SPINE Volume 32, Number 24, pp 2771–2776

Thoracolumbar Deformity Arthrodesis Stopping at L5

Fate of the L5-S1 Disc, Minimum 5-Year Follow-up

Craig A. Kuhns, MD,* Keith H. Bridwell, MD,† Lawrence G. Lenke, MD,†
Courtney Amor, BS,† Ronald A. Lehman, MD,‡ Jacob M. Buchowski, MD,†
Charles Edwards, II, MD,§ and Baldus Christine, RN†

Study Design. A retrospective long-term follow-up study.

Objective. Evaluate the fate of L5-S1 disc analyzing subsequent disc degeneration and associated risk factors for degeneration at minimum 5-year follow-up (average 9-year follow-up).

Summary of Background Data. Two previous studies reported the results of long deformity fusions terminating at L5 with minimum 2-year follow-up only.

Methods. Thirty-one consecutive patients with an average age of 45 years (range, 20–62 years) were fused from the thoracic spine to L5 and were evaluated at a mean follow-up of 9.4 years (range, 5–20.1 year). Patients were evaluated before surgery, after surgery, and latest follow-up with radiographs and Scoliosis Research Society Patient Questionnaire-24 scores. Disc degeneration using validated radiographic Weiner grades. Grade 0 to 1 discs were "healthy" and Grade 2 to 3 were degenerated. Patients with "healthy" discs preoperative that subsequently degenerated were designated subsequent advanced degeneration (SAD).

Results. Two out of 31 patients had preoperative advanced degeneration of the L5-S1 disc (Weiner grade 2–3). Three additional patients had an early revision to the sacrum secondary to sagittal imbalance not thought to be related to SAD. Twenty-six out of 31 patients were assessed as "healthy discs" preoperative (Weiner grade 0–1) and were evaluated for SAD. By latest follow-up, L5-S1 SAD developed in 18 of these 26 patients (69%). Risk factors for the development of SAD included long fusions extending into the upper thoracic spine down to L5 ($P = 0.02$) and having a circumferential lumbar fusion ($P = 0.02$). Although preoperative sagittal balance was not significantly different between the "healthy" and SAD group, sagittal balance at follow-up was: C7 plumb >5 cm in 67% of SAD patients and only 13% of "healthy" disc patients ($P = 0.009$). There was a trend toward inferior Scoliosis Research Society Patient Questionnaire-24 pain scores at follow-up in SAD patients (average score 4.1 *vs.* 3.4, $P = 0.13$). Eleven out of 30 patients (35%) had subsequent spinal surgery with 7 of 31 (23%) having extension of their fusion to the sacrum. An additional 6 of 31 (19%) were considered for extension to the sacrum but comorbidities precluded surgery (3 patients) or the patients declined further surgery (3 patients).

Conclusion. Advanced L5-S1 DDD developed in 69% of deformity patients after long fusions to L5 with 5 to 15 year follow-up. SAD frequently results in significant positive sagittal balance at a minimum 5-year follow-up. Long fusions to the upper thoracic spine down to L5 and circumferential fusion may further promote subsequent L5-S1 disc degeneration.

Key words: deformity, adjacent segment disease, fusion, instrumentation, revision surgery, outcomes measures. **Spine 2007;32:2771–2776**

Numerous studies report the results of long fusions for adult spinal deformity,[1–12] but the difficult decision of whether to stop the fusion at L5 or the sacrum remains controversial as documented in a recent debate by Polly *et al* published in *Spine*.[13] There is concern about stopping at L5 because of the potential for subsequent advanced L5-S1 disc degeneration developing, leading to pain and possibly a second surgery. Other concerns about stopping at L5 include the potential for distal screw loosening or loss of fixation because of the patulous nature of the L5 pedicle. This can lead to loss of correction as reported by Edwards *et al*[12] in their study of long adult deformity fusions stopping at L5.

Surgeons often choose to stop at L5 out of concern that fusing to the sacrum requires a more extensive dissection, it takes away the last remaining spinal motion segment which may alter biomechanics and it increases the potential for pseudarthrosis. Reasons surgeons favor fusing to the sacrum instead of stopping at L5 include (1) previous decompression at L5; (2) spondylolysis or listhesis at L5; (3) preoperative advanced disc degeneration at L5-S1.[11] The previously cited study by Edwards *et al*[12] evaluated the fate of the L5-S1 disc after long fusions stopping at L5 with a minimum 2-year follow-up, but the question of whether to stop at L5 or S1 persists.

Our study is an extension of the Edwards *et al*[12] study with longer term follow-up (minimum 5-year follow-up) of these patients with long fusions stopping at L5 in an attempt to further improve our understanding of the fate of the L5-S1 disc. The information gathered with longer follow-up can provide useful information for surgeons when deciding to stop a long fusion at L5 or the sacrum

From the *Department of Orthopaedic Surgery, University of Missouri, Columbia, Missouri; †Department of Orthopaedic Surgery, WA University School of Medicine, St. Louis, Missouri; ‡Department of Orthopaedics and Rehabilitation, Walter Reed Army Medical Center, Washington, DC; and §Maryland Spine Center, Mercy Medical Center, Baltimore, Maryland.
Acknowledgment date: October 19, 2006. First revision date: May 30, 2007. Second revision date: July 31, 2007. Acceptance date: August 2, 2007.
The manuscript submitted does not contain information about medical device(s)/drug(s).
No funds were received in support of this work. No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.
Address correspondence and reprint requests to Keith H. Bridwell, MD, Washington University in St. Louis, One Barnes-Jewish Hospital Plaza, Suite 11300 West Pavilion, Campus Box 8233, St. Louis, MO 63110; E-mail: bridwellk@wudosis.wustl.edu

and provide patients with information on what they might expect over time. In addition, this longer-term follow-up can provide useful information regarding complications, revision procedures, and outcomes measures. The authors' prestudy expectation was that the rate of subsequent advanced disc degeneration (SAD) would not increase with longer follow-up and that the C7 plumb relative to the sacrum would not change significantly with longer follow-up.

■ Materials and Methods

A prospectively collected patient database which includes all patients operated on by 2 senior surgeons at a single institution was searched for all adult ambulatory patients fused from the thoracic spine down to L5 from 1985 to 2000. The surgical database included all adult patients who had surgical fusion and instrumentation of the thoracic and lumbar spine. All patients were included in the current study if follow-up was a minimum 5 years from the time of surgery. All patients in the database had routine standing radiographs preoperative, immediately postoperative and at each follow-up, and Scoliosis Research Society Patient Questionnaire (SRS-24) and Oswestry questionnaires completed and at each of these time periods that were entered into the database prospectively. Patients were excluded if they had a previous decompression or fusion involving L5 or S1, radiographic evidence of sacralization of L5, or were diagnosed with a systemic neurologic or connective tissue disorder. A total of 38 potential patients were identified from the database. Two patients were deceased before having 5-year follow-up and 5 other patients did not have 5-year follow-up despite attempts to contact the patients by phone and having letters sent to their previously known address. Thirty-one patients met the inclusion criteria and were evaluated in this study whereas 34 patients were previously reported on in the Edwards *et al* study.[12] Thirty of the 31 patients in the current study were patients previously included in the Edwards *et al* study. One patient in the current study was not reported on in the Edwards *et al* study because of the inability to obtain minimum follow-up at the time of their reporting, but was obtained subsequently. Four patients from the Edwards *et al*[12] study were not included in the current study because of the inability to obtain minimum 5-year follow-up for the reasons mentioned.

In the current study, the average age at the time of surgery was 45 years old (range, 20–62 years). Twenty-eight out of 31 patients were women with 18 out of 31 being primary surgeries where 13 patients had a previous thoracic or lumbar spine surgery. The principle diagnosis prompting surgical intervention included adolescent or degenerative adult scoliosis (20 patients), sagittal imbalance related to flatback syndrome, post-traumatic kyphosis or postlaminectomy kyphosis (8 patients), and extension of a previous deformity fusion for adjacent segment degeneration without sagittal imbalance (3 patients). Nineteen patients underwent circumferential fusion procedures with the vast majority undergoing long circumferential fusions through a thoracoabdominal approach: T10-L5 (1 patient), T11-L5 (6 patients), T12-L5 (7 patients), L1–L5 (2 patients), L2–L5 (2 patients), L3–L5 (1 patient). Twelve patients underwent posterior only fusion. Twenty-six patients had hybrid segmental fixation constructs with proximal hooks and distal pedicle screws. Four patients had all screw constructs and 1 patient had an all hook construct.

Table 1. Radiographic Scoring System for Osteoarthritis of the Lumbosacral Spine Intervertebral Disc

Score	Characteristic
0	No degeneration, defined by normal disc height, no spur formation, no eburnation, no listhesis, no gas
1	Mild degeneration, defined by <25% disc space narrowing, small spur formation, minimal eburnation, no listhesis and no gas
2	Moderate degeneration, defined by 25% to 75% disc space narrowing, moderate spur formation, moderate eburnation, listhesis ≥3 mm and no gas
3	Advanced degeneration, defined by >75% disc space narrowing, large spur formation, marked eburnation, listhesis ≥5 mm, gas present

Degeneration severity was defined by the most severe radiographic component at a particular level.

Radiographic Analysis

Standing long cassette posterior-anterior and lateral radiographs from immediately before surgery, after surgery (1–6 weeks), and at latest follow-up were reviewed. A single observer (the lead author who is not one of the operating surgeons) recorded global and segmental coronal and sagittal measurements from each patient in the study. Global sagittal balance was measured by dropping a C7 plumb line from the middle of the C7 vertebral body and measuring the distance from the posterior superior cortical margin of the S1 vertebral body. This has been used because of the relative ease of identifying this location on S1.

L5-S1 disc degeneration was evaluated at each time point in the study using a radiographic classification system modified by Weiner *et al*.[12,14] Discs were graded from 0 to 3 using the characteristic appearance of the disc as delineated in Table 1. Each patient's radiographs were evaluated by 3 surgeons (not the operating surgeons) independently at each time point: preoperative, immediately postoperative, and at latest follow-up. When there was a discrepancy in grading of a particular disc which the reviewers conferenced, a consensus was achieved and the disc was graded accordingly. For the purpose of analysis, discs assessed as grade 0 (no degeneration) or grade 1 (mild degeneration) were considered "healthy" discs and those assessed as grade 2 or 3 (moderate to advanced degeneration) were considered to have "degenerated" discs. Those patients that before surgery had "healthy" L5-S1 discs that later developed "degenerated" discs were assessed as having SAD.

Loss of implant fixation at L5 was evaluated as had been done in the previous study by Edwards *et al*.[12] Postoperative and latest follow-up radiographs were critically compared to detect changes in implant position. If a change in implant position was noted then all interval postoperative radiographs were also examined for verification.

Statistical Analysis

An analysis of variance was used for each dependent variable comparing the preoperative radiographic data with that obtained at the various postoperative time points. An analysis of covariance was used to make specific comparisons of radiographic criteria at 2 time points. The Fisher exact test was used to compare dichotomous variables. Statistical significance was set at a $P < 0.05$ level.

■ Results

In the 31 patients evaluated in this study, the average follow-up was 9.4 years (range, 5–20.1 year). Patients had on average 10 levels (range, 5–15 levels) fused with most having a circumferential approach (23 of 31 patients) whereas 8 patients underwent a posterior only arthrodesis. For the 20 patients with significant coronal deformity, the average improvement in the main thoracic curve was 31% (15°) with an average preoperative Cobb of 52° (range, 40°–69°) and an average Cobb at follow-up of 37° (range, 7°–66°). The thoracolumbar/lumbar Cobb improved 33% (21°) with an average preoperative Cobb of 62° (range, 42°–82°) and an average Cobb at follow-up of 41° (range, 19°–72°). For the 7 patients with major sagittal imbalance, the average C7 plumb (as measured relative to the posterior superior aspect of the S1) improved from +101 mm (range, +66–165 mm) before surgery to 65 mm (range, +45–98 mm) immediately after the operation and +106 mm (−11 to +158 mm) at final follow-up. Seven patients underwent osteotomies as part of the arthrodesis to L5 to correct sagittal imbalance [pedicle subtraction (3 patients), posterior chevron (3 patients), and combined anterior/posterior (2 patients)]. The average sagittal C7 plumb measurement for the 7 patients who underwent osteotomies was +79 mm (range, +18 to 165 mm) before surgery, +39 mm (range, −33 to +85 mm) immediately after surgery and +75 mm (range, −33 to +158 mm) at the most recent follow-up.

Evaluation of L5-S1 Disc

The L5-S1 disc was analyzed for development of SAD. Two patients were excluded from this analysis secondary to having "degenerated" (grade 2) discs before surgery. These 2 patients were thought to be physiologically unlikely to successfully achieve a solid arthrodesis from the thoracic spine to the sacrum and therefore fusion was stopped at L5 with the knowledge that further degeneration of the L5-S1 disc was likely. Three other patients were excluded from the L5-S1 disc analysis because of early extension of their fusion to the sacrum: each of the 3 patients were noted to have significant sagittal imbalance in the early postoperative period with kyphosis at the L5-S1 disc. Twenty-six of the 31 patients underwent evaluation of the L5-S1 disc with an average follow-up of 9.5 years (range, 5–20.1 year). Sixty-nine percent (18 of 26) of the patients developed SAD (grade 2 or 3 discs) at L5-S1 with this minimum 5 year follow-up (Figure 1). Rapid development of SAD did occur, but more commonly there was a gradual progression of disc degeneration over many years.

Risk factors for the development of SAD were evaluated including age at the time of the index procedure, preoperative sagittal balance, length of the fusion, and whether a circumferential lumbar fusion made an impact on the development of SAD (Table 2). Un-like what was previously reported in the Edwards *et al*[12] study, age did not have a meaningful impact on the development of

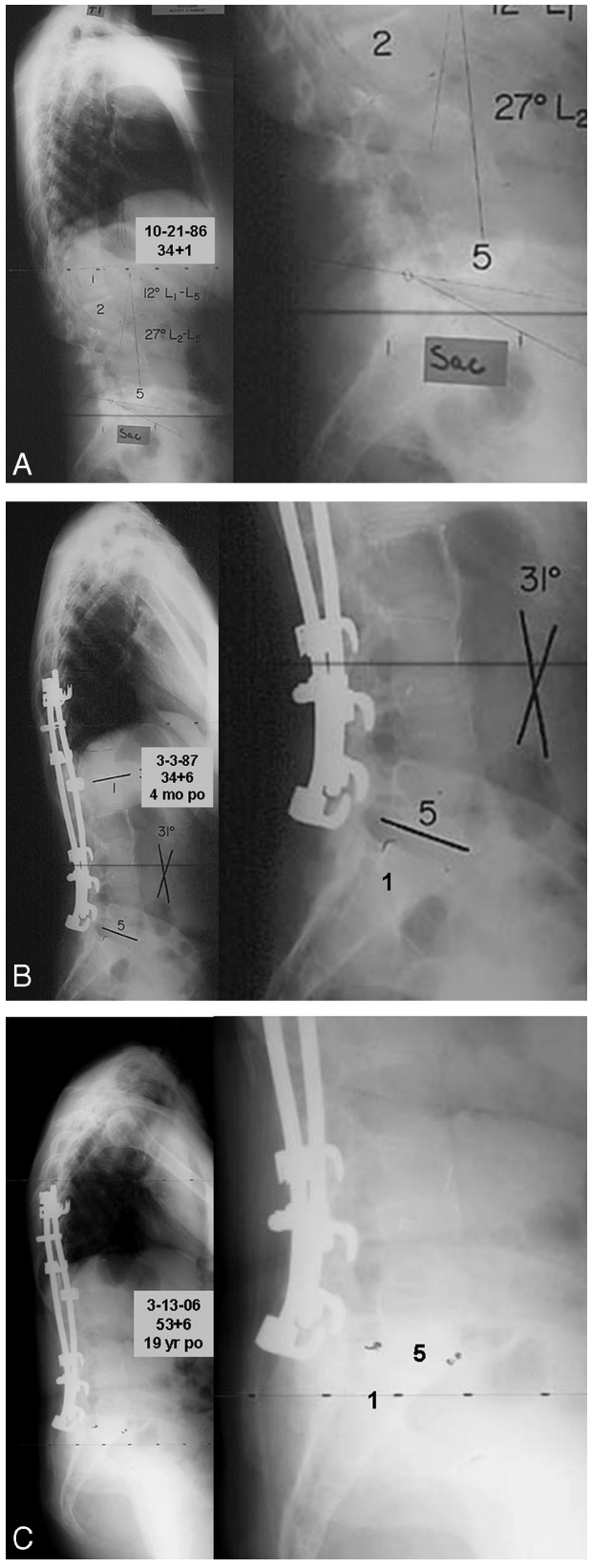

Figure 1. Case of SAD at long-term follow-up. **A**, Standing long cassette sagittal radiograph preoperative with cone down on L5-S1. **B**, Standing long cassette sagittal radiograph at 4 months postoperative with cone down on L5-S1. **C**, Standing long cassette sagittal radiograph at 19 years postoperative with cone down on L5-S1.

Table 2. Risk Factors Associated With SAD

	L5-S1 Disc
Length of fusion	
Long (T1–T7 down to L5)	72% SAD
Short (T8–T12 down to L5)	28% SAD
	$P = 0.02$
Fusion approach	
Circumferential lumbar fusion	87% SAD
Posterior only fusion	45% SAD
	$P = 0.02$

SAD in this study: average age in the "healthy" disc group was 48.1 and the average age in the SAD group was 44.3 ($P = 0.25$). Preoperative sagittal balance was also not predictive of SAD: average C7 plumb in the "healthy" disc group was +1.3 mm and the average in the SAD group was +3.2 mm ($P = 0.31$). Despite the finding that preoperative sagittal balance and the immediately postoperative sagittal balance were not different between the 2 groups, sagittal balance at latest follow-up was different between the "healthy" and SAD group (Table 3). Although age and preoperative sagittal balance were not associated with the development of SAD, "long fusions" (extending from T2-T7 down to L5) and circumferential lumbar fusion procedures were associated with the development of SAD (Table 2). Most of the patients with "long fusions" had an upper-instrumented vertebrae at or above T5 with only 1 patient at T7 and none at T6. Most of the patients with "short fusions" had a upper-instrumented vertebrae of T10, T11, or T12, with 2 patients at T9 and only 1 patient at T8. Twenty-six patients evaluated for SAD had a circumferential lumbar spine fusion with the vast majority of these anterior fusions extending from T11 or T12 down to L5. Two patients were fused anteriorly down to L4 and 1 patient was fused down to L3.

Outcomes Measures

SRS questionnaires were evaluated between the "healthy" disc group and the SAD group. There was no significant difference between the 2 groups before surgery, but at latest follow-up there was a trend toward improvement in the SRS-24—in the pain domain the "healthy" disc and the SAD group scores were 4.14 and 3.45, respectively ($P = 0.13$), and the total score in the "healthy" disc and SAD group were 4.20 and 3.71, respectively ($P = 0.15$). Oswestry scores were also evaluated and again there was no difference between the 2 groups before surgery (43.7 and 47.6, $P = 0.79$), but at latest follow-up there was a trend toward more improvement in the "healthy" disc than the SAD group Oswestry scores which were 17.7 and 29.6, respectively ($P = 0.21$).

Table 3. Sagittal Balance at Latest Follow-up

Average C7 plumb at latest follow-up	
"Healthy" group	0 mm
SAD group	+64 mm
	$P = 0.005$
Percent of patients with C7 plumb ≥5 cm at latest follow-up	
"Healthy" group	13%
SAD group	67%
	$P = 0.009$

Preoperative sagittal imbalance was not a risk factor for SAD.

Subsequent Surgeries

Eleven of the 31 patients (35%) in the study had a subsequent surgery of which 7 (7 of 31 or 23%) had their arthrodesis extended to the sacrum. Three of these 7 were revised secondary to early sagittal imbalance whereas the remaining 4 were revised secondary to the development of symptomatic advanced degeneration of the L5-S1 disc and sagittal imbalance. An additional 6 out of the 31 patients (19%) were noted to have symptomatic advanced degeneration of the L5-S1 disc with sagittal imbalance, but have not been revised: 3 of these 6 patients are being observed because of significant medical comorbidities whereas the other 3 patients declined further surgery. Four other patients had revision procedures but were not extended to the sacrum. One of these patients underwent 2 subsequent surgeries secondary to pseudarthrosis. One patient underwent early revision posterior spinal fusion for postoperative coronal decompensation. Another patient had a pedicle subtraction osteotomy secondary to postoperative flat back syndrome. The last patient developed a transition syndrome above the previous arthrodesis and had the fusion subsequently extended into the upper thoracic spine.

■ Discussion

The fundamental goals of adult deformity surgery are to maintain and/or restore optimal coronal and sagittal balance and alleviate symptomatic neural compression. At the current time, optimal coronal and sagittal balance in the adult deformity patient is achieved through arthrodesis procedures that eliminate spinal motion segments and increase the stress on the remaining motion segments. Surgeons are often faced with the decision of where to stop a long adult deformity arthrodesis: stop at L5, preserving the last motion segment (L5-S1) or extend the fusion to the sacrum. Previous studies have reported the challenges of long fusions to the sacrum, but few have reported on the results of stopping long fusions at L5.[2,3,12] Edwards *et al*[12] reported on the fate of the L5-S1 disc after long adult deformity fusions stopping at L5 with a minimum 2-year follow-up, but it is important to know what happens to that last remaining motion segment with longer term follow-up as most surgeons expect results that last much longer.

The purpose of this study was to provide a longer term analysis of the Edwards *et al*[12] study with a minimum 5-year follow-up. The goals of the current study were to further elucidate the fate of the L5-S1 disc by looking at the development of SAD and attempt to determine risk factors that might be important in developing SAD degeneration. It is also important to look at what subse-

quent surgeries might be expected in this patient population over time. This long-term follow-up study is essential given the fact that it is usually the goal of the surgeon and the patient for the surgical treatment to be successful well beyond the 5 year mark.

Edwards *et al*[12] reported SAD developing at L5-S1 in 61% of the patients after long fusions stopping at L5 with an average 5.6 year (range, 2.1–14.3 year) follow-up. Using the same inclusion criteria for the SAD analysis as the Edwards *et al*[12] study, the rate of SAD in our study demonstrated an overall SAD rate of 72% with an average 9.4 year (range, 5.0–20.1 year) follow-up. There were 3 patients included in the SAD analysis by Edwards *et al*[12] that had early revision secondary to early sagittal imbalance and therefore we excluded these 3 patients from the minimum 5-year SAD analysis. The acute sagittal decompensation observed in these 3 patients occurred within the first 12 months after the surgical procedure performed to L5. Although the decompensation occurred because of additional acute kyphosis at L5-S1, we did not consider this change to be attributable to advanced disc degeneration at L5-S1 *per se*. With these 3 patients excluded from the Edwards *et al*[12] study, 57% (16 of 28) of patients developed SAD instead of the 61% that was reported in their study. In our current study, with the same 3 patients excluded because of the early sagittal imbalance, SAD developed in 69% (18 of 26) of patients. This translates to an additional 12% of patients developing advanced degeneration at the L5-S1 disc with an average 3.8 years more follow-up. This clearly demonstrates that we can expect marked L5-S1 disc degeneration in the majority of our patients with long fusion to L5 if we follow them long enough. The main finding between minimum 2-year follow-up and subsequent minimum 5-year follow-up was not only further degeneration of the L5-S1 segment, but most importantly the development of increasingly positive sagittal balance. If degeneration occurs at the L2–L3 disc below a long fusion that stops at L2, the patient may have back pain but will probably be able to compensate through multiple segments below. However, when disc degeneration advances at L5-S1, there is no capacity for the patient to compensate through other mobile segments, therein, sagittal imbalance is very likely to be the ultimate outcome.

Subsequent surgeries are fairly common in this group of adult deformity patients with long fusions down to L5 with a minimum 5-year follow-up: 35% (11 of 31) of the patients. In the current study 23% (7 of 31) of the patients were revised with extension of their fusion to the sacrum which is nearly twice as many patients when compared with that in the Edwards *et al*[12] study where 12% (4 of 34) were revised to the sacrum. Defining the "revision rate" after these long fusions stopping at L5 is difficult to accurately address because an additional 19% (6 of 31) patients in the current study were considered for revision to the sacrum because of symptomatic L5-S1 SAD and sagittal imbalance: 3 had medical comorbidities which precluded this treatment option and 3 other patients declined subsequent surgery despite having advanced L5-S1 disc degeneration, positive sagittal imbalance, and pain localized to the lumbosacral region. No known infections or significant neurologic deficits occurred in the group of patients studied. Complications defined as a subsequent surgery occurred in 11 patients as previously mentioned with 7 being revised to the sacrum. Four other patients had revision surgery for the following diagnosis: pseudarthrosis (1 patient), flatback (1 patient), coronal imbalance (1 patient), and transition syndrome above the previous fusion (1 patient). Loss of L5 implant fixation as defined by Edwards *et al*[12] was noted in the same 6 patients without any changes in their findings now with a minimum 5-year follow-up. Four patients had early loss of L5 implant fixation that stabilized and seems to be without clinical significance. As they reported, 2 patients had early revision surgery related to the loss of fixation. Deep seating of L5 within the pelvis still seems to be a significant risk factor for L5 implant loosening and needs to be considered.

The most significant objective clinical manifestation of developing SAD was the development of a forward shift in sagittal balance. Patients in the SAD group had an average C7 plumb at follow-up of +64 mm whereas the "healthy" L5-S1 disc group C7 plumb was 0 mm ($P = 0.005$). The SAD group also had a significantly greater percentage of patients at follow-up with marked sagittal imbalance ($\geq$+50 mm): 67% of SAD patients and only 13% of the "healthy" L5-S1 group ($P = 0.009$). Patient related pain was evaluated with the SRS-24 Pain domain and only demonstrated a trend toward increased pain in the SAD group relative to the "healthy" L5-S1 group (4.1 and 3.4, respectively, $P = 0.13$). Oswestry disability index scores did not demonstrate a significant difference between the 2 groups at follow-up: SAD group 29.6 and "healthy" group 17.7, $P = 0.21$, respectively.

Potential risk factors for the development of SAD included long fusions extending into the upper thoracic spine down to L5 and having a circumferential fusion procedure. Examination of the length of the fusion as a potential risk factor for promoting L5-S1 disc degeneration demonstrated that 28% of the patients with "short fusions" (T8–T12 down to L5) demonstrated SAD whereas 72% of the patients with "long fusions" (T1–T7 down to L5) demonstrated SAD ($P = 0.02$). Our prestudy hypothesis was the relatively longer lever arm associated with longer fusions (from the upper thoracic spine as opposed to from the distal thoracic or upper lumbar spine) would not lead to more stress and more subsequent disc degeneration at L5-S1. This hypothesis was statistically refuted. It intuitively makes more sense that a 12 or 13 segment fusion would put more stress on L5-S1 than a 5 to 7 segment fusion. Also, with a longer fusion there are fewer mobile segments above through which the patient might be able to maintain sagittal balance. Given this association between "long fusions" and

increased SAD at L5-S1, surgeons might be more inclined to stop at L5 with a short fusion than a long fusion where fusing to the sacrum might be a better option. Further examination of what characteristics of the arthrodesis may contribute to promoting advanced L5-S1 disc degeneration led us to analyze whether a circumferential fusion had an affect on the rate of SAD. Eighty-seven percent of the patients who underwent a circumferential lumbar fusion developed SAD whereas only 45% of the patients in the posterior only group developed SAD ($P = 0.02$). Many have hypothesized that a circumferential fusion creates a stiffer construct than a posterior only fusion and therefore we expected that a circumferential fusion might distribute more stress on the remaining L5-S1 motion segment leading to earlier disc degeneration. The effect of a 1 or 2 level distal anterior fusion (at L4–L5 alone or L3–L4 and L4–L5) was not evaluated in this study as nearly all of the patients in this study had multilevel anterior fusions through a thoracoabdominal approach. Based on this data, we believe that it is advisable to avoid multilevel anterior surgery if trying to stop a long fusion at L5. Although we do find great utility in circumferential fusion procedures, because of enhanced fusion rates and improved deformity correction, now we rarely find multilevel anterior procedures necessary when trying to stop a fusion at L5.

Age and preoperative sagittal balance were noted to be risk factors for the development of SAD in the Edwards *et al*[12] study, but were not associated with an increased risk of SAD in the current study. Two of the 3 patients which were dropped from the SAD analysis in the current study were under the age of 50 and if included in this analysis of SAD would have led to younger age being a statistically significant risk factor for developing SAD.

■ Conclusion

Long adult deformity fusions down to L5 were associated with a high rate of subsequent advanced degeneration of the L5-S1 disc. Subsequent advanced degeneration of the L5-S1 disc was associated with loss of lordosis at that disc level and positive sagittal balance. Longer fusions that extended from the upper thoracic spine and circumferential lumbar fusions predisposed to subsequent degeneration of the L5-S1 disc after deformity fusion to L5.

■ Key Points

- SAD at L5-S1 developed in 69% of deformity patients after long fusions to L5 with 5 to 20 year follow-up.
- The development of SAD at L5-S1 was highly correlated with the development of positive sagittal balance.
- Twenty-three percent of the patients fused to L5 were subsequently revised to the sacrum, but this underestimates the number of patients who actually developed symptomatic L5-S1 subsequent disc degeneration.
- Long fusions that extend from the upper thoracic spine down to L5 were associated with a higher rate of subsequent L5-S1 disc degeneration when compared with patients that were fused from the lower thoracic spine to L5.
- Circumferential lumbar fusions were associated with a higher rate of L5-S1 SAD when compared with posterior only fusion.

References

1. Balderston RA, Winter RB, Moe JF, et al. Fusion to the sacrum for nonparalytic scoliosis in the adult. *Spine* 1986;11:824–9.
2. Edwards CC, Bridwell KH, Patel A, et al. Long adult deformity fusions to L5 and the sacrum: a matched cohort analysis. *Spine* 2004;29:1996–2005.
3. Eck KR, Bridwell KH, Ungacta FF, et al. Complications and results of long deformity fusions down to L4, L5 and the sacrum. *Spine* 2001;26E:182–92.
4. Emami A, Deviren V, Bradford DS, et al. Outcome and complications of long fusions to the sacrum in adult spine deformity: Luque-Galveston, combined iliac and sacral screws, and sacral fixation. *Spine* 2002;27:776–86.
5. Grubb SA, Lipscomb HJ, Suh PB. Result of surgical treatment of painful adult scoliosis. *Spine* 1994;19:1619–27.
6. Horton WC. Fusion of L5-S1 in adult scoliosis. *Spine* 1996;21:2520–1.
7. Kostuik JP. Treatment of scoliosis in the adult thoracolumbar spine with special reference to fusion to the sacrum. *Orthop Clin North Am* 1988;19:371–81.
8. Kostuik JP, Musha Y. Extension to the sacrum of previous adolescent scoliosis fusion in adult life. *Clin Orthop Relat Res* 1999;364:53–60.
9. Kuklo TR, Bridwell KH, Lenke LG, et al. Minimum 2-year analysis of sacropelvic fixation and L5-S1 fusion using S1 and iliac screws. *Spine* 2001;26:1976–83.
10. Ponder RC, Dickson JH, Harrington PR, Erwin WD. Results of Harrington instrumentation and fusion in the adult idiopathic scoliosis patient. *J Bone Joint Surg Am* 1975;57:797–801.
11. Bridwell KH. Osteotomies for fixed deformities in the thoracic and lumbar spine. In: Bridwell KH, Dewald RL, eds. *The Textbook of Spinal Surgery*. 2nd ed. Vol. 1. Philadelphia, PA: Lippincott-Raven; 1997:821–35.
12. Edwards CC, Bridwell KH, Patel A et al. Thoracolumbar deformity arthrodesis to L5 in adults: the fate of the L5-S1 disc. *Spine* 2003;28:2122-2131.
13. Polly DW, Hamill CL, Bridwell KH. Debate: To fuse or not to fuse to the sacrum, the fate of the L5-S1 disc. Spine 2006;31(suppl):179–84.
14. Weiner DK, Distill B, Studenski S, et al. Does radiographic flexibility correlate with flexibility of the lumbar spine? *J Am Geriatr Soc* 1994;42:257.