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# Anterior Instrumentation in the Treatment of Scoliosis

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**Abstract:** The anterior approach to the spine, which was initially used exclusively for the management of spinal tuberculosis, is now indicated for infections, tumors, trauma, and increasingly to correct scoliosis. Anterior instrumentation for thoracolumbar and lumbar scoliosis has the advantage of providing greater correction than the traditional posterior approach while instrumenting fewer vertebrae, thus preserving distal motion segments. Despite these advantages, both non-union and kyphosis over the instrumented segments have been observed more often than with the use of posterior segmental spinal instrumentation.

Accordingly, improvements in anterior construct design have evolved in an effort to provide greater stability while restoring the sagittal profile. Design modifications have been facilitated by biomechanical testing, which also enables comparison between different implants. As a result, increased implant rigidity has enhanced arthrodesis. It seems that the addition of solid interspace support to solid rod constructs may also enhance stability while maintaining anterior column length, thus avoiding instrumental kyphosis.

Recently, minimally invasive techniques have been used for anterior releases in the thoracic and lumbar spine. As experience is gained, the video-assisted approach may enable placement of anterior implants.

With further improvements in implant design and techniques for insertion, anterior instrumentation may provide an alternative to segmental posterior instrumentation for a variety of indications.

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## Historical Perspective

The anterior approach to the spine through a thoracotomy or thoracoabdominal exposure was originally devised as a more direct method to treat tuberculous spondylitis [34,41]. In contrast to laminectomy and costotransversectomy, this technique provides wide exposure and excellent visualization, and enables a thorough debridement as well as structural grafting. Although this radical approach to Pott's disease was first described by Ito, et al. in 1934 [41], the technique was popularized by A.R. Hodgson in the late 1950s in Hong Kong [34]. Over the past few decades the indications for an anterior approach have expanded to include a variety of pathologic conditions including primary and metastatic tumors, infections, trauma, and deformities [4,6,7,9,10,15--18,20,21,26--30,31,34--36,41,43--50,55--64,67,69--73,79,84,85,91--93,100,101,103].

The anterior approach to scoliosis was first reported by Dwyer in 1969 [15], and although techniques for instrumentation have expanded, the benefits of this strategy continue to be observed. The anterior release provides excellent mobility and can enhance the correctibility of stiffer curves. In addition to improving cosmesis, greater correction decreases the risk of non-union and subsequent hardware failure, which are at risk when larger residual deformities remain. Anterior arthrodesis also eliminates vertebral body growth potential, which may be beneficial in cases at greater risk for postoperative correction loss after posterior spinal fusion, the so-called crankshaft phenomenon [14,32,74,75,88]. Although the most reliable risk factors remain controversial, it seems that children below the age of 10 years, those with open triradiate cartilages, and those that require fusion before reaching peak growth velocity are at greater risk to crankshaft. For populations at greater risk for non-union including myelomeningocele, neurofibromatosis, and those who have developed a pseudarthrosis after a posterior procedure, the provision of a greater surface area for fusion has improved rates of arthrodesis when combined with a posterior approach [4,9,21,26,67]. Anterior implants have also been used in conjunction with posterior instrumentation systems for collapsing, neuromuscular deformities [85].

The anterior approach has also been useful to treat several other complex spinal disorders. Convex hemi-epiphyseiodesis produces asymmetric growth arrest that may enable the spontaneous correction of residual deformity in select patients with congenital scoliosis [97,98]. Hemi-vertebral resections have been completed safely using this approach, and thoracoplasty may also be performed [79,80]. Complex revision cases involving rigid, multi-planar deformities also require anterior surgery to provide the necessary mobility for realignment, either through discectomies or osteotomies of congenital bars or previous fusion masses [21].

## Spinal Instrumentation

Spinal implants are used to apply corrective forces, to maintain the correction achieved, and to provide the necessary rigidity to optimize rates of arthrodesis [2,3,25,94]. All spinal constructs serve as temporary internal splints. The failure to achieve union will result in prolonged cyclic loading, which ultimately results in fatigue failure of the implant. These devices share loads with the spine in a dynamic relationship in which the implant initially bears most of the load. Implant loading gradually diminishes as healing progresses, and should be minimal after consolidation of the fusion mass.

Via their attachment sites to the spine, both anterior and posterior implants may apply corrective forces including distraction, compression, and translation. Posterior implants gain purchase through placement of hooks on the pedicles, laminae, or transverse processes, by threading of wires around the laminae or through the bases of the spinous processes, and by placement of transpedicular screws. In contrast to the variety of posterior implants, anterior devices generally rely on single vertebral body screws. As the bone-implant interface is within the cancellous vertebral body, these systems may be inherently less stable than posterior constructs. Bone mineral density becomes an important variable affecting the stability of the screw-bone interface [1,52,53,82,89]. A certain degree of osteopenia, which has yet to be quantified based on DEXA scans and insertional torque values, may predispose to acute failure during the corrective maneuver or to early loosening because of fatigue.

Mechanical studies assessing anterior vertebral screws have revealed that maximal stability is achieved with bicortical purchase and the addition of a staple, and that preparation of the far cortex is not necessary [37,51,54,82]. Future research is required to enhance stability at the interface.

## Biomechanical Testing

Biomechanical studies are essential in the development and modification of instrumentation systems [2,3,8,20,24,25,65,66,68,77,78,81,82,86,87,94--96,99,102]. The experimental model should simulate the clinical pattern of instability; however, the creation of a clinically realistic scoliotic deformity has been difficult to achieve. Bovine specimens have uniform bone mineral density in comparison with human cadaveric spines, and are both mechanically and anatomically similar to human spines [11,86,96]. The limitations of in vitro testing include finite specimen viability, the absence of stabilizing effects from the surrounding musculature, and the inability to assess the affects of progressive bony consolidation on implant loads [2,3,94].

The most clinically relevant information is provided by non-destructive testing, and testing of a spine-implant composite evaluates construct rigidity and provides an estimate of the immediate post reconstruction stability under physiologic loading. As clinical failure occurs most often during cyclic loading over months to years, fatigue protocols are an important component of the evaluation [25,94,99]

## Alignment and Balance

Scoliosis involves alterations in the coronal, sagittal, and axial planes. The thoracolumbar and lumbar curves involve counterclockwise rotation of both the spinal segment and the apical vertebral bodies, producing a rotational kyphosis [83]. This contrasts with the typical thoracic curve in which the spinal segment is rotated counterclockwise and the apical vertebral bodies are rotated clockwise [83]. Corrective strategies must address all planes of deformity, and although the magnitude of correction is important, maintaining balance in the frontal and sagittal planes is paramount. Alterations in spinal alignment may result in the formation of pathologic compensatory curves. Consequences of this include asymmetric loading of lower motion segments that may predispose to degenerative changes. Symptomatic disc degeneration may require extension of the fusion. Alterations in spinal balance, if not compensated adequately, may also create pain from paraspinal overload. Anterior multi-level discectomies and instrumentation provides superior correction in the axial and frontal planes, however maintenance of sagittal alignment in thoracolumbar and lumbar regions is difficult because of shortening of the anterior column, and thoracolumbar kyphosis may occur [7,15--18,26,27,31,38,43--47,55,56,58--61,63,64,71,91,92].

Whereas the spine should be straight in the coronal plane with the weight reaction line through the center of the sacrum, normal sagittal alignment includes thoracic kyphosis (20 to 50 degrees), a straight or slightly lordotic thoracolumbar junction, and a lordotic lumbar spine (20 to 60 degrees) with approximately two-thirds occurring between L4 and the sacrum [5,22,42]. The weight reaction line, or sagittal plumb line, normally falls through the posterosuperior corner of S1. The maintenance of sagittal alignment has been a focus of research in the management of scoliosis over the past decade.

## Evolution in Anterior Construct Design

Anterior spinal instrumentation for scoliosis has traditionally been indicated for thoracolumbar and lumbar curves to provide greater correction while instrumenting fewer vertebrae. Preservation of distal motion segments theoretically decreases the risk of late degeneration below the fusion mass. Problems such as kyphosis over the instrumented segments and non-union are observed more frequently than with posterior segmental spinal instrumentation (Table 1) [15--18,27,31,39,43,44,47,55,56,58,59--61,63,64,71,84,91,92].

**Table 1.** A summary of clinical reports concerning the use of anterior instrumentation for thoracolumbar and lumbar scoliosis. The full range of patient ages are represented, and overall results are better for adolescents in comparison with adults.

| Author | Method | Age | Graft | Frontal % | Rotation % | Non union | Correction loss | Kyphosis |
|---|---|---|---|---|---|---|---|---|
| Dwyer | Dwyer | <18 | MG | 70 | NR | 12% | 37% | NR |
| Dwyer | Dwyer | NR | MG | NR | NR | 20% | 29% | 23% |
| Luk | Dwyer | 16 | MG | 88 | 37 | 0 | 4 degrees | 27 degrees |
| Kohler | Dwyer | 16 | MG | 80 | NR | 11-23% | 10 degrees | 20 degrees |
| Hall | Dwyer | NR | NR | NR | NR | 33% | NR | NR |
| Hsu | Dwyer | 15.3 | MG | 67 | 37 | 0 | NR | 18--26 degrees |
| Ogiela | Zielke | 23.2 | MG | 64 | NR | 17% | 6% | 5 degrees |
| Lowe | Zielke | 21 | MG | 69 | NR | NR | 6 degrees | 8 degrees |
| Trammel | Zielke | 41 | MG | 65 | 36 | 23% | 12 degrees | NR |
| Kostuik | Zielke | 37.4 | MG,IC | 68 | NR | 0 | 0 | 24% |
| Suk | Zielke | 16.7 | MG | 77 | 42 | 3% | 5 degrees | 10 degrees |
| Luk | Zielke | 16 | MG | 91 | 47 | 0 | 7 degrees | 10 degrees |
| Moe | Zielke | 26 | BR | 77 | NR | 29% | 6 degrees | 6 degrees |
| Horton | Zielke | 26.5 | MG | NR | NR | NR | 5.1 degrees sagittal | 9.7 degrees |
| Kaneda | Zielke | 17.5 | MG,IC | 70 | 46 | 6.5% | 3 degrees | 8 degrees lordosis |
| Moskowitz | Zielke | 27 | MG | 73 | 57 | 20% | 6 degrees | 7.7 degrees |
| Puno | Zielke | 28.3 | MG | 70 | 70 | NR | 25% | 9.7 degrees |
| Hammerberg | Zielke | 18 | MG | 76 | NR | 25% | NR | NR |
| Turi | TSRH | 14.6 | MG | 75 | 49 | 0 | 5 degrees | 9-22 degrees in 6/19 |
| Johnston | TSRH | 14.8 | MG | 73 | 46 | 26% | 6% | 4.7 degrees |
| Hopf | CDH | 15.3 | MG | 69 | 37 | NR | 4% | 16 degrees lordosis |
| Kaneda | Kaneda | 16.2 | BR | 90 | 86 | 0 | 1.5 degrees | 4 degrees lordosis |

Abbreviations: MG = Minced Graft, IC = Iliac Crest, BR = Bicortical Rib, NR = Not Reported.

The first system was developed by Dwyer and included vertebral body screws and a braided titanium cable [15--18,27,39,46]. After anterior release, correction was achieved by sequential compression. Frontal plane correction ranged from 64 to 88%; however, significant loss of correction occurred in up to 40% of patients. The anterior column was shortened resulting in kyphosis of up to 27 degrees over the instrumented segments. The flexibility of the system resulted in non-union in up to 33% of cases.

These observations led to the Zielke system, which used a semi-rigid, 3.2-mm threaded rod [7,23,31,38,44,47,55,60,61,63,64,70,71,84,91,100,101,103]. Although this method also relies on compression, Zielke did provide for a de-rotation maneuver in an attempt to better control sagittal contours. Also, by placing the central vertebral screws more posteriorly than the peripheral ones, some improvement in sagittal alignment could be achieved. Frontal correction from 64 to 91% with rotational correction of 37--70% has been reported. Despite these improvements, similar problems were encountered including kyphosis of 5 to 10 degrees and non-union in 0--30% of patients. Loss of correction was observed in up to 25% of cases.

The need for further refinement led to the solid rod systems, which similarly use de-rotation but provide greater rigidity. The first was the Texas Scottish Rite Hospital (TSRH) system [43,92]. A solid rod (4.8 mm or 6.4 mm) is pre-contoured and placed within the screws, and then a rotation maneuver is performed to convert the coronal plane deformity into the sagittal plane. Segmental compression is then added to secure the screws to the rod. Clinical follow-up of this implant has revealed frontal correction of 75% and rotational correction of 49%, however non-union occurred in 5 of 19 patients and kyphosis of 4.7 degrees was observed. An example of an anterior solid rod construct is shown in Figure 1.

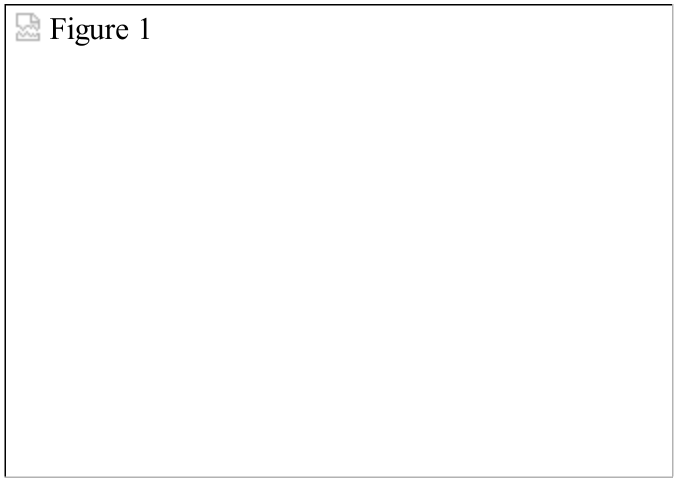


**Fig. 1.** Spine model instrumented with an anterior solid rod construct using CD Horizon Implants.

Most recently, the dual rod constructs have been developed to further enhance rigidity while restoring the sagittal contour [20,29,30,36,65]. The Kaneda multi-segmental system uses two semi-rigid, 4-mm rods that are attached to triangulated vertebral body screws [45,77]. The screws are placed through a vertebral plate at each level, improving the pull-out strength by 50%. The first report of this system with 3-year follow-up included frontal correction of 90%, rotational correction of 86%, with maintenance of sagittal alignment. Correction loss was minimal and no cases of non-union were observed. %Despite these excellent early results, there remains the concern over implant profile and the risk of impingement on neighboring visceral and neurovascular structures, particularly in children. Further experience in different centers will be required before the acceptance of these newer designs.

An alternate strategy for improving anterior single rod constructs for thoracolumbar and lumbar scoliosis involves the provision of structural anterior inter-body support, which may maintain anterior column length and improve stability [7,33,82]. Management of the inter-space has received limited attention previously, and nearly all authors have used minced, corticocancellous graft, which may settle in the post-operative period. A recent experimental study concluded that structural grafts were essential to produce lordosis and simultaneously correcting a scoliotic deformity with anterior instrumentation [66].

Structural inter-body devices include femoral ring allografts, titanium cages, and cortical dowel grafts [7,8,12,25,48,49,76,82,87,95]. These implants have been studied in the laboratory, and have been used for degenerative lumbar pathology. Femoral ring allografts, despite some early subsidence, maintained disc space height in 59--100% of cases, and provided an average distraction of 2.4 mm [12,48,49]. An in vivo study in sheep suggested that distraction could be maintained with titanium cages despite some loss of height in the early postoperative period [76]. Other studies have suggested that these devices may increase the stiffness, or decease laxity of the isolated motion segment [68,87,95].

These observations led us to a biomechanical study in which we investigated the addition of multi-level, threaded cortical dowel grafts to an anterior solid rod construct in a bovine model [82]. As might be applied to the acute post reconstruction period, our results suggested that stiffness was increased in all load paths except axial rotation. Stability was superior to a clinically relevant posterior instrumentation comparison group except in axial rotation, and was equivalent to a clinically relevant posterior construct except in anterior flexion. Lordosis within the instrumented spine was achieved using this strategy. The optimal device for providing structural inter-space support remains to be established. Important variables to be evaluated in future studies include the dimensions of the device, material properties, osteogenic capability including means of incorporation, and cost. Although clinical reports are not yet available, this strategy has the potential to improve anterior solid rod construct biomechanics and may serve as a viable alternative to the dual rod constructs.

## Preoperative Planning for Thoracolumbar Instrumentation

An anterior, solid rod construct has been used most often for thoracolumbar and lumbar scoliosis. The preoperative selection of fusion levels for the anterior approach is based on both the standing PA film and the right and left lateral bending films, the latter of which assesses the flexibility of both the primary curve and any compensatory curves [16,26,38,43,103]. Compensatory deformities may include both a thoracic curve and a fractional lumbosacral curve.

In contrast to the levels selected using a posterior approach, only the structural component of the curve is instrumented, as identified on the side-bending radiograph. Segmental inclusion criteria are vertebral rotation of 20 degrees or greater and disc space wedging greater than 10 degrees on standing radiographs, as well as the ability of the vertebra to de-rotate and become horizontal relative to the sacrum on the side-bending radiographs. Also, the adjacent disc space to the instrumented segment should open on both sides on the bending films, the fractional lumbosacral curve should be correctable, and a compensatory thoracic curve should correct to less than 30 degrees to be left out of the instrumentation.

A modification of this basic approach has been described by Hall, et al. and consists of short segment (3--4 vertebral bodies) instrumentation with apical over-correction of the deformity [28,59]. The ideal patient has a flexible deformity that can be over-corrected by approximately 10 degrees. Patients should have less than 15 degrees of kyphosis, and if a compensatory thoracic curve is present, this should correct to less than 20 degrees on side-bending films. If the apex is a disc space, then four vertebral bodies are instrumented with two above and two below this apical disc. If the apex is a vertebral body, then three bodies and two disc spaces may be included in the construct. The disc spaces adjacent to the planned levels of instrumentation must open on both bend films.

The senior author has used this approach with an anterior solid rod construct for thoracic and thoracolumbar curves in idiopathic scoliosis, for various syndromes including Marfan's, and in conjunction with posterior instrumentation in neuromuscular patients who demonstrate lumbar hyperlordosis preoperatively. In the setting of hyperlordosis, shortening of the anterior column facilitates the placement of posterior implants. Both frontal plane and axial plane correction have been greater than with the Dwyer or Zielke systems, and one to two distal motion segments have been spared. Acceptable spinal balance has been achieved, although kyphosis over the instrumented segments is still observed.

## Case Report

A 16-year-old white female presents with a 48-degree curve from T11 to L3 (Figure 2). She has significant lateral translation of both her rib cage and her head and neck (C7 spinous process deviated 4.5 cm. to the right of the central sacral line) in the coronal plane as there is no compensatory thoracic curve. This de-compensated state is partially offest by the presence of a fractional lumbosacral curve. In the sagittal plane she has 4 degrees of kyphosis from T11 to L3, and her total lumbar lordosis (L1-S1) measures 48 degrees. Bending films suggest that the structural components of her curve span from T11 to L3, and that the stable vertebra is L3 or L4. Standing right-bend films show reduction of the curve to 19 degrees, whereas a supine traction bend reveals a residual curve of 10 degrees. Both the L2/L3 and the L3/L4 disc spaces open on both bend films. On the left-standing bend film, the fractional lumbosacral curve corrects, both L2 and L3 become horizontal to the sacrum, and L3 de-rotates.

Figure 2

**Fig. 2.** Case report. **A:** Initial standing radiograph demonstrates a 48-degree curve from T11 to L3 with right coronal decompensation. **B:** The right-standing bend film shows correction to 19 degrees. **C:** The left-standing bend film demonstrates correction of the fractional lumbosacral curve, the ability of both L2 and L3 to horizontalize to the sacrum, and the ability of L3 to derotate. L3 was selected as the distal level of instrumentation due to persistence of rotation at L2. **D:** Follow-up standing radiograph at 1 year with correction of curve to 8 degrees, significant improvement in trunk shift and in balance of the head over the pelvis. **E:** The post-operative standing lateral radiograph demonstrates kyphosis of 18 degrees over the instrumented segment. Sagittal balance was maintained.

Based on these observations, it was elected to instrument the curve from T11 to L3, as L2 demonstrated residual rotation on the side bend, which may result in post-operative de-compensation. Minced rib graft was used for inter-space support. Follow-up radiographs at 1 year post-operatively reveal a residual curve of 8 degrees, excellent improvement in trunk shift, correction of the fractional lumbosacral curve, and improvement in the deviation of the C7 spinous process to 1.0 cm. However, sagittal alignment values include kyphosis of 18 degrees over the instrumented segment, with a total lumbar lordosis of 42 degrees. Sagittal balance was maintained.

## Applications for Thoracic Scoliosis

Anterior instrumentation for thoracic scoliosis appeared in the late 1970s using the Zielke system [23,31,102]. Although reports have been infrequent [6,10,33], interest has increased because of the inability of posterior segmental constructs to reliably provide de-rotation and restore normal kyphosis in patients with hypokyphosis or lordosis [19,89]. In addition, the posterior de-rotation maneuver may transmit torsional forces to adjacent spinal segments, which can result in decompensation, and may paradoxically increase the cosmetic deformity in some cases.

The anterior approach enables better rotational correction and is ideal for cases in which there is hypokyphosis because the anterior column is shortened. A double thoracotomy (which may be performed through a single skin incision), is frequently required to gain a long enough exposure. Authors have recommended both compression and de-rotation strategies for curve correction.

Preliminary reports involving the Moss-Miami single-rod construct have recently become available [6,10]. A prospective study comparing anterior spinal fixation using a 3.2-mm flexible rod with a segmental, posterior construct suggested that although correction was greater using the anterior approach and an average of 2.5 motion segments were spared, non-union was observed in 5% (versus 1% for the posterior group) and implant failure occurred in 31% of cases [6]. No revisions have been necessary. The authors are currently evaluating a stiffer 4-mm rod. The perceived benefits of this strategy will need to be validated by long-term studies after improvements in existing implants.

## Minimally Invasive Spine Surgery

Endoscopic techniques for spine surgery were introduced in the early 1990s and have been applied to both thoracic and lumbar deformities [13,39,49,56,61,68,71,72,92]. Goals have included minimizing recovery time, decreasing morbidity, and decreasing both the length of stay and the total cost. Procedures are generally performed in conjunction with a thoracic or general surgeon, and a significant learning curve has been described. Typically, four to eight portals (short, transverse incisions) are required for a multi-level release in the thoracic spine. These are placed in the mid axillary line, which may be a cosmetic advantage, as the arm is held over this region. Both experimental studies and clinical experience has suggested that the mobility obtained after endoscopic release is comparable to that obtained via an open approach [39,61,68]. Although operative times are generally greater, thoracoscopy may result in less post-operative pain in comparison with standard thoracotomy [49]. Newton, et al. found a similarity in blood loss, complications, and amount of curve correction, however costs were increased 29% versus open thoracotomy, because of both operating time and equipment [61]. Perhaps with greater experience and modifications in equipment, the cost effectiveness of this strategy may be validated. Most recently, preliminary data have been presented on the correction of thoracic scoliosis, including the placement of instrumentation using this approach [68]. The ultimate role for these techniques remains to be determined.

## Conclusions

The indications for anterior spinal surgery have expanded over the past several decades, and both anterior implants and the techniques for their application have evolved to allow greater correction of deformities, maintenance of alignment in three planes, and optimal stability to enhance rates of arthrodesis. Anterior instrumentation for thoracolumbar and lumbar scoliosis provides greater correction while preserving distal motion segments. The problems of instrumental kyphosis and non-union are currently being addressed by improvements in construct design, and newer strategies include the use of dual rod constructs and the provision of structural disc space support with femoral rings, titanium cages, or cortical bone dowels. With further research, anterior instrumentation may provide an alternative to posterior instrumentation for a variety of indications.

Additionally, the anterior approach for thoracic scoliosis is currently being investigated, and the minimally invasive endoscopic techniques may shorten recovery time, improve cosmesis, and decrease morbidity for a variety of procedures including decompressions for tumors or burst fractures and multi-level releases for deformity. The ability to easily instrument the spine anteriorly using these minimally invasive techniques may be realized within the next several years.

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