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Late Complications of Adult Idiopathic Scoliosis Primary Fusions to L4 and Above

The Effect of Age and Distal Fusion Level

Anthony Rinella, MD, Keith Bridwell, MD, Yongjung Kim, MD, Jonas Rudzki, MD, Charles Edwards, MD, Michael Roh, MD, Lawrence Lenke, MD, and Annette Berra, BA

Study Design. A retrospective analysis of primary cases of adult idiopathic scoliosis treated with long instrumented fusions from the thoracic spine proximally to segments that range from T11 to L4 distally.

Objective. To analyze whether patients requiring revision surgery had lower postoperative SRS-24 scores; age ≥40 years correlated with higher rates of revision surgery; disc degeneration below the fusion occurred more commonly with a more distal lowest instrumented vertebra or older patient age (≥40 years); and whether smokers had higher rates of major complications or revision surgery.

Summary of Background Data. Few reports describe complications related to primary long fusions using modern 2+ rods, hook/pedicle screw instrumentation methods in the treatment of adult idiopathic scoliosis.

Methods. Sixty-seven patients were analyzed with an average age of 38.8 years (range 21–61 years). The average clinical follow-up was 7.8 years (range 2–16 years): 42 patients had >5 years follow-up, including 23 patients with >10 years follow-up. Patients were categorized by age (< or ≥40 years) and level of the lowest instrumented vertebra (T11–L2 *vs.* L3–L4). Upright radiographs and postoperative SRS-24 questionnaires from the latest follow-up date were analyzed.

Results. Patients requiring revision surgery had lower total score (average 72.0) than those that did not (total score = 94.2; P = 0.01). More specifically, patients with pseudarthrosis had lower total scores (average 74.7) than those without (average total score = 93.5; P = 0.02). When analyzing age, there were similar rates of pseudarthrosis, but higher rates of transition syndrome (2) and sagittal/coronal imbalance (1 each) in patients ≥40 years. Subsequent distal disc degeneration did not correlate significantly with more distal lowest instrumented vertebra or older patient age. Smokers did not have higher rates of major complications or revision surgery than nonsmokers.

Conclusions. Patients with adult idiopathic scoliosis and long fusions had similar pseudarthrosis rates, but higher rates of transition syndrome when lowest instrumented vertebra was L3–L4 relative to levels T11–L2. When categorized by age, complication rates were similar in each group. Patients with pseudarthroses or other diagnoses requiring revision surgery had lower SRS-24 total scores than those without (P = 0.02 and P = 0.01, respectively). [Key words: complications, primary fusions, adult idiopathic scoliosis] **Spine 2004;29:318–325**

The decision of fusion levels in the surgical treatment of adult idiopathic scoliosis (AIS) is often complex and based on a number of factors: sagittal and coronal balance, the degree and pattern of degenerative changes or neurologic compromise, as well as the patient's overall health, symptoms, and expectations. Several studies have delineated patient outcomes—often in the form of pain or functional assessments[1–3]—and complication rates. These studies are frequently based on experience with Harrington instrumentation[4–7] or mix various diagnoses[8] or treatment type[9] (primary *vs.* revision, *etc.*). There is some evidence that long fusions to more distal lumbar levels increases the likelihood of complications, especially with fusions to L5 or S1.[10–12] All of these factors make extrapolation of conclusions to more modern 2+ rod-segmental hook/screw constructs difficult.

In order to study a relatively homogenous group, we chose to assess patients with adult scoliosis after primary instrumented fusions from the thoracic spine proximally to segments ranging from T11 proximally to L4 distally. The following hypotheses were made and tested:

1. Patients with pseudarthrosis or other diagnoses requiring revision surgery will have lower postoperative SRS-24 scores in all domains relative to patients not requiring revision surgery.
2. Major long-term complications requiring revision surgery will be more likely in older patients (≥40 years) than younger patients.
3. Subsequent disc degeneration below the fusion will:
   a. Have a higher incidence in patients with more distal lowest instrumented vertebra (LIV);
   b. Be more likely in older patients (≥40 years).
4. Smokers will have a higher rate of major complications and revision surgery than nonsmokers.

From the Department of Orthopaedic Surgery, Washington University School of Medicine, St. Louis, Missouri.
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Address correspondence and reprint requests to Keith Bridwell, MD, Washington University School of Medicine, Department of Orthopaedic Surgery, One Barnes-Jewish Hospital Plaza, Suite 11300 WP, Campus Box 8233, St. Louis, MO 63110, USA; E-mail: bridwellk@msnotes.wustl.edu

Materials and Methods

Seventy-seven patients with AIS that underwent primary spinal fusions from the thoracic spine proximally to segments ranging from T11 to L4 distally were identified from a computerized patient database that was generated over a 15-year time period. All surgeries were performed by one of two spine surgeons at the same university hospital between 1986 and 2000. Inclusion criteria were: 1) age >21 years at the time of surgery; 2) no prior spinal surgery; 3) fusions including at least 6 vertebral segments; 4) scoliosis of idiopathic etiology; 5) more than 2-year minimum follow-up; and 6) 2+ rod with segmental hook or pedicle screw instrumentation. Patients were included in the study if a complete set of radiographs and/or postoperative SRS-24 questionnaire data were available. One patient was excluded due to death on the day of surgery due to an intracerebral air embolus. Nine patients were excluded due to insufficient follow-up radiographs or postoperative SRS-24 questionnaire data.

Hospital records and surgeon's office notes were reviewed, specifically noting patients' medical and surgical histories, medical comorbidities, major and minor complications, and smoking status. Operative notes were reviewed in each case. Major long-term complications were pseudarthrosis or loss of fixation requiring revision surgery, deep infection, transition syndrome requiring revision surgery, and symptomatic instrumentation requiring complete instrumentation removal. A diagnosis of pseudarthrosis was made when there was radiographic evidence of implant failure accompanied by loss of correction. Because loss of correction was implicit to the diagnosis, patients with pseudarthrosis were not further listed in the radiographic descriptions as having radiographic imbalance. A diagnosis of transition syndrome implies significant disc degeneration adjacent to the instrumented levels, either proximally or distally. (Usually a 10° increase in segmental kyphosis and/or a 5 mm reduction in anterior disc height.) Only cases of transition syndrome that led to revision surgery due to persistent pain or neurologic compromise were considered major complications. Minor complications were asymptomatic instrumentation failure (without loss of correction) and prominent implants requiring partial removal.

The LIV in each case was calculated by a number of factors: sagittal and coronal balance, the degree and pattern of degenerative changes or neurologic compromise, as well as the patient's overall health, symptoms, and expectations. In most cases, this was a stable (intersected by the central sacral line) and neutral segment that was amenable to horizontalization with surgical instrumentation (based on analysis of standing and flexibility radiographs) and without apparent disc degeneration below. Decisions about whether to perform a posterior and/or anterior procedure were made on an individual basis without predetermined algorithms. Similarly, decisions about the type of implants used reflect the availability of various technologies (*e.g.*, thoracic pedicle screws), surgeon preference, and patient anatomy.

For statistical comparisons data were analyzed using the Statistical Analysis System (version 8.2, S.A.S. Institute, Inc., Cary, NC). Fisher exact test was used to evaluate the likelihood of smokers *versus* nonsmokers having pseudarthrosis or other major complications requiring revision surgery.

Radiographic Analysis. Standing long-cassette anteroposterior and lateral radiographs were reviewed in the immediate preoperative, immediate postoperative (1–6 weeks), and final postoperative follow-up periods. All cases were reviewed by two independent reviewers (A.R. and J.R.) who did not include the operating surgeons. In cases where fusions were later extended to L5 or the sacrum, radiographic measurements were based on radiographs before the revision. Measurements were only obtained if complete radiographs in each of the three time periods were available. Measurements included all thoracic and lumbar curves greater that 10° in magnitude in both the sagittal and coronal planes. Global balance was assessed by reviewing the C7 plumb line intersection with the sacrum in the sagittal and coronal planes. Sagittal measurements were based on the C7 plumb line intersection with the posterior aspect of the S1 superior endplate. Measurements were considered positive if the C7 plumb line intersected the sacrum anterior to this point and negative if the intersection was posterior to this point. Measurements greater than 5 cm in the positive direction were considered to have sagittal imbalance. In each case, the arm position remained constant in either the crossed-chest position or arm-extended positions. Similarly, coronal balance was based on the C7 plumb line intersection with the center of the superior S1 endplate. Measurements more than 3 cm from this point in either direction were noted to have radiographic coronal imbalance.

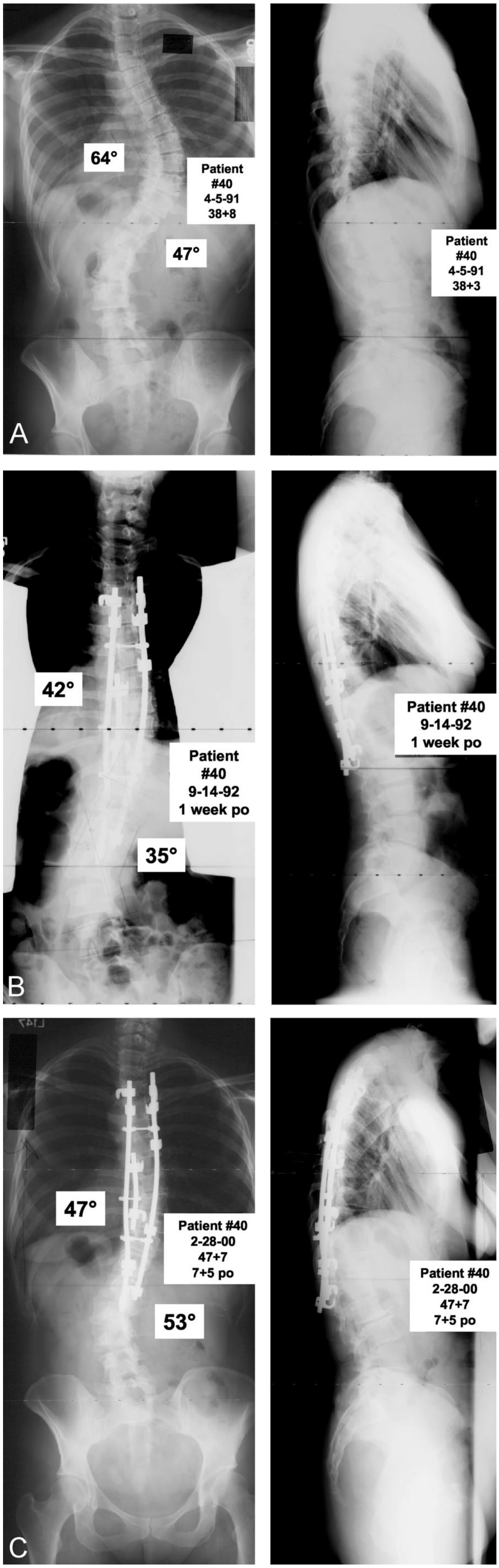
Table 1. Radiographic Scoring System for Osteoarthritis of the Lumbosacral Spine Intervertebral Disc, Modified From Weiner *et al.*[19]

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%–75% disc space narrowing, moderate spur formation, moderate eburnation, listhesis ≥3 mm, and no gas
3	Advance degeneration, defined by >75% disc space narrowing, large spur formation, marked eburnation, listhesis ≥5 mm, gas present

Note: degeneration severity is defined by the most severe radiographic component at a particular level.

To assess disc degeneration below the fusions, two independent reviewers other than the operating surgeons assessed the remaining discs based on the system proposed by Weiner *et al.*[13] The scoring system has four grades: 0 = no degeneration, 1 = mild degeneration, 2 = moderate degeneration, and 3 = advanced degeneration (Table 1). In addition to the criteria included by Wiener *et al*,[13] the presence of sagittal listhesis is added to further define the progression of degeneration as described by Edwards *et al.*[14] The severity of degeneration was defined by the most severe component at a particular level. For example, if there is moderate spur formation but less than 25% disc narrowing, a score of 2 is assigned. Radiographic assessment of disc degeneration was made for the immediate postoperative and latest follow-up time periods. In order to assist with objective assessment of the discs, the anterior and posterior disc height were measured and recorded on the radiograph by the first reviewer.

Correlations of disc ratings between reviewers were performed to assess interobserver variability. Discs were also studied for patterns in relation to the LIV (for example, directly below the fusion, two levels below, *etc.*). Intraclass correlation coefficients were calculated to analyze interobserver variability in the two major time periods (immediate postoperative and



final postoperative periods). The Kruskal-Wallis test was used to calculate *P* values for patterns of degeneration below the LIV as described above.

"Mean disc degeneration values" were calculated for each patient and categorized by patient age at the time of surgery and LIV. Mean disc degeneration values were used instead of individual values in order to compare patients with each of the six potential LIVs (from T11 to L4). The values were calculated by adding the individual disc degeneration ratings for each disc below the fusion and dividing the sum by the number of discs included. Individual disc degeneration values were also analyzed to seek patterns of degeneration (*e.g.*, one level below the fusion, two levels below, *etc.*) Wilcoxon test generated *P* values for comparisons of individual LIV groups, and for comparisons of Group 1 (combined data for LIVs T12–L2) and Group 2 (combined data for LIVs L3–L4). Spearman correlation coefficients were used to correlate continuous variables such as age at the time of surgery and length of follow-up to patients' mean disc degeneration values for each observer.

Outcomes Assessment. Patients with and without complete radiographs were included for outcomes assessment based on the Scoliosis Research Society's SRS-24 questionnaire. Our research staff attempted to contact all patients that had not filled out the questionnaire in the past calendar year. Complete questionnaire data were available for 56 patients. All patients with major and minor complications except one (left-sided distal hook dislodgement 3 months after surgery that required revision) provided SRS-24 data. All radiographic coronal or sagittal imbalances were included. The seven domains as proposed by Haher *et al*[15] were reduced to four domains (in accordance with the Asher *et al*[16] recommendations) to include pain, self image, function, and satisfaction. Questionnaire data were compared based on age, LIV, and presence of a major complication and radiographic imbalance (coronal imbalance >3 cm or positive sagittal balance >5 cm).

For our statistical analysis, *P* values were generated using the Kruskal-Wallis test to compare SRS-24 scores in each domain and total score in groups of patients categorized by the individual LIVs. The Wilcoxon test was used to compare SRS-24 outcomes of patients with pseudarthrosis and other major complications requiring revision surgery.

Study Groups. Patients were divided into two major groups based on age at the time of surgery and LIV. When categorizing patients by age, Group A included 36 patients <40 years of age. Group B included 31 patients ≥40 years of age. Patients were also analyzed based on LIV: Group 1 included 32 patients with LIV T11–L2, and Group 2 included 35 patients with LIV L3–L4. Patients were also analyzed based on each individual LIV. From a statistical perspective, the Wilcoxon test generated *P* values when comparing Groups A and B and Groups 1 and 2.

Figure 1. **A,** Standing long cassette coronal and sagittal radiographs before surgery. **B,** Long cassette coronal and sagittal radiographs done at 1 week postop. **C,** Long cassette coronal and sagittal radiographs done at 7.5 years postop showing progression of the lumbar deformity in both the coronal and sagittal planes. Particularly note the subsequent disc degeneration throughout the lumbar spine and segmental kyphosis from T12–L4.

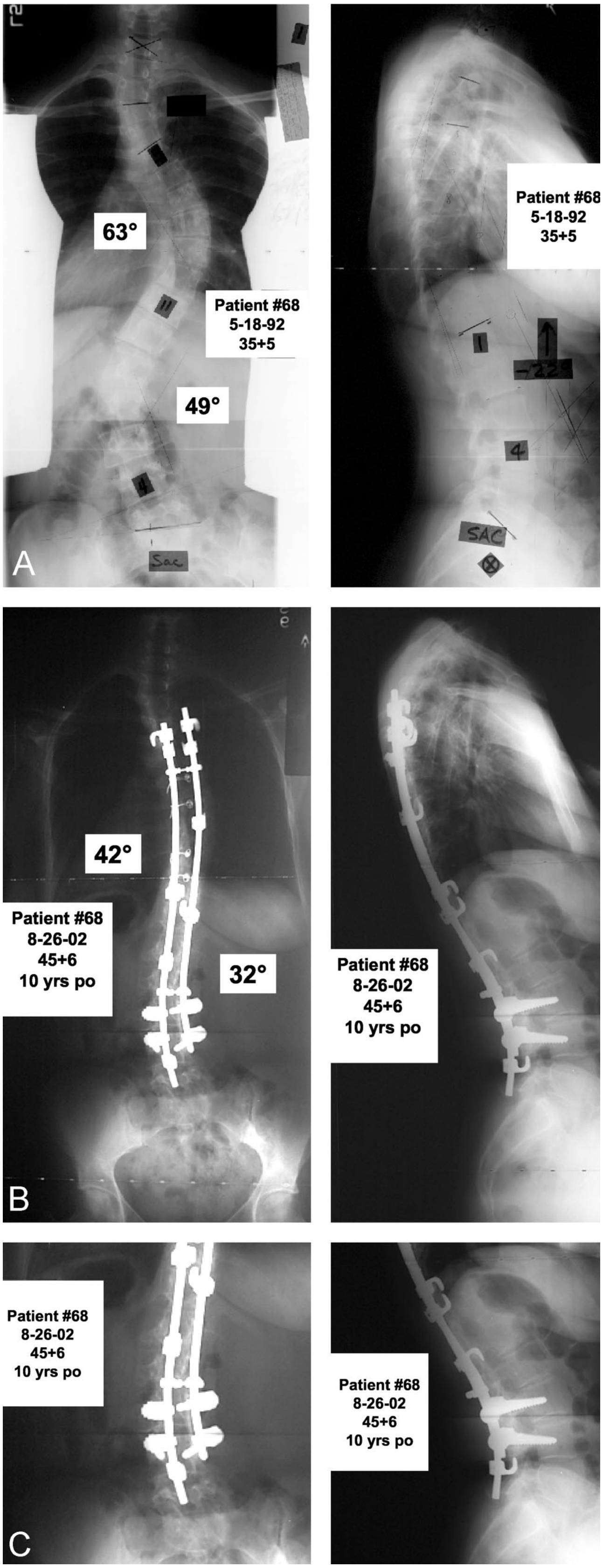


Figure 2. **A,** Standing long cassette coronal and sagittal radiographs before surgery. **B,** Standing long cassette coronal and sagittal radiographs 10 years postop. **C,** Coned down standing coronal and sagittal radiographs at ultimate follow-up. At this ultimate follow-up, the discs below (L4–L5 and L5–S1) still look very healthy.

Results

Sixty-seven patients were included in our analysis. There were 62 women and 5 men with an average age of 38.8 years (range 21–61 years). The average clinical follow-up was 7.8 years: 42 patients had >5 years follow-up, including 23 patients with >10 years follow-up. Fifty-six of the 67 patients had complete radiographs and were included in the radiographic analysis (Figures 1 and 2). The remaining 11 patients did not have complete radiographs but were included in the outcomes analysis. Similarly, 56 of the 67 patients had postoperative SRS-24 questionnaire data but lacked complete radiographic data. These patients either lacked preoperative, immediately postoperative, or 2+-year follow-up radiographs and therefore were not included in the radiographic analysis. Forty-five of the 67 total patients had complete radiographic data and SRS-24 data.

The LIV was T11 (1 patient), T12 (8 patients), L1 (16 patients), L2 (9 patients), L3 (6 patients), and L4 (27 patients). There was 1 anterior-only instrumented fusion, 50 posterior spinal fusions (5 with 3-rod technique), 2 same-day anterior/posterior spinal fusions, 6 staged anterior/posterior spinal fusions, 7 staged anterior instrumented/posterior spinal fusions, and 1 posterior/anterior/posterior spinal fusion. The staged procedures were performed approximately 7 days apart.

Radiographic Analysis

Fifty-six patients had complete radiographs including standing anteroposterior and lateral radiographs in the immediate preoperative, immediate postoperative (1–6 weeks), and latest follow-up periods. In 3 cases, the remaining disc spaces below the LIV were considered "unassessable" due to underpenetration of the radiograph; therefore, 53 patients were included for disc degeneration assessment. Of the 56 patients with complete radiographs, the LIV included: T11 (1 patient), T12 (5 patients), L1 (11 patients), L2 (9 patients), L3 (4 patients), and L4 (26 patients). The patients excluded from the disc degeneration assessment included 1 patient from the LIV groups T11, L2, and L4. A total of 179 discs were analyzed by two reviewers other than the operating surgeons over 4 time periods leading to a total of 716 measurements.

Table 2 summarizes the following data based on patients grouped by LIV: the number of patients in each group; the average number of levels fused; the average age of the patient at the time of surgery; the average size of the major curve before surgery, immediately after surgery, and at final follow-up; and average clinical follow-up time.

A review of major long-term complications (pseudarthrosis requiring revision surgery, instrumentation dislodgement requiring revision surgery, symptomatic instrumentation requiring complete instrumentation removal, or transition syndrome leading to revision surgery) and radiographic imbalances (positive sagittal balance >5 cm or coronal imbalance >3 cm) are included in

Table 2. Demographic and Radiographic Summary Data Sorted by LIV

LIV	Total n	Average No. of Levels Fused	Average Age at Surgery (yrs)	No. of Patients in Radiographic Analysis	Average Major Curve Preop (°) (range)	Average Major Curve Immediately Postop (°)	Average Major Curve Final Postop (°)
T11	1	7.0	45.8	1	84	60	62
T12	8	9.5	27.8	5	58 (53–72)	38	45
L1	16	10.9	38.2	13	60 (45–87)	38	43
L2	9	11.2	37.6	6	55 (46–67)	31	34
L3	6	11.7	32.7	6	53 (45–65)	34	32
L4	27	11.7	44.1	25	65 (45–115)	38	42

LIV = lowest instrumented vertebra.

Table 3. A general summary of the major groups is included in Table 4. There were no minor complications. There are 10 major complications, including 6 cases of pseudarthroses, 2 cases of transition syndromes requiring extension of the fusion distally, 1 case of complete symptomatic instrumentation removal, and 1 case of instrumentation dislodgement 3 months after surgery that required revision. The case of complete instrumentation removal was presumed to be a pseudarthrosis *versus* symptomatic instrumentation causing pain before surgery. Exploration of the fusion demonstrated a solid fusion throughout, so the instrumentation was removed and the patient's pain resolved. In the case of instrumentation dislodgement, the distal hook dislodged between 6 weeks and 3 months after surgery leading to 40 mm of coronal imbalance. The patient was revised circumferentially to include anterior spinal instrumentation from T11–L4 (the prior LIV). One patient with pseudarthroses required extension of the instrumentation by 1 level (from L1 to L2). In this case, the patient was considered to have a LIV of L2 for radiographic disc assessment purposes; however, for clinical assessment purposes, the patient was considered to have a LIV of L1 with pseudarthroses requiring revision. In the other cases with pseudarthrosis, the levels of pseudarthroses were confirmed at the revision surgery.

Most of our assessments of disc degeneration below the fusion revealed no statistically significant conclu-

Table 3. Major Complications and Radiographic Variations

Age at Surgery (yrs)	UIV	LIV	No. of Levels Fused	Primary Procedure	Complication *vs.* Radiographic Variation	Type	Postop Time (yrs)	Revision?
32	T2	T12	11	PSF	Symptomatic instrumentation removal	Major	2.5	Removal
32	T2	L1	12	PSF	Pseudarthroses T7–T12	Major	3.0	Yes
39	T4	L1	10	PSF	Pseudarthroses T7–T8, T10–T11	Major	4.5	Yes
37	T4	L1	10	PSF	Pseudarthroses T6–T7, T11–T12	Major	1.0	Yes
42	T2	L3	14	PSF	Pseudarthrosis T9–T10	Major	6.0	Yes
45	T4	L4	13	Staged anterior/PSF	Pseudarthroses T7–T8, T11–T12	Major	1.5	Yes
60	T3	L4	14	PSF	Pseudarthrosis T10–T12, L3–L4	Major	2.0	Yes
34	T4	L4	13	PSF	Instrumentation dislodged L4	Major	0.3	Yes
45	T10	L4	7	Staged ASSI/PSF	Transition syndrome with extension to L5	Major	10.0	Yes
52	T10	L4	7	Staged ASSI/PSF	Transition syndrome with extension to L5	Major	9.0	Yes
36	T3	T12	10	PSF	Negative sagittal balance (−63 mm)	Radiographic variation	4.0	No
30	T4	T12	9	PSF	Negative sagittal balance (−59 mm)	Radiographic variation	2.0	No
40	T4	L1	10	PSF	Positive sagittal balance (+53 mm)	Radiographic variation	7.5	No
49	T4	L2	11	PSF	Coronal imbalance (−37 mm)	Radiographic variation	4.5	No
39	T3	L4	14	PSF	Negative sagittal balance (−58 mm)	Radiographic variation	2.0	No

UIV = upper instrumented vertebra; LIV = lowest instrumented vertebra; PSF = posterior spinal fusion; ASF = anterior spinal fusion; ASSI = anterior segmental spinal instrumentation.

Table 4. Summary Data Sorted by Major Groups

	Procedure					Complications			SRS Data				
	n	ASF (Instrumented)	ASF/ PSF	ASSI/ PSF	PSF	Major	Minor	Radiographic Variation	Pain	Function	Self-image	Satisfaction	Total Score
<40 yrs (Grade A)	36	1	3	3	29	5	0	3	27.5	30.3	23.3	13.0	94.1
≥40 (Grade B)	31	0	5	5	21	5	0	2	26.0	27.1	22.9	12.8	88.8
T11–L2 (Grade 1)	34	1	3	0	30	4	0	4	27.4	30.0	23.1	12.6	93.1
L3–L4 (Grade 2)	33	0	6	6	21	6	0	1	26.0	27.5	22.9	13.2	89.5

ASF = anterior spinal fusion; PSF = posterior spinal fusion; ASSI = anterior segmental spinal instrumentation; SRS = Scoliosis Research Society.

sions. There was fair to poor agreement between observers (as described by Landis and Koch[17] in assessments of postoperative discs below the fusion at the levels of T12–L1, L1–L2, L2–L3, and L5–S1) and moderate agreements at L3–L4 and L4–L5. Based on final postoperative data, there was fair to poor agreement in levels T12–L2 below the LIV, with moderate agreement in distal levels. Because of the poor agreement between observers, there are limits to which statistical analysis can support clinically relevant trends. The following trends were analyzed based on data of discs below the fusion:

1) *Disc degeneration patterns*: no significant patterns. Therefore, discs directly below a fusion were not more likely to degenerate based on our criteria.
2) *Average subsequent disc degeneration based on LIV*: when analyzing mean disc degeneration values categorized by LIV, there were no significant trends due to high levels of variability in scores relative to the means. Therefore, discs distal to fusions with an LIV of L4 were not more likely to demonstrate degenerative changes than fusions with an LIV of T12.
3) *Average subsequent disc degeneration based on age*: statistical significance was not reached when comparing patients with age above and below 40 years to mean disc degeneration values for the two reviewers ($P = 0.13$ and 0.28 for the two reviewers, respectively). When age was analyzed as a continuous variable, no statistical trends were noted. Therefore, our definition of groups based on patient age being < or ≥40 years of age did not bias potential useful information regarding disc degeneration below the fusion.
4) *Subsequent disc degeneration over time*: the only area that demonstrated statistical significance was the verification that increasing length of follow-up lead to increases in disc degeneration below the LIV ($P = 0.003$ and 0.022 for the two reviewers, respectively). Therefore, later in the postoperative period, discs below the fusion tended to show more degenerative changes. These may represent natural changes in the discs with aging and have unclear clinical relevance.

Outcomes Analysis

The results of the SRS-24 questionnaire data are included in Table 5. There are no significant SRS-24 outcomes score differences based on the domains of pain, function, self-image, satisfaction, and total score when comparing groups stratified by individual LIVs or major groups of Group 1 and 2. Similarly, there were no score differences based on age at the time of surgery, including combined data for Groups A and B.

When analyzing smoking status and the risk for major complications, there were no data suggesting that a positive smoking history lead to higher rates of pseudarthrosis or other major complications that required revision surgery. Smoking status was available on 56 patients (including all major complications); 10.4% of nonsmokers (5 of 48 patients) had pseudarthrosis, whereas 12.5% of smokers (1 of 8 patients) had pseudarthrosis ($P = 1.0$). Similarly, age at the time of surgery had no bearing on the likelihood of pseudarthrosis or revision surgery.

Table 5. SRS Domain Averages Sorted by LIV

					SRS-24 Domains				
LIV	n	Average No. of Levels	Average Age at Surgery (yrs)	n With SRS-24 Data	Pain (Max. 35)	Function (Max. 40)	Self-image (Max. 30)	Satisfaction (Max. 15)	Total Score (Max. 120)
T11	1	7.0	45.8	1	34.0	36.0	24.0	12.0	106.0
T12	8	9.5	27.8	6	26.5	33.0	21.7	13.0	94.1
L1	16	10.9	38.2	15	27.2	29.2	23.8	12.4	92.5
L2	9	11.2	37.6	5	28.0	27.6	22.8	12.6	91.0
L3	6	11.7	32.7	5	20.0	25.3	20.8	12.0	78.0
L4	27	11.7	44.1	24	26.9	27.0	23.0	13.4	90.4

SRS = Scoliosis Research Society; LIV = lowest instrumented vertebra.

Patients with pseudarthrosis (n = 6) did have statistically significant lower SRS-24 scores at their most recent follow-up in the domains of pain (average = 19.7; P = 0.03), satisfaction (average = 11.2; P = 0.04), and total score (average = 74; P = 0.02), but not function (average = 23.7; P = 0.09) or self-image (average = 20.2; P = 0.11). Four of the 6 patients with pseudarthrosis had more than 2-year follow-up since their subsequent pseudarthrosis repair surgery, and there was a trend toward decreased satisfaction (average = 11.3; P = 0.06) and total score (average = 77.8; P = 0.07), but not pain (average = 21.5; P = 0.11), function (average = 24.5; P = 0.16), or self-image (average = 20.5; P = 0.13) when compared to all patients that did not undergo revision surgery. Patients with revision surgery of any kind (including all major complications) had statistically significant decreased levels of SRS-24 scores in the domains of pain (average = 19.9; P = 0.05), function (average = 21.7; P = 0.02), self-image (average = 19.7; P = 0.02), satisfaction (average = 10.7; P = 0.02), and total score (average = 72.0; P = 0.01).

■ Discussion

The Scoliosis Research Society (SRS-24) questionnaire was developed as a quality-of-life instrument to assess patient outcomes after operative treatment of adolescent idiopathic scoliosis. Haher *et al*[15] designed and tested the instrument finding it to be both reliable (Cronbach alpha coefficient >0.6 for each domain) and valid—as demonstrated by comparisons to age-matched normal high-school students. There has been some question as to whether the instrument was as effective in assessing outcomes of adult patients. In our study, the SRS-24 questionnaire was useful in the assessment of patients with major complications requiring revision surgery. Patients with pseudarthrosis requiring revision surgery (n = 6) had a statistically significant decrease in average scores of pain (average = 19.7; P = 0.03), satisfaction (average = 11.2; P = 0.04), and total score (average = 74.1; P = 0.02), but not function (average = 23.7; P = 0.09) or self-image (average = 20.2; P = 0.11) relative to patients without pseudarthrosis. This analysis included 2 patients' data before revision surgery. In the remaining 4 of the 6 patients with more than 2-year follow-up after revision surgery for pseudarthrosis repair, satisfaction and total score remained depressed relative to patients not requiring revision surgery, but did not reach statistical significance (P = 0.06 and P = 0.07, respectively). Similarly, patients requiring revision surgery for all major complications had statistically significant decreased levels of SRS-24 scores in the domains of pain (average = 19.9; P = 0.05), function (average = 21.7; P = 0.02), self-image (average = 19.7; P = 0.02), satisfaction (average = 10.7; P = 0.02), and total score (average = 72.0; P = 0.01).

Outside of our outcomes correlations, the value of our findings lie more in the hypotheses that were not proven to be true rather than our positive findings. Age at the time of surgery and level of LIV did not correlate with an increased incidence of major complications or poorer outcomes. Of interest, however, is that all of our pseudarthrosis occurred with LIVs L1, L3, or L4, and in all cases the lower thoracic spine (T9–T12) was involved in the pseudarthroses. To some extent, the pseudarthroses associated with the LIV L1 may be due to the transition between the relatively rigid thoracic spine and the more mobile lumbar spine. This phenomenon may also lead to the frequent pseudarthroses in the thoracolumbar junction. The relatively smaller size of the posterior elements at these levels may also contribute. The pseudarthroses in the lower LIVs may occur in part due to the added length of the fusility when assessing discs in patients with scoliosis fusions extending to the L4 and L5 levels (excluding the lower levels of degeneration—scores of 0 or 1). They did not review cases in which the LIV was in the upper lumbar spine—the area with poor interobserver correlation based on our analysis. The authors did not find statistical significance between lumbar pain (based on a Visual Analogue Scale) and disc degeneration (r = 0.29, P = 0.10).[18] Our correlations were based on a complete set of data including all scores. As our initial hypothesis suggested, scoliosis fusions to levels above L4 lead to higher variability between observers. Rotation and angulation of the residual curve below the LIV are often inevitable leading to added difficulties assessing the discs below the fusion. In terms of technique, despite measuring anterior and posterior disc height as well as sagittal listhesis, the concordance rate using the Weiner system was relatively low to moderate in this population.

None of the patients listed as sagittal or coronal imbalances required revision surgery. The single case of positive sagittal balance greater than 5 cm was due to progressive degenerative disc disease leading to an 18° increase in upper lumbar (L1–L3) kyphosis below her fusion (a Type II curve treated with posterior fusion, posterior segmental spinal instrumentation from T4 to L1). Her most recent SRS-24 questionnaire data suggested increased pain and dissatisfaction relative to the average for her LIV.

In general, our findings were similar to other studies describing the outcomes of AIS using modern segmental instrumentation systems. Takahashi *et al*[19] recently noted a 5% pseudarthrosis rate based in their analysis of 58 adult patients treated with Cotrel-Dubousset instrumentation. Although our pseudarthrosis rate was 8.9%, several of our pseudarthroses were discovered after 7 years after surgery, beyond the maximum follow-up of the Takashi *et al*[19] study. Our rates of other complications (instrumentation dislodgement or failure in absence of a pseudarthrosis) were similar to or lower than their outcomes. We did not have any late-onset deep infections or neurologic complications.

Conclusions

Patients with AIS and long fusions had similar pseudarthrosis rates, lower sagittal/coronal radiographic variation rates, but higher rates of transition syndrome when LIV was L3–L4 relative to levels T11–L2. When separated by age, patients ≥40 years had more anterior/posterior spinal fusion, but late complication rates were similar to the <40 year group. Patients with pseudarthroses or other diagnoses requiring revision surgery had lower SRS-24 scores in all domains than those without ($P = 0.02$ and $P = 0.01$, respectively). To our knowledge, this is the largest series of patients reviewing outcomes and radiographic criteria in patients fused from the thoracic spine to L4 or higher using modern 2+ rod hook/pedicle screw instrumentation methods.

Key Points

- Patients with pseudarthrosis and other diagnoses requiring revision surgery had lower postoperative SRS-24 scores in all domains compared to patients not requiring revision surgery.
- Major midterm complications (2–16 years postoperation) requiring revision surgery were not more likely in the older patients (≥40 years) than in the younger patients.
- Subsequent disc degeneration below the fusion did not correlate significantly with either the distal lowest instrumented vertebra or the age of the patient.

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