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Anterior Instrumentation for Thoracolumbar Adolescent Idiopathic Scoliosis

Do Structural Interbody Grafts Preserve Sagittal Alignment Better Than Morselized Rib Autografts?

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Study Design. This is a retrospective, sequential cohort study of 34 patients treated by anterior instrumented fusion with single solid rod, single screw constructs with at least 2-year follow-up. Sixteen of the patients received structural grafts as interbody spacers in disc levels below T12, while the other 18 patients received only morselized rib autograft.

Objective. To determine if structural interbody grafts preserve sagittal alignment better than morselized rib autograft.

Summary of Background Data. Some studies have shown that structural grafts are more effective in preserving sagittal alignment, while others have found them to be no more effective than morselized rib graft.

Methods. Anterior-posterior radiographs were measured for primary, secondary, and fractional Cobb curves, and C7–sacrum plumb lines. Lateral radiographs were measured for: T5–HIV (highest instrumented vertebrae), instrumented levels, LIV (lowest instrumented vertebrae)–S1, T12–LIV, and T12–S1 angles, C7–sacrum plumb lines, and LID-A (lowest instrumented disc-angle).

Results. The increase in kyphosis from preoperative to follow-up radiographs of the angle between T12–LIV was significantly more for the patients with morselized rib graft compared with those with structural grafts, 9° and 1°, respectively ($P < 0.05$).

Conclusions. The structural grafts placed in disc spaces below T12 were able to maintain sagittal alignment over this region, while the spines that received only morselized rib graft collapsed into kyphosis.

Key words: scoliosis, interbody, graft, anterior instrumentation. **Spine 2006;31:2337–2342**

Posterior instrumented fusion has been the standard treatment for spinal deformity since the advent of Harrington rods. For correction of thoracolumbar and lumbar scoliosis, anterior instrumented fusion has potential advantages, including fewer levels of fusion, better rotational correction, and preservation of posterior musculature.[1–5] The original anterior instrumentation systems such as Dwyer's cable and screws system had high pseudarthrosis, instrumentation failure, and reoperation rates.[6] In addition, anterior instrumentation and fusion has been shown to have a kyphosing effect on the instrumented segments.[1,4,5,7,8] It was the hope that, with the advent of modified anterior instrumentation systems, the latter problem could be avoided.

Structural grafts, such as interbody spacers, have become a popular adjuvant for the prevention of kyphosis through the instrumented segment. Some reports have shown that structural grafts are more effective in preserving sagittal alignment,[6] whereas others have found them to be no more effective than morselized rib graft.[9,10] The purpose of our paper was to determine if structural grafts were more effective than morselized rib graft in preventing kyphosis. We also report on pseudarthrosis, instrumentation failure, curve correction, and coronal and sagittal balance on 34 patients with adolescent thoracolumbar and lumbar scoliosis who underwent anterior instrumented fusion with a single solid rod, single screw construct.

Materials and Methods

From 1995 to 2001, 40 patients with a diagnosis of primary thoracolumbar and lumbar adolescent idiopathic scoliosis were treated by the three senior authors (B.J.F., M.P.G. and J.K.W.) at the same institution. Thirty-four patients with preoperative bending films and preoperative, postoperative, and at least 2-year follow-up anterior-posterior and lateral radiographs were included in this retrospective, sequential cohort study. Six patients were excluded because of incomplete records and inadequate follow-up. The average follow-up was 2.8 years (range, 2.0–5.5 years). The average age at operation was 15.8 years (range, 10.8–21.8 years). Three patients were over 18 years of age. They were included in the study because their curves had progressed while they were adolescents. The timing of surgery was delayed beyond the age of 18 years in 2 cases for the completion of schooling and in 1 case while on the waiting list for surgery. Thirty-one patients were female and 3 were male. The apex of the primary curve was between the T11–T12 disc and the vertebral body of L2 in all cases. The thoracolumbar curves had an apex between the T11–T12 disc and the L1 vertebral body and the lumbar curves had an apex between the L1–L2 disc and the L2 vertebral body. There were 11 left thoracolumbar and 11 right thoracolumbar curves and 8 left lumbar and 4 right lumbar curves. All curves were classified as Lenke Type 5. Specific preoperative coronal and sagittal measurements are included in Tables 1 and 2.

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Table 1. Coronal Radiographic Measurements

Primary Curve Cobb Angle	Morselized Rib (°)	Structural Graft (°)
Preoperative	48	52
Postoperative	16	13
Follow-up	18	16
Difference preoperative to follow-up	−30	−35
Secondary Curve Angle	**Morselized Rib (°)**	**Structural Graft (°)**
Preoperative	27	30
Postoperative	17	16
Follow-up	17	16
Difference preoperative to follow-up	−10	−14
Fractional Curve Angle	**Morselized Rib (°)**	**Structural Graft (°)**
Preoperative	14	12
Postoperative	1	−2
Follow-up	−3	−3
Difference preoperative to follow-up	−17	−14
Coronal Plumb C7–VCSL	**Morselized Rib (mm)**	**Structural Graft (mm)**
Preoperative	25	28
Postoperative	29	22
Follow-up	15	12
Difference preoperative to follow-up	−10	−16

Table 2. Sagittal Radiographic Measurements

Instrument Sagittal Angle	Morselized Rib (°)	Structural Graft (°)
Preoperative	−7	−1
Postoperative	7	2
Follow-up	9	8
Change preoperative to follow-up	16	9
T12–LIV Sagittal Angle	**Morselized Rib (°)**	**Structural Graft (°)**
Preoperative	−8	−4
Postoperative	−3	−4
Follow-up	1	−3
Change preoperative to follow-up	9*	1*
LIV–S1 Sagittal Angle	**Morselized Rib (°)**	**Structural Graft (°)**
Preoperative	−54	−49
Postoperative	−49	−43
Follow-up	−58	−48
Change preoperative to follow-up	−4	1
T12–S1 Sagittal Angle	**Morselized Rib (°)**	**Structural Graft (°)**
Preoperative	−62†	−53†
Postoperative	−52	−48
Follow-up	−57	−52
Change preoperative to follow-up	5	1
T5–HIV Sagittal Angle	**Morselized Rib (°)**	**Structural Graft (°)**
Preoperative	25	24
Postoperative	23	26
Follow-up	27	27
Change preoperative to follow-up	3	4
Sagittal Plumb C7–Sacrum	**Morselized Rib (mm)**	**Structural Graft (mm)**
Preoperative	−8	−4
Postoperative	32	23
Follow-up	7	−4
Difference preoperative to follow-up	15	−1
LID–A Sagittal Angle	**Morselized Rib (°)**	**Structural Graft (°)**
Preoperative	−10	−12
Postoperative	−9	−10
Follow-up	−9	−10
Difference preoperative to follow-up	0	2

*$P = 0.0398$, one-way ANOVA.
†$P = 0.0482$, one-way ANOVA.

Surgical Technique. All patients were treated with an identical anterior-only surgical technique. In general, levels within the primary curve, as measured by the Cobb method, were fused. If the disc adjacent to the curve did not horizontalize on concave bending films, it was also included in the fusion. After circumferential exposure of the vertebral bodies, thorough discectomies were performed. The entire anulus fibrosis and nucleus pulposus were removed back to, but not through, the posterior longitudinal ligament.

The most cephalad and caudad vertebra had a staple placed, and then all levels received a bicortical screw. The rotational alignment of the screws formed a relatively smooth arc, with the apex of the arc directed posteriorly; care was also taken to ensure coronal plane placement of the screws parallel to the lower endplate of each respective vertebra. This ensured maximum frontal plane corrective forces applied to the vertebra at the time of the cantilever and translation maneuver.

The use of structural cages as interbody spacers below T12 came into practice midway through this selection of patients. Before this, morselized rib graft was used to fill every disc space. The change in practice was due to both reports and the perception of the senior authors of increased kyphosis with anterior instrumentation. Structural cages, such as femoral ring allograft or Syncage (Synthes, Switzerland) or Moss Miami cage (Depuy Acromed, Raynham, MA), were used to preserve lordosis in levels below T12. Eighteen patients received only morselized rib graft and 16 patients a structural cage. Of the 16 patients, 12 received a cage at 1 level, 3 at 2 levels, and 1 at 3 levels. All other levels were filled with morselized rib graft.

A single solid 6-mm prebent rod was engaged in the proximal screw and then cantilevered into the distal screws. A mechanical persuader was used to help insert the rod into the screws. This device permitted the screw (and therefore vertebra) to be brought up and toward the rod (thus ensuring appropriate derotation of the vertebra) before securing the screw to the rod. After the rod captured all the screws, the rod was inspected to ensure it was in the appropriate sagittal alignment. If needed, the rod was rotated into proper alignment. Next, intersegmental compression was applied beginning at the apex and working toward the ends of the construct.

All patients were mobilized as tolerated after surgery. No patients were treated with a brace. Activity was restricted to walking for the first 6 weeks, followed by light aerobic exercises until 6 months, and return to full activity by 1 year, if the spine fusion appeared solid.

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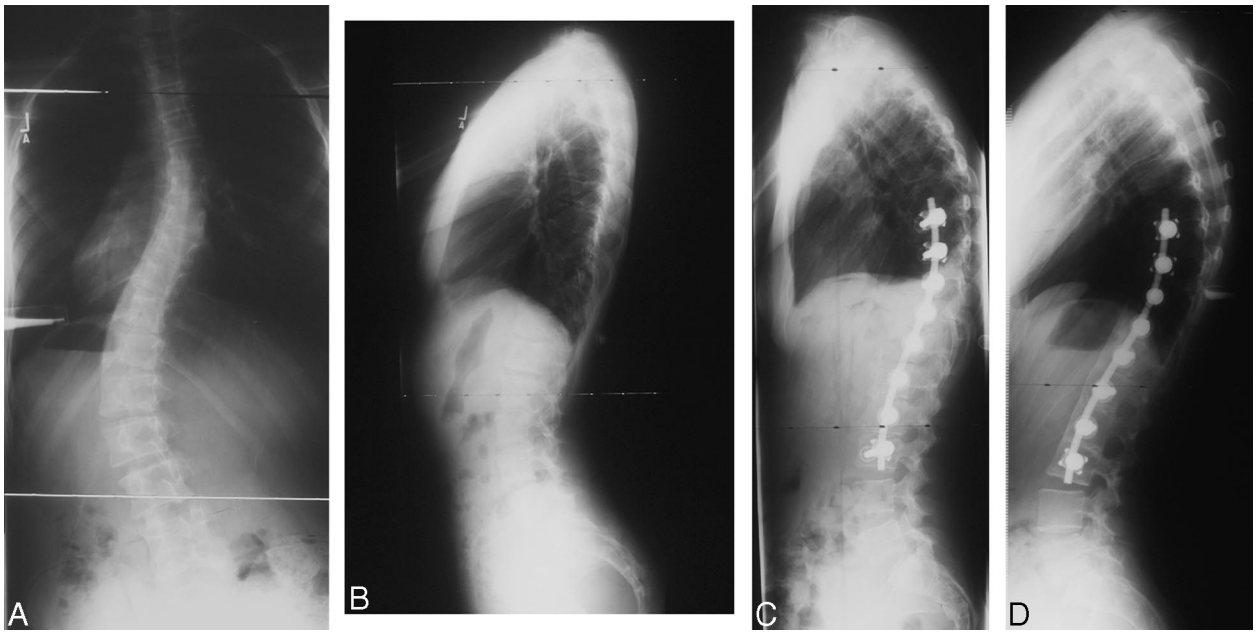

Figure 1. (**A**) Preoperative AP radiograph. Thoracolumbar primary curve with Cobb angle of 52° from T8–L3. (**B**) Preoperative lateral radiograph. Lordosis from T12–L3 (future LIV) is −16°, lateral plumb measures 36 mm, and lordosis below to be instrumented levels (LIV–S1) is −40°. (**C**) Postoperative lateral radiograph. There is a loss of lordosis from T12–LIV to −8°, the lateral plumb shifts anteriorly to 59 mm, despite increasing lordosis below the instrumentation to −51°. (**D**) Follow-up lateral radiograph. The lordosis from T12–LIV is −7°, the lordosis below the instrumentation increases to −61°, which shifts the lateral plumb posteriorly to 20 mm.

Radiographic Analysis. Standing long cassette anterior-posterior and lateral radiographs at preoperative, 1-week postoperative, and final follow-up of at least 2 years were measured by two authors (R.G.W., N.H.) not involved in the surgery. In addition, preoperative fulcrum bending radiographs were measured on each patient for each curve.

Anterior-posterior radiographs were used to measure Cobb angles of the primary thoracolumbar or lumbar curve, secondary thoracic curves, and fractional lumbosacral curve. Trunk shift was measured by lateral displacement (in millimeters) of the coronal plumb line from the seventh cervical spinous process to the vertical center sacral line. The measurement was recorded in absolute value on all radiographs.

Preoperative fulcrum bending films were used to measure the flexibility of the primary, secondary, and fractional curves. Lateral radiographs were used to measure sagittal Cobb angles for: T5 to the highest instrumented vertebra (HIV), the instrumented levels (HIV–LIV), and the lowest instrumented vertebra (LIV) to S1, T12 to LIV, and T12 to S1. When an endplate was not clearly visible within the instrumented levels, a perpendicular line from the anterior vertebral body was used and correlated with the preoperative association between the two. In addition, the adjacent disc angulation below the instrumentation was recorded. Disc angulation below the lowest instrumented vertebra was defined as the intersection in degrees of a line along the inferior endplate of the lowest instrumented vertebra with a line along the superior endplate to the next lower uninstrumented vertebra. Sagittal balance was determined by measuring anterior or posterior displacement of the C7 plumb line relative to the posterior superior corner of the first sacral vertebra. Sagittal balance was considered positive if anterior and negative if posterior to the sacral promontory.

An interbody space was considered fused if there was trabecular bone in continuity bridging between the adjacent vertebral endplates without radiolucency between either endplate or the interbody fusion mass.

Statistical analysis was performed using one-way analysis of variance and two–tailed paired sample *t* test.

■ Results

The datasets comparing patients with morselized rib *versus* structural grafts are located in Tables 1 and 2. We will discuss specific values of interest.

The initial preoperative lordosis from T12–S1 is significantly different between the 2 groups: −62° in morselized rib patients and −53° in structural graft patients ($P = 0.048$). No other preoperative values are significantly different, including T12–LIV.

Between preoperative and postoperative films, the primary Cobb angle shows greater correction for structural graft patients, 75% *versus* 67% ($P = 0.023$), and the sagittal alignment over the entire instrumented segment gains more kyphosis in rib patients, 14° *versus* 3° ($P = 0.035$). However, both of these findings are not statistically significant by final follow-up.

The increase in kyphosis from preoperative to follow-up radiographs of the angle between T12–LIV is significantly more for the patients with morselized rib compared with those with structural grafts, 9° and 1°, respectively ($P = 0.04$). The morselized rib patients tend to compensate for this increased kyphosis with hyperlordosis below the instrumentation more than the structural graft patients, −4° and 1°, respectively. Of note, the hyperlordosis does not occur at the disc immediately caudal to the instrumentation; the LID-A change from preoperative to follow-up is 0 for morselized rib patients and 2 for structural graft patients. Despite the tendency to offset kyphosis from T12–LIV with hyperlordosis below the instrumentation, the morselized rib patients still increase

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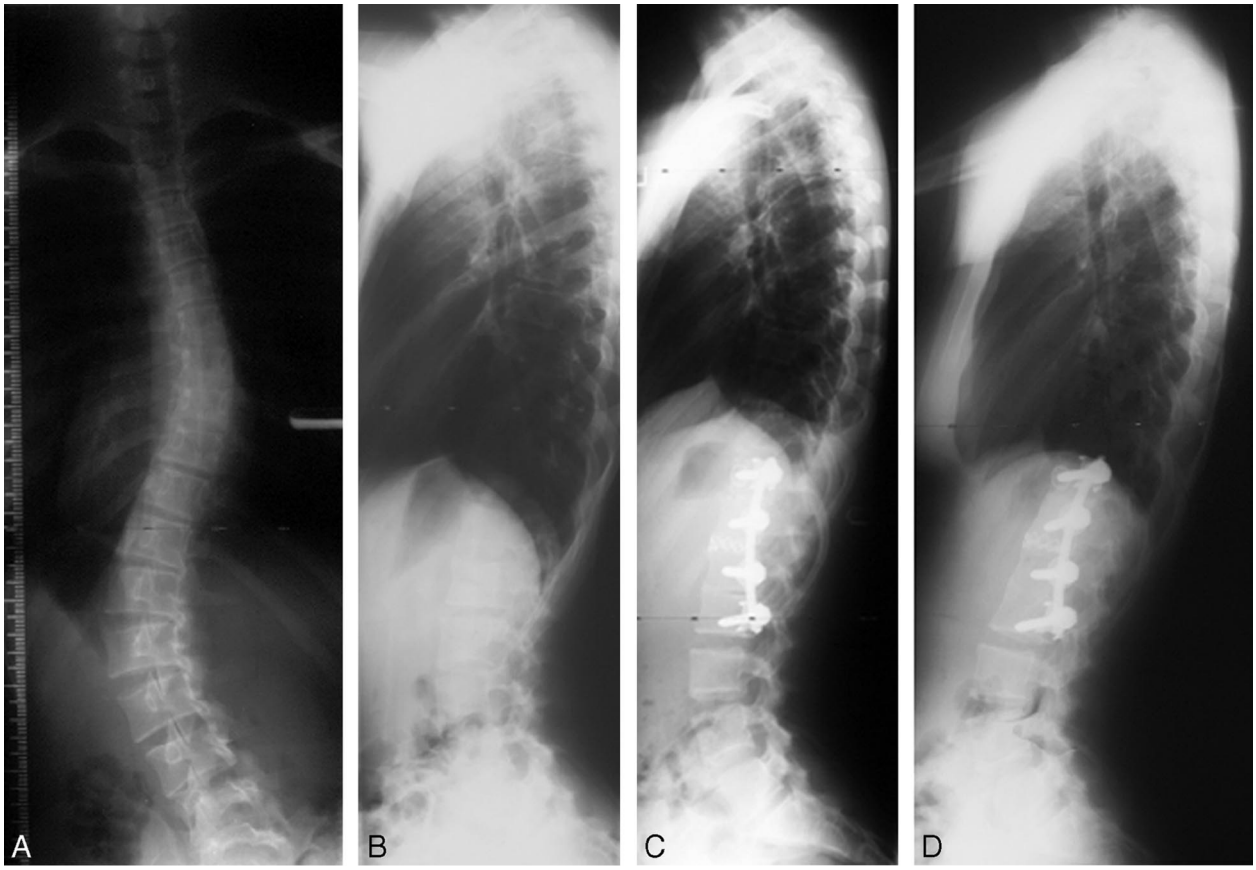

Figure 2. (**A**) Preoperative AP radiograph. Thoracolumbar primary curve with a Cobb angle of 48° from T11–L3. (**B**) Preoperative lateral radiograph. Lordosis from T12–L3 (future LIV) is −7°, lordosis below to be instrumented levels (LIV–S1) is −39°, and lateral plumb measures −10 mm. (**C**) Postoperative lateral radiograph. There is a loss of lordosis from T12–LIV to −1°, lordosis below the instrumentation remains at −41°, and lateral plumb shifts slightly anteriorly to −5 mm. (**D**) Follow-up lateral radiograph. The lordosis from T12–LIV is −4°, the lordosis below the instrumentation increases to −52°, and the lateral plumb shifts posteriorly to −36 mm.

their lateral plumb line from C7–S1 by 15 mm into forward balance from preoperative to follow-up, as compared with the decrease of 1 mm in structural graft patients. However, all three of these later findings were not statistically significant.

Examples of patients compensating for increased kyphosis between T12–LIV by hyperlordosing below the instrumentation are in Figures 1 and 2. Analysis of the two groups combined shows significant correction of the primary curve (65%, $P < 0.001$), secondary curve (43%, $P < 0.001$), and fractional curve (122%, $P < 0.001$) from preoperative to follow-up. Of note, the original correction of the primary curve from preoperative to postoperative was 71%. The loss of correction to settle at the follow-up average of 65% does show statistical significance ($P = 0.006$). On the other side, the fractional curve continued to reverse direction between postoperative and follow-up at a statistically significant rate, 0 to −3 ($P = 0.021$). There was no significant difference comparing the two groups in terms of correction of any of the curves from preoperative to follow-up.

The fulcrum bending correction index for the 2 groups combined was 100, which means the average follow-up Cobb measurement of the primary curve was equal to the average preoperative fulcrum bending film.

Six patients, four patients with morselized rib graft and two patients with structural graft, had radiographic pseudarthrosis. One patient, who received a structural graft, experienced instrumentation failure (1 of 34, 3%), in the form of distal rod breakage, requiring posterior fixation. There were no complications stemming from the anterior surgical approach.

■ Discussion

A common problem with anterior instrumented fusion for the correction of thoracolumbar and lumbar scoliosis is producing kyphosis across the instrumented segment.[1,4,5,7,8] Studies have shown that patients compensate by increasing lordosis caudal to the instrumentation.[10,11] This may cause excessive stress on the caudal segments leading to degeneration and chronic pain.[10,12]

Advances in surgical technique and instrumentation may prevent kyphosis through the instrumented segment. Interbody spacers are often used to preserve lordosis. Additionally, the use of dual semirigid rod, dual screw constructs has been shown to maintain sagittal alignment.

Brodner *et al*[2] reported on 11 patients (9 Lenke Type 5 curves and 2 Lenke Type 6 curves) treated with Kaneda anterior instrumented fusion with at least 15 months of follow-up. Cages or structural grafts were used at 7

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levels. The sagittal alignment over the instrumented segment did not change significantly.

Kaneda *et al*[3] reviewed 25 patients who underwent anterior correction of thoracolumbar and lumbar scoliosis with a dual-screw, dual-semirigid-rod system. Only 13 of these patients had adolescent idiopathic curves. The instrumented segment went from 7° kyphosis to 9° lordosis immediately postoperative. After an average follow-up of 3 years, the instrumented segment lost 1.5° lordosis to settle at 7.5° lordosis. The segment distal to the instrumentation went from 51° lordosis to 34° lordosis immediately postoperative. Unfortunately, they did not report the follow-up lordosis. However, the immediate postoperative results are similar to other studies in that as the instrumented segment became more lordotic; the segment distal to the instrumentation lost lordosis to compensate.[11,13–16]

Reports on the use of structural interbody grafts to prevent kyphosis across the instrumented segment have differed in their conclusions. Some authors have shown grafts help to maintain sagittal alignment,[6] while others have shown grafts to be no more effective than morselized rib allograft.[9,10]

Moe *et al*[6] produced an early report of the success of structural grafts in maintaining lordosis with anterior instrumentation for thoracolumbar and lumbar scoliosis. Thirty-one patients with an average age of 26 years (range, 10–62 years) with at least 1-year follow-up underwent anterior correction with Zielke flexible rod instrumentation. Fourteen patients received anterior wedge graft and 17 did not receive a graft. Kyphosis over the instrumented segment in patients with the graft decreased by 6°, from 12° preoperative to 6° follow-up. Kyphosis for the patients who did not receive a graft increased by 11°, from −1° preoperative to 10° follow-up. Although the 2 groups are difficult to compare because of differing preoperative values, the sum difference of 17° between the two groups was remarkable.

In 2001, Sweet *et al*[16] reported on 47 adolescent patients with thoracolumbar and lumbar scoliosis treated with single solid rod instrumentation (CD and Moss-Miami). All levels below T12 were filled with titanium structural interbody cages. They reported that the instrumented segment from T12 to LIV gained lordosis immediately after the surgery. The segment distal to the instrumentation lost lordosis, perhaps to compensate and maintain the overall lordosis relatively unchanged. By 2 years' follow-up, the instrumented segment lost some lordosis and the distal segment regained. Overall from preoperative to follow-up, the instrumented segment from T12–LIV gained 4° of lordosis and the segment distal to the instrumentation (LIV–S1) lost 4° of lordosis; therefore, the overall lordosis remained the same.

Ouellet *et al*[10] reported on 50 adolescent patients with thoracolumbar and lumbar scoliosis treated with Texas Scottish Rite Hospital single solid rod instrumentation. Eighteen patients received rib strut grafts as interbody spacers while the other 32 patients received only morselized rib autograft. Thirty-eight percent (19 of 50) of the total patients lost 10° or more in the sagittal plane from postoperative to follow-up. They did not find a correlation between strut grafts *versus* morselized rib in loss of correction. Overall, the instrumented segments gained 4° kyphosis from preoperative to follow-up, while the total lordosis from T12–S1 did not change. Most likely, the patients compensated for the increased kyphosis through the instrumentation with hyperlordosis caudally.

In 2003, Lowe *et al*[9] reported on 41 patients with thoracolumbar scoliosis treated with a single solid rod (Moss-Miami, CD Horizon, or M8) with an average 3-year follow-up. Twenty patients received morselized rib allograft and 21 patients received structural interbody grafts. Both groups maintained preoperative lordosis through the instrumented segments. Overall lordosis (T12–S1) slightly decreased in both groups but was not statistically significant.

A common trend in these studies is that the segments caudal to the instrumentation will compensate for changes in the sagittal alignment over the instrumented segments. If the instrumented segments fall into kyphosis, the distal segments hyperlordose. If the instrumented segments increase in lordosis, the distal segments will lose some lordosis.

In our study, we have shown that with a single solid rod, single screw system, structural interbody grafts maintain sagittal alignment better than morselized rib autograft. Analysis of the sagittal alignment from T12 to the lowest instrumented vertebrae is most relevant because this is where the structural grafts are used to prevent kyphosis. The patients who received morselized rib autograft fell into kyphosis over T12–LIV and tended to compensate with increased lordosis below the instrumentation. The patients who received structural interbody grafts maintained the T12–LIV sagittal alignment and tended to maintain the lordosis caudal to the instrumentation.

Increased lordosis beneath a kyphotic instrumented segment is not necessarily a benign development. Increased facet joint loading and increased peak posterior anular stresses may lead to premature segment failure.[10,12] Therefore, every effort should be made to maintain lordosis over the whole lumbar spine (including the instrumented sections).

A potential limitation to our study is that the initial preoperative lordosis from T12–S1 is significantly different between the two groups. However, no other preoperative values are significantly different, including T12–LIV which is the main area of our focus.

Primary curve correction for our combined group of patients (Cobb correction 65%) is comparable to other reported rates of 51% to 83%.[1–3,7–11,13,14,16] We did not find a statistically different amount of correction between the rib and graft patients.

A review of the literature shows instrumentation failure rates up to 10%,[10] screw pullout rates up to 27%,[6] and pseudarthrosis rates up to 30%.[10]

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Our study revealed 6 patients with radiologic evidence of pseudarthrosis (18%). Any patient with a radiolucent line at any disc space was considered a pseudarthrosis, even though clinically they may have been asymptomatic. One patient experienced instrumentation failure (3%) in the form of distal rod breakage, requiring posterior fixation.

■ Conclusion

Our results show that structural interbody grafts maintain sagittal alignment better than morselized rib autograft with the use of single solid-rod instrumentation.

■ Key Points

- Adolescents treated by anterior instrumented fusion with single solid rod, single screw constructs were assessed.
- Sixteen of the patients received structural grafts as interbody spacers below T12, while the other 18 patients received only morselized rib autograft.
- The structural grafts were able to maintain sagittal alignment better than morselized rib autograft.

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