted	$ 900	Yes	No	Optional	No	No	Major	Minor
Luque	1/4-inch, 3/16-inch	$1,050	No	No	Yes (sublaminar)	No	No	Minimal	Intermediate
Wisconsin	Ratcheted Harrington plus convex Luque	$1,470	Yes	No	Yes (spinous process)	No	No	Major	Major
CD	5.0-mm knurled, 7.0-mm knurled	$2,200†	No	Yes	No	Strippable (irreversible)	Yes	Minor	Major
TSRH	4.8-mm smooth, 6.4-mm smooth	$3,300†	No	Yes	No	Eyebolt	Yes	Minor	Major
Isola	1/4-inch smooth, 3/16-inch smooth	$3,300†	No	Yes	Optional (sublaminar)	Allen screw	Yes	Minor	Major
Moduloc	4.8-mm smooth	$2,800†	No	Yes	No	Morse taper connection	Yes	Minor	Major

* For right thoracic curve. Cost of implants only. Cost figures may vary.
†Two rods, eight hooks, two transverse connectors, and miscellaneous elements, such as blockers and eyebolts.

who underwent Luque sublaminar segmental spinal instrumentation. Although improved sagittal alignment was observed, there was a high incidence of neurologic complications. Three patients had major spinal cord injury, and 11 patients had transient sensory changes. The authors attributed the high incidence of neurologic complications to surgeon inexperience.

More recently, other researchers have developed segmental instrumentation devices that have the capacity to correct the three-dimensional component of scoliosis. The CD system consists of two knurled rods attached by multiple hooks to the posterior elements. The rods are cross-linked by two or three transverse connectors that produce a rectangular configuration, giving added strength[23] (Fig. 1). The CD instrumentation has been demonstrated to have improved ability to obtain and maintain coronal and sagittal plane correction with improved stability without the risks associated with sublaminar wires. Fitch et al[24] compared the data on 32 consecutive patients treated with CD instrumentation with those of 30 consecutive patients treated with Harrington rods supplemented with Bobechko hooks, sublaminar wires, and postoperative bracing. The correction averaged 68% with CD instrumentation, compared with 53% with Harrington distraction instrumentation. The mean loss of correction was 1.8 degrees with CD instrumentation and 8.1 degrees with Harrington instrumentation. The CD instrumentation produced a 58% increase in thoracic kyphosis, while the Harrington distraction instrumentation produced a 30% increase. The TSRH, Isola, and Moduloc systems would be expected to have similar effects (Fig. 2).

As more experience has been gained with segmental instrumentation, certain concepts have been clarified. Early in the CD and TSRH experience, it was felt that the so-called derotation maneuver resulted in rotational correction of the apical scoliotic vertebrae. Lenke et al[25] compared pre- and postoperative CT scans of 20 patients with idiopathic scoliosis in order to assess the improvement in vertebral rotation produced by the derotation maneuver. The percentage of improvement at the apical vertebrae in the longitudinal axis of rotation relative to the midline was merely 16%. When the longitudinal axis of rotation was compared with the sagittal plane, an improvement of 10% was observed. However, the 66% mean Cobb angle improvement and the reduction of apical vertebral translation were more substantial. This suggests that at the apex, use of CD instrumentation and the derotation maneuver results more in reduction of vertebral translation than in reduction of actual vertebral rotation. However, higher degrees of derotation were observed at junctional zones, such as the thoracolumbar junction.

Bridwell et al[26] reviewed the sagittal-plane corrections after CD instrumentation in 160 patients with idiopathic scoliosis. In 25 cases in which CT scans were obtained through the apex of the deformity, the findings suggested that the translation / derotation maneuver improves thoracic hypokyphosis. For those with kyphosis of less than 15 degrees, there was an average

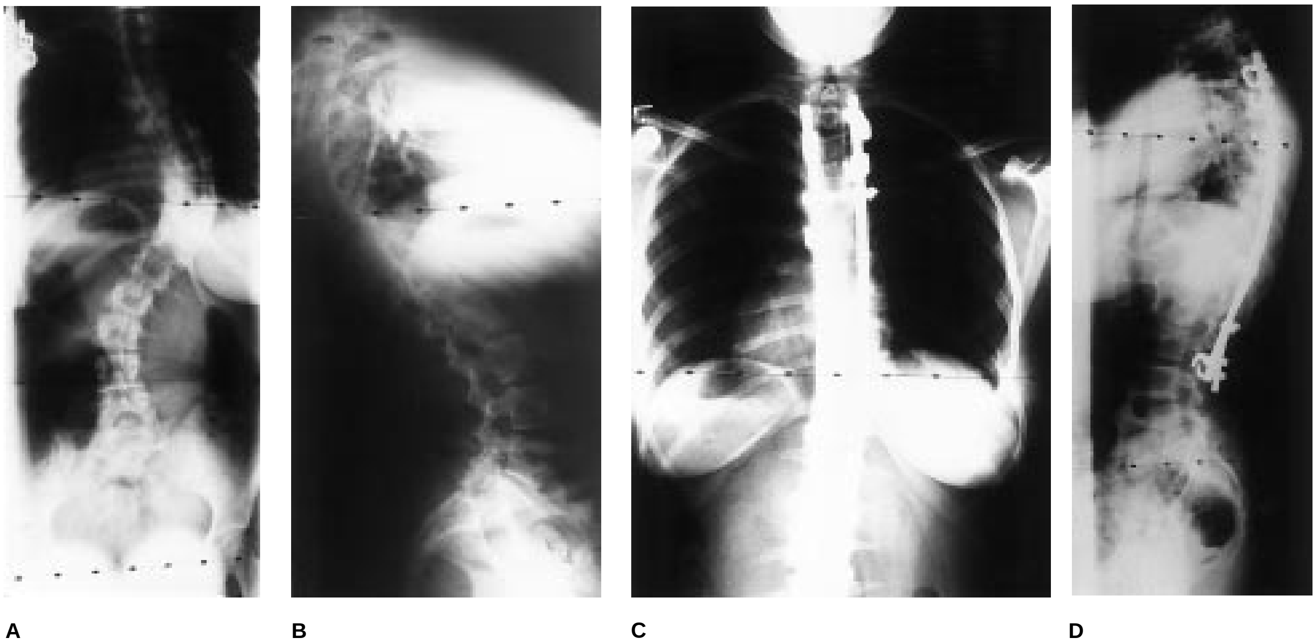


Fig. 1 **A** and **B**, Preoperative radiographs of a girl aged 13 years 10 months with a 68-degree right thoracic curve and a 38-degree left lumbar curve. **C** and **D**, Postoperative views of same patient at age 14 years 5 months, after posterior spinal fusion performed with CD instrumentation following first-stage anterior spinal release / fusion performed because of the rigid nature of the thoracic curve. Right thoracic curve measures 20 degrees; left lumbar curve, 18 degrees.

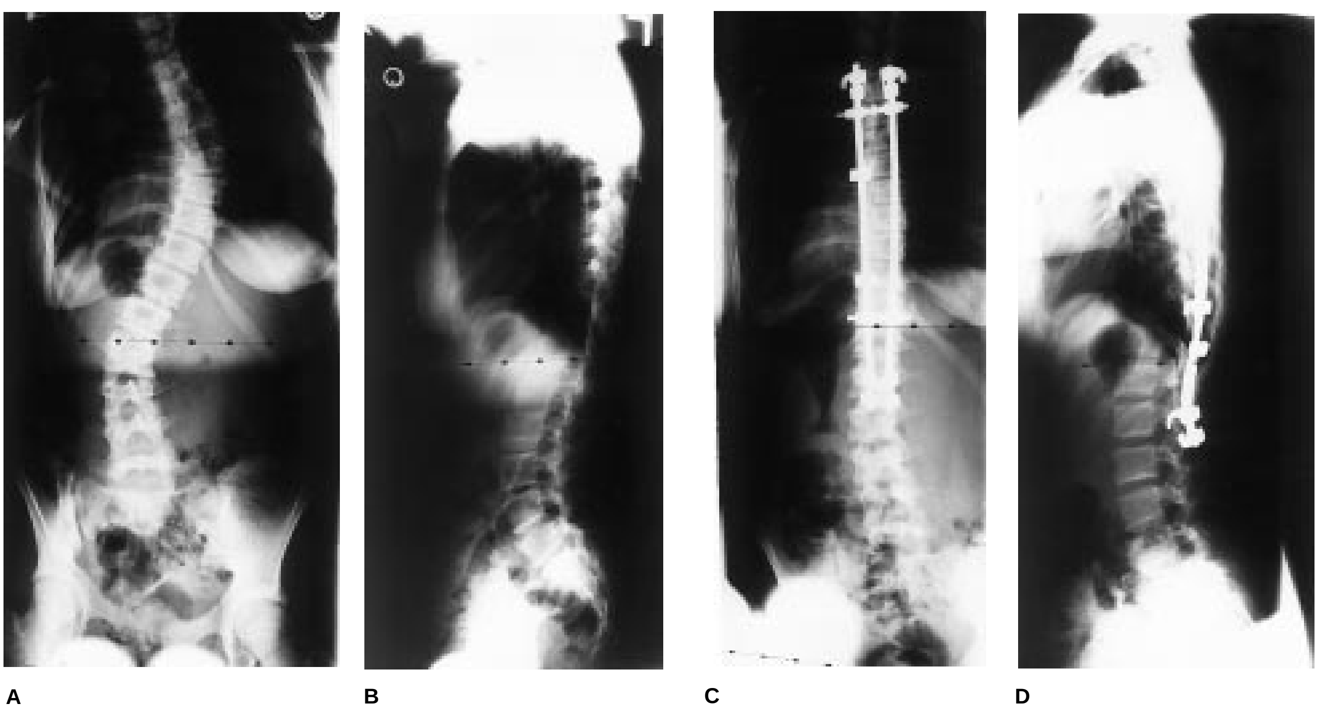


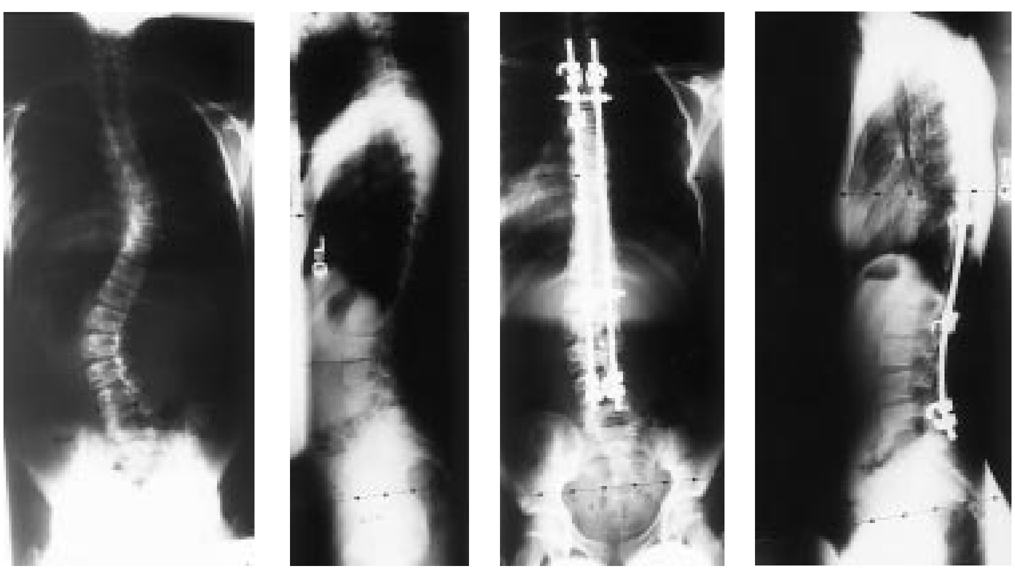
Fig. 2 **A** and **B**, Preoperative radiographs of a girl aged 9 years 8 months with a 50-degree right thoracic curve. **C** and **D**, Postoperative radiographs of same patient demonstrate a thoracic curve of 14 degrees following posterior spinal fusion performed with Isola instrumentation. Sublaminar wires were not used because of the flexible nature of the thoracic curve.

improvement of 13 degrees, as measured from T-5 to T-12. The junctional lordosis from T-12 to L-2 was preserved when a reverse bend was placed on the rod from T-12 to L-2 and a compression force was applied across this area. The patients treated with instrumentation to L-2, who had a reverse bend or compression across the junctional area, had an average of 3 degrees of preferred lordosis postoperatively, while those treated without the reverse bend or reverse configuration had an average of 3 degrees of undesired kyphosis postoperatively. The authors concluded that CD instrumentation consistently preserves sagittal contours. Similar effects would be anticipated with the TSRH, Isola, and Moduloc systems.

Aggressive overcorrection of scoliosis with segmental posterior instrumentation can lead to balance problems in some patients. Decompensation of the trunk to the left after fusion of right thoracic curves has been observed following segmental instrumentation. Richards et al[27] reviewed the data on 27 patients with King type 2 curves and 26 patients with King type 3 curves after an average follow-up of 12 months. They found that the type 2 curves tended to decompensate to the left. Following initial decompensation, the smaller curves improved, but the larger curves remained decompensated. For the larger type 2 curves, it is recommended that the fusion extend into the lumbar curve beyond the apical vertebrae. Larger curves are defined as thoracic curves greater than 60 degrees and lumbar curves greater than 45 degrees. Extension of the fusion in these larger curves also has the potential to prevent postoperative junctional kyphosis. The type 3 curves were all well balanced.

The mechanism of decompensation is unclear. To analyze it further, Thompson et al[28] reviewed the data on 30 patients who underwent posterior spinal fusion with CD instrumentation for adolescent idiopathic scoliosis. Planar radiographs and CT scans consisting of single axial sections from T-1 to S-1 were obtained preoperatively and 1 week postoperatively. Correction of the major curve averaged 68%, despite a preoperative flexibility of only 58%. The secondary curve was corrected an average of 58%, although the preoperative flexibility averaged 88%. The balance was worse postoperatively in 14 (47%) of 30 patients. The majority of the decompensated patients had type 2 curves. Important determinants of the spinal imbalance and decompensation after CD instrumentation were overcorrection of the major curve and extension of the instrumentation beyond the mobile segments into the secondary curve.

Thompson et al[28] recommend avoiding correction of the major curve in excess of preoperative flexibility. To limit the correction, the concave thoracic rod is contoured so that it mirrors the right thoracic curve seen on the supine right-side bending film for single curves and mirrors both the right thoracic curve on the right-side bending film and the left lumbar curve on the supine left-side bending film (Fig. 3). Also, instrumentation should involve as few spinal segments as possible, particularly avoiding the mobile transition segments, to prevent transmission of torsion to the lumbar secondary curve. In cases in



A B C D

Fig. 3 **A** and **B**, Preoperative radiographs of a girl aged 11 years 1 month with a 47-degree right thoracic curve and a 47-degree left lumbar curve. **C** and **D**, Postoperative radiographs of same patient at age 11 years 6 months, after posterior spinal fusion performed with Isola instrumentation, show a 10-degree right thoracic curve and a 17-degree left lumbar curve.

which overcorrection and decompensation have occurred, postoperative bracing may play a corrective role.

Decompensation also has been identified after fusion with CD instrumentation to the stable vertebrae. Too much thoracic correction may occur for the lumbar curve to accommodate spontaneously after segmental instrumentation. The surgeon has two methods to reduce decompensation with segmental instrumentation. Either fusion can be placed one segment short of the stable vertebrae with all hooks in a distraction mode, or the rod bend can be reversed and the hooks can be placed on the thoracic concave side between the neutral and the stable vertebrae. The choice between these alternatives should be dictated by the patient's preoperative sagittal contour and the need to normalize it at the upper lumbar spine. If the spine from T-12 to L-2 displays more than 5 degrees of kyphosis, it is preferable to fuse to the stable vertebrae with a distal reversal of hooks and rod bend.

Other factors that may need to be considered when contemplating a selective thoracic fusion using segmental posterior instrumentation relate to the structural characteristics of the lumbar curve, including the flexibility, the degree of rotation, and the amount of deviation of the apical vertebra from the central sacral line.[29]

Another technical issue is the necessity of using an apical thoracic convex hook. In a review of 82 patients, Puno et al[30] noted that the pedicle hook at the apex of the convexity was dislodged in 21. These patients did not show any significant loss of correction or increased risk of trunk decompensation. This raises the question of the need for its use. Their study also showed no significant difference in the amount of decompensation when the different lengths of fusion were compared.

Pedicle Screws

In a letter to the American Academy of Orthopaedic Surgeons, cited in the September 1993 issue of *AAOS Report*, the Office of Device Evaluation of the Center for Devices and Radiological Health of the US Food and Drug Administration (FDA) clarified that agency's official position on the use of bone screws in the pedicle, which is that they may "pose a potentially significant risk to patients" and are Class III devices. Further, the letter states that "there are no legally marketed bone plates, bone screws, spinal screws, pedicle screws, or device systems that incorporate bone screws commercially available in the United States, that have been cleared or approved [by the FDA] for spinal fixation when used for attachment through the pedicle of a vertebra." The position of the FDA is that the use of pedicle screws should be limited to approved, ongoing studies submitted under the Investigational Device Exemption provisions of the 1976 Medical Device Amendments.

If the use of pedicle screws is planned, the preoperative evaluation should include CT scans of the lumbar vertebrae to assess pedicle morphology and orientation. Some believe that CT studies should also be obtained postoperatively to confirm proper placement. Many of the segmental instrumentation systems can be combined with pedicle screws (Fig. 4).

Anterior Instrumentation

Posterior spinal fusion with instrumentation is indicated in most progressive or severe idiopathic curves treated surgically. An exception is the isolated thoracolumbar curve, for which anterior spinal fusion with instrumentation may more appropriately be selected.[31,32] The indications for anterior spinal fusion with instrumentation are thoracolumbar (apex of T-11, T-12, or L-1) or high lumbar curves of 40 to 60 degrees. The presence of thoracolumbar kyphosis is no longer a relative contraindication to anterior surgery, given the newer solid-rod systems, such as the TSRH anterior system, which has the ability to provide rotational correction and restore and maintain lumbar lordosis without the use of adjunctive intervertebral cortical wedge grafts. If an associated thoracic curve is present, it should be flexible enough to reduce to 20 degrees or less as measured on the supine right-side bending radiographs.

In preoperative surgical planning, the right-side bending film is used to assess the thoracic curve. The left-side bending film is used to determine the level of fusion as follows: The first disk spaces that wedge open in the reverse direction above and below the rigid thoracolumbar segment are left alone. The instrumented area is that part of the rigid thoracolumbar segment between these mobile disk spaces (Fig. 5). With this technique, three to six levels will typically be fused. The distal instrumentation level may be as proximal as L-2 or as distal as L-4.

Compared with posterior systems, anterior devices obtain equivalent, if not greater, correction while often preserving one or more lumbar motion segments. Kohler et al[33] reported on 21 patients who underwent the Dwyer procedure. A reduction of the mean preoperative scoliosis of the primary curve from 56 degrees to 4.3 degrees was measured postoperatively; the mean curve was 14 degrees at the 10-year follow-up. The secondary curve was corrected from 34 to 18 degrees postoperatively; this correction was maintained at the 10-year follow-up. In general, the results at 10 years were comparable with the results at

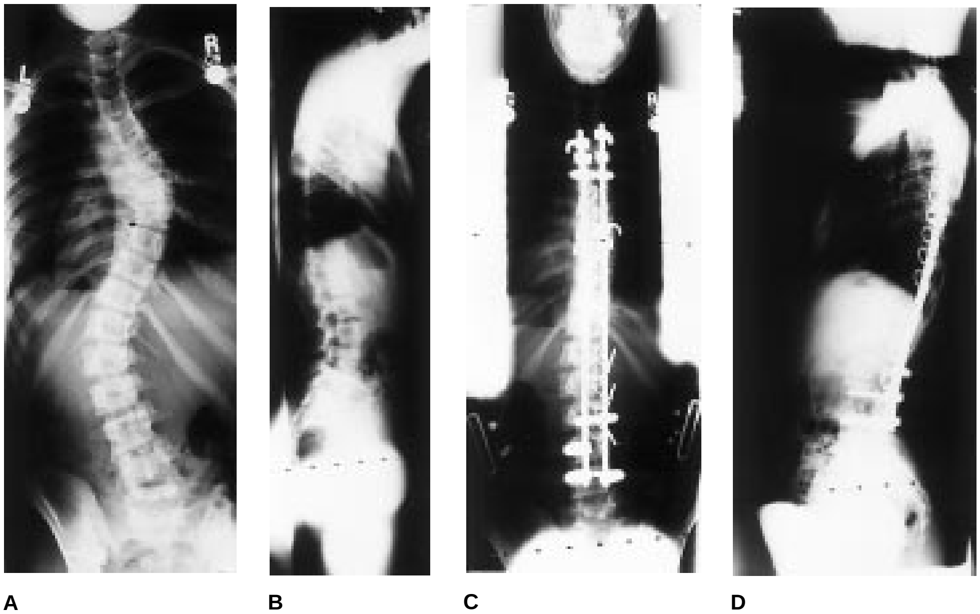


Fig. 4 **A** and **B**, Preoperative radiographs of a girl aged 12 years 10 months with a 53-degree right thoracic curve and a 52-degree left lumbar curve. **C** and **D**, Postoperative radiographs of same patient at 13 years show a 20-degree right thoracic curve and a 13-degree left lumbar curve after posterior spinal fusion performed with use of Isola instrumentation and lumbar pedicle screws. (Courtesy of Michael F. Schafer, MD, Chicago.)

2 years. Pseudarthroses were common, however, and mechanical failure accounted for deterioration in many patients. An undesirable kyphotic effect of this anterior instrumentation was evident after 10 years, with an average of 20 degrees of kyphosis. Nevertheless, the Dwyer operation does provide satisfactory correction of the primary curve with a limited instrumentation area. Three disadvantages are the frequency of mechanical complications, the kyphotic effect, and the unpredictable final overall rebalancing of the spine.

The Zielke ventral derotation spondylodesis system and the MOSS system substitute threaded rods and nuts for the flexible cable of the Dwyer system. Puno et al[34] evaluated the data on 34 patients who had solid fusions following anterior fusion with Zielke instrumentation for idiopathic scoliosis, with a minimum follow-up of 2 years. Immediately postoperatively, the correction of the primary curve averaged 70%, but at final follow-up a mean loss of correction of 25% had occurred. The thoracic compensatory curve was initially improved. Subsequent loss of correction was more evident if the primary curve was fused short of the Cobb measurement. Worsening of the thoracic compensatory curve was more likely when the fusion was carried more cephalad than the upper-end vertebra of the primary curve. Most patients showed an increase in kyphosis at the final follow-up. The importance of preoperative planning and the persistent problem of postoperative kyphosis must always be borne in mind.

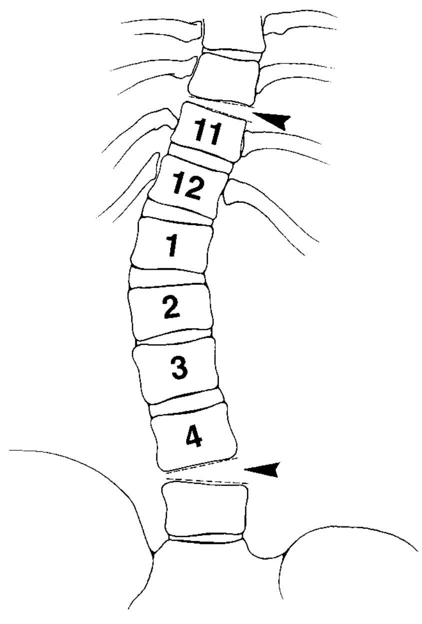


Fig. 5 Diagrammatic representation of preoperative left-side bending supine radiograph obtained for assessment of fusion / instrumentation levels to be used for anterior-approach correction. The instrumented level will be T-11 to L-4 (i.e., between the mobile disk segments).

Wojcik et al[35] reviewed the data on 18 patients treated with the Zielke operation. Most of the lower curves and 50% of the upper curves progressed during the follow-up period. Progression was most marked in the thoracolumbar segment of the spine. The key factors leading to curve progression after the Zielke operation were spinal asymmetry in the frontal plane, linear spinal growth, and concave lumbar muscle tethering.

The TSRH solid-rod system has been developed more recently for anterior spinal instrumentation. Turi et al[36] reviewed the data on 14 consecutive patients with idiopathic thoracolumbar or lumbar scoliosis treated with this new system. The solid-rod system can be contoured for the appropriate lordosis, compressed, and rotated to correct coronal and axial plane deformity. The average preoperative curve of 56 degrees was corrected to 14 degrees, an improvement of 75%. This correction represented 130% of the curve correction predicted on the basis of preoperative bending radiographs. Loss of correction has been minimal to date. The noninstrumented thoracic curve was corrected well also. The spontaneous correction averaged 82% of that predicted from the preoperative bending radiographs. The rotation of the apical vertebra improved by an average of 49%; this improvement resulted in a significant improvement in cosmesis with well-maintained sagittal contours. There have been no pseudarthroses or implant failures. The construct is stiffer; this is thought to have resulted in more rapid fusion, which lessened the rate of decompensation. The problem with kyphosis after anterior compression was minimized by virtue of the stiffer solid-rod construct and more rapid fusion (Fig. 6).

Autograft Versus Allograft

The standard of care for spinal fusion is autograft, although allograft may be substituted, based on the patient's particular needs and the surgeon's preference. Fabry[37] compared a group of 83 patients who underwent posterior spinal fusion for idiopathic scoliosis with either autograft or allograft. Significant reductions in operative time and blood loss were seen in the allograft group. After 1 year, there was no significant difference in correction of the curve. Allograft alone without autogenous graft may be considered, although we prefer autogenous graft with or without allograft supplementation in our center.

The consensus on postoperative bracing for segmental posterior instrumentation cases is that it is not routinely necessary. The decision to brace remains at the discretion of the surgeon when segmental instrumentation is used.

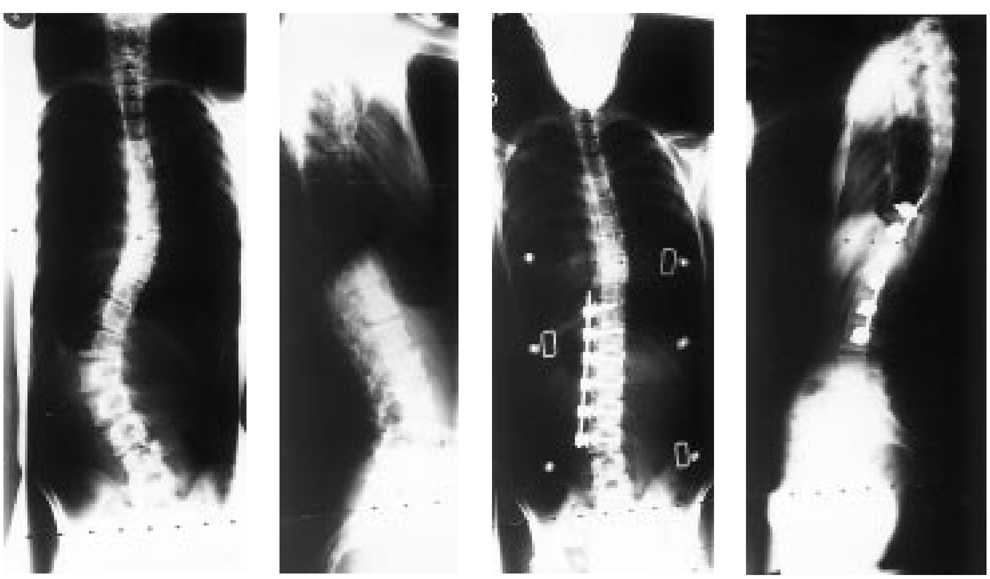
Complications

Mortality

The 1991 Morbidity and Mortality Report of the Scoliosis Research Society (SRS) (unpublished data) noted an overall complication rate of 8% in the surgical treatment of scoliosis. This rate has been consistent in the SRS reports of the past several years. Mortality is extremely rare. In the 1992 SRS report (unpublished data), there was one death after an anterior and posterior spinal fusion for adolescent idiopathic scoliosis. This death was attributed to a pulmonary embolus.

Neurologic Injury

Neurologic injury is fortunately rare, but is most likely to occur during instrumentation correction of scoliosis.[2] In the 1991 Morbidity and Mortality Report of the SRS, there were eight reported cases of incomplete neurologic deficits after spinal fusion and instrumentation. Since the report does not separate the number of patients with idiopathic scoliosis from those with scoliosis



A B C D

Fig. 6 **A** and **B**, Preoperative radiographs of 14-year-old girl with 39-degree right thoracic curve and 60-degree left thoracolumbar curve. **C** and **D**, Postoperative radiographs of same patient at age 14 years 8 months, after anterior fusion with the TSRH anterior instrumentation, show a 24-degree right thoracic curve and a minimal residual thoracolumbar curve.

due to other causes, the exact incidence of idiopathic scoliosis cannot be calculated, but it is probably less than 1%.

The risk of neurologic injury seems to be higher when sublaminar wires are used. For example, Wilber et al[38] reported that 12 of 69 patients (17%) had neurologic complications after segmental spinal instrumentation with sublaminar wires, in contrast to the 1.5% incidence (1 of 68 patients) in the patients who underwent Harrington distraction instrumentation only. Nine of the 12 patients with complications in the sublaminar-wire group had transient sensory changes thought to be due to either slow hemorrhage from small epidural vessels or postoperative edema. Spinal cord injury was seen in 4% of the patients in the sublaminar-wire group, compared with 1.5% in the distraction-only group. While SSEP spinal cord monitoring was useful in identifying those who sustained a major spinal cord injury, the technique was not useful in identifying those who developed transient sensory changes, presumably because these changes developed postoperatively. The rate of recovery from iatrogenic neurologic injury was better if the implants were removed within 2 to 3 hours of the onset of the neurologic problem.[2]

Wound infection after surgery for idiopathic scoliosis occurs in fewer than 1% of patients. Routine antibiotic prophylaxis beginning within 1 hour of the start of surgery and continuing for 48 hours postoperatively is recommended.[2]

Malnutrition

Malnutrition is a potential issue for patients undergoing two-stage procedures and is thought to be a risk factor for infection. Therefore, it has been recommended that parenteral hyperalimentation be instituted immediately after the first procedure and continued until adequate oral intake is established after the second procedure.[2]

Late Complications

The pseudarthrosis rate after fusion for adolescent idiopathic scoliosis is approximately 1%.[2] This diagnosis is suggested when plain radiographs demonstrate progressive loss of correction. Failure of instrumentation and back pain may also indicate pseudarthrosis. Dawson et al[39] studied 198 patients who underwent posterior spinal fusion for scoliosis to determine the best way to determine when pseudarthrosis is present. They concluded that anteroposterior planar tomography is the most accurate method and can be used to identify a pseudarthrosis before failure of fixation or loss of correction is seen.

Two risk factors appear to be significant for low back pain after posterior spinal fusion for idiopathic scoliosis: extension of the fusion and instrumentation mass below the third lumbar vertebra and loss of the normal lumbar lordosis.[2] Since the newer instrumentation systems restore neutral sagittal contours and maintain more harmonious relationships between the instrumented areas and the junctional zones of the nonoperatively treated spine, it is hoped that the incidence of late low back pain after posterior spinal fusion and instrumentation may decrease.

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