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Operative Management of Degenerative Scoliosis: An Evidence-Based Approach to Surgical Strategies Based on Clinical and Radiographic Outcomes

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Scoliosis in the adult encompasses patients with deformity that has been present since childhood or adolescence and patients with new onset of deformity or de novo scoliosis. Degenerative scoliosis is a de novo deformity of the lumbar spine that is caused by degeneration of spinal motion segments with resultant deformity in the coronal, sagittal, and axial planes. The fundamental role of degenerative pathologic change in the cause and progression of deformity patterns supports the description of de novo scoliosis in adults as degenerative scoliosis [1–5].

Degenerative scoliosis commonly affects the lumbar spine and thoracolumbar spine and involves concurrent disorders, such as degenerative disc disease; facet joint pathologic change; spinal stenosis; lumbar hypolordosis; osteoporosis; and segmental instability, including rotatory subluxation and olisthesis [6–9]. The incidence and prevalence of degenerative scoliosis affecting adults has been reported variably, with curves greater than 10° present in more than 50% of elderly women with back pain and osteoporosis, and new onset of deformity observed in more than 30% of elderly patients with straight spines at enrollment [3,10,11]. In this article, degenerative scoliosis is defined as a lumbar curve measuring greater than 15° without a structural thoracic curve in an adult aged older than 35 years with no known history of scoliosis as an adolescent. Degenerative scoliosis is an important disorder affecting the aging spine, and management of degenerative scoliosis with nonoperative and operative care accounts for a significant and increasing portion of our health care economy.

Scoliosis has a significant and measurable impact on health-related quality of life in adults presenting to a physician managing disorders of the spine [12,13]. Affected domains include pain, function, self-image, and mental health. The adult with degenerative scoliosis characteristically presents with symptoms that include axial and neurogenic pain and progressive truncal imbalance [14–18]. Spinal stenosis and nerve compression are commonly components of the clinical presentation and are important considerations in the patient's decision to pursue care [19–22]. Present pain and disability are common in the adult presenting with degenerative scoliosis. These symptoms are not characteristic of adolescent idiopathic deformity without degenerative changes. The differences in curve patterns and in clinical presentation between the adult with degenerative scoliosis and the adolescent with idiopathic scoliosis underlie the fundamental differences in the goals of treatment and surgical strategies for these populations. In the adolescent with idiopathic scoliosis, the goal of care is to prevent progression of deformity and consequences of deformity progression, including pain, functional

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limitations, and truncal imbalance. In the adult with degenerative scoliosis, the goal of care is to improve present pain and disability. The presence of measurable compromise in health-related quality of life in the adult with degenerative scoliosis offers a measurable variable of the success of management and a quantifiable approach for developing an evidence-based approach to care based on patient self-assessment of changes in health status.

The surgical goals in treating the patient with degenerative scoliosis include neural decompression, improvement of back pain, and restoration of spinal alignment [18,23]. There exists tremendous variability in the operative management of degenerative scoliosis, with little consensus on surgical strategy regarding approach and levels [24]. The presence of variability is clear evidence of the absence of an evidence-based approach. Specific areas of controversy in the surgical management of degenerative scoliosis include the role of decompression or limited arthrodesis, the role of combined anterior and posterior surgery, and the choice of fusion levels at the thoracolumbar junction and the lumbosacral junction. The relation between surgical strategies and outcome, including complications, has not been well established. The purpose of this retrospective study is to report the results of operative treatment of patients with degenerative scoliosis and to determine the outcome of specific surgical strategies on clinical and radiographic outcomes.

Material and methods

A consecutive series of patients treated by means of surgery for a primary diagnosis of degenerative scoliosis at the University of California in San Francisco Medical Center was reviewed. The inclusion criteria for the diagnosis of degenerative scoliosis in this study included adults older than the age of 35 years with a lumbar major curve measuring greater than 15° without a structural thoracic curve and no known history of scoliosis as an adolescent. Patients with prior decompressive procedures involving the lumbar spine were included, although patients with prior fusion procedures were excluded. Patients with posterior-based osteotomies for fixed sagittal plane deformity were also excluded. All patients in this series were treated with an instrumented fusion of the spine, with no fixation extending above the level of T10. All patients had a minimum of 2 years of clinical follow-up.

Clinical records from outpatient and inpatient charts were reviewed. Clinical status at most recent follow-up was determined by patient self-assessment using the Short Form-36 (SF-36) and Scoliosis Research Society (SRS) instruments. Standing posteroanterior and lateral views of the spine were measured at intervals, including before surgery, immediately after surgery, and at follow-up. Predictor variables include patient demographics, curve characteristics (eg, end vertebra, magnitude), and surgical strategy (eg, fusion levels, approach [anterior/posterior versus posterior only]). Outcome variables include radiographic parameters and self-assessment health status measures.

Results

Sixty consecutive patients met the inclusion criteria of primary arthrodesis for degenerative scoliosis with cephalad fixation below T9. Complete data, including clinical and radiographic variables, were available for 38 patients (28 female and 10 male) with a minimum of 2 years of clinical follow-up. The average age of patients was 64 years (range: 40–82 years). Thirty patients were treated with a posterior-only fusion, 4 patients with anterior-only surgery, and 4 patients with a combined anterior and posterior approach. The average age of the patients who underwent posterior-only surgery was 68.3 years (range: 45.5–82 years). Patients treated with combined anterior and posterior surgery had an average age of 52.5 years (range: 41–57 years), and patients treated with anterior surgery had an average age of 41.3 yeas (range: 40–59 years). Clinical follow-up averaged 54.7 months (range: 24–161 months), and radiographic follow-up averaged 28.0 months (range: 1–113 months).

Radiographic outcomes

Rotatory subluxation was present at one or more levels in 34 patients (89%), and spondylolisthesis was present in 8 patients (21%). Lumbar curves averaged 29.8° (range: 15°–64°) before surgery and 21.1° (range: 8°–36°) at most recent follow-up. All patients with posterior instrumentation extending above L1 also had anterior surgery or a transforaminal lumbar interbody fusion (TLIF) to gain structural support of the anterior column. The mean lumbar curve in the anterior spinal fusion (ASF) group (54.8°) was greater than that in the posterior spinal fusion (PSF) group (25.6°; $P < .05$) and in the combined

ASF/PSF group (36.2°; $P < .05$). Average curve correction from an anterior approach was 20%, and average corrections were 39% from combined anterior and posterior approaches and 59% from anterior-only approaches.

Lumbar lordosis considerations

The ASF group had more preoperative lumbar lordosis than the PSF and combined ASF/PSF groups (−51.8° versus −42.4° and −42.0°, respectively). Average postoperative lumbar lordosis decreased to −43.2° in the ASF group and was unchanged in the PSF group (−39°) and in the combined ASF/PSF surgery group (−41.3°). Of the patients with greater than −30° of lumbar lordosis before surgery (hypolordotic group), all were treated with a posterior-based approach without three-column osteotomies in this series. The maximum increase in lordosis was 15° in the posterior-based group.

Thoracic and junctional kyphosis considerations

The PSF group had more preoperative thoracic kyphosis (44.1°) than the ASF group (35.2°) and the ASF/PSF group (32.8°). Postoperative thoracic kyphosis at most recent follow-up decreased in the PSF group (28.0°) and increased in the ASF group (41.8°) and in the ASF/PSF group (45.0°). These values correspond to a postoperative lumbar lordosis in each group of −39° in the posterior surgery group, −43.2° in the anterior surgery group, and −41.3° in the combined anterior and posterior surgery group. There were no other statistically significant radiographic differences between the three surgical groups, including preoperative and postoperative compensatory thoracic curves or sagittal and coronal balance. Average kyphosis at the thoracolumbar junction (T12-L2) was 5.5° before surgery and did not change significantly at most recent follow-up in any group.

The cephalad levels fused were T10 (n = 2), T11 (n = 3), T12 (n = 5), L1 (n = 9), L2 (n = 9), L3 (n = 8), and L4 (n = 2). The caudad levels fused were L2 (n = 1), L4 (n = 7), L5 (n = 13), and S1 (n = 17). Overall, 9 (24%) of 38 patients required revision surgery during the follow-up period (1 of 4 patients with combined ASP/PSF and 8 of 30 patients with PSF only). Five patients underwent revision surgery for proximal extension of arthrodesis, 1 patient required a distal extension of arthrodesis, 1 patient required a distal and proximal extension, and 2 patients had implant removal. Six (18%) of 33 patients with a cephalad level fused below the structural thoracic spine (T12 or lower) required a proximal extension of the fusion, whereas 0 of 5 patients fused to the structural thoracic spine required a proximal revision. Two (10%) of 21 patients with a caudad level maintaining mobile segments required revision surgery for distal extension of arthrodesis, whereas 0 of 17 patients fused to the sacrum required revision of distal fixation. Three (17%) of 18 patients fused to a cephalad level below the measured Cobb curve required revision surgery for proximal extension of arthrodesis, whereas 3 (15%) of 20 patients fused to or above the measured Cobb curve proximally required revision surgery for adjacent segment degeneration.

Clinical outcomes

Postoperative SF-36 and SRS-30 scores were available on all 38 patients. The SRS-30 outcomes instrument (scale of 1–5, low to high) demonstrated overall mean postoperative scores as follows: 3.9 for pain, 3.4 for function, 4.0 for mental health, 3.5 for self-image, and 3.7 for overall satisfaction. Twenty-nine patients reported a change in health status compared with their preoperative health status. Nineteen (66%) of 29 patients thought that surgery resulted in clinically significant improvement of their back pain, 4 (14%) of 29 thought that their pain was unchanged, and 6 (21%) of 29 thought that their pain was worse after surgery. The patients who thought that their pain was worse were significantly older (73.8 versus 60.9 years; $P = .01$) and had less severe lumbar curves (25.5° versus 32.5°; $P = .06$) than patients who thought that their pain was improved or unchanged. Thirteen (45%) of 29 patients thought that surgery resulted in a clinically significant improvement of function and daily activity, 6 (21%) of 29 thought that their function was unchanged, and 10 (34%) of 29 reported that their function was decreased. The patients who reported having worse function were also significantly older (69.5 versus 60.4 years; $P < .05$) and had greater thoracolumbar (T12-L2) sagittal Cobb curves before surgery (11.6° versus 4.8°; $P < .05$) and at their most recent follow-up (15° versus 4.2°; $P < .05$) (Table 1).

The SF-36 outcomes instrument resulted in overall mean postoperative scores as follows: 48.5 for bodily pain, 63.6 for general health, 53.3 for vitality, 72.7 for mental health, 73.6 for social

Table 1
Postoperative scores for 38 patients with primary arthrodesis for degenerative scoliosis with cephalad fixation below T9

SRS-30		SRS-36	
	Mean scores		Mean scores
Pain	3.9	Bodily pain	48.5
Function	3.4	General health	63.6
Mental health	4.0	Vitality	53.3
Self-image	3.5	Mental health	72.7
Overall satisfaction	3.7	Social function	73.6
		Physical function	50.6
		Role-physical	49.2
		Role-emotional	75.5

Abbreviation: SRS, Scoliosis Research Society.

function, 50.6 for physical function, 49.2 for role-physical, and 75.5 for role-emotional.

Patients were grouped and analyzed by surgery type to compare PSF with ASF and combined ASF/PSF outcomes. The SRS pain score of the ASF group (3.8) was significantly better than that of the ASF/PSF group (3.1; $P < .05$) but was not significantly different from that of the PSF group (3.2). The ASF group also had a significantly higher SRS function score than the PSF group (4.4 versus 3.3; $P < .05$), whereas the combined ASF/PSF group had a score of 3.6. The PSF group had a lower SF-36 bodily pain score (41.7) than the ASF group (79.5; $P < .05$) and the ASF/PSF group (66.2; $P = .08$). The ASF group had a higher SF-36 general health score (82.2) than the PSF group (61.6; $P < .05$) and ASF/PSF group (59.2; $P = .07$) (Table 2).

Within the PSF group, 12 (55%) of 22 of patients thought that surgery improved their back, 4 (18%) of 22 reported no change, and 6 (27%) of 22 thought that their pain was worse. Four (100%) of 4 patients in the ASF group and 3 (100%) of 3 patients in the ASF/PSF group thought that surgery improved their pain. When asked about the change in their function and daily activity after surgery, 9 (41%) of 22 patients in the PSF group reported an improvement, 5 (23%) of 22 thought there was no change, and 8 (36%) of 22 thought that they were worse. Three (75%) of 4 patients in the ASF group reported an increase in function/activity after surgery, whereas 1 (25%) thought there was no change. One (33%) of 3 patients in the ASF/PSF group thought there was improvement in function/activity, and 2 (66%) of 3 believed that they were functioning at a lower level than they were before surgery. After surgery, 7 (32%) of 22 of patients in the PSF group reported an increase in their ability to participate in hobbies and sports, 8 (36%) of 22 thought there was no change, and 7 (32%) of 22 felt worse. Three (75%) of four of the ASF patients reported an improvement in hobbies/sports, and 1 (25%) reported a decrease. One (33%) of 3 of the ASF/PSF patients reported an increase in hobbies/sports, whereas 2 (66%) of 3 thought there was a decrease.

Table 2
Outcome comparison: posterior spinal fusion versus anterior spinal fusion versus combined anterior spinal fusion/posterior spinal fusion

	ASF	PSF	ASF/PSF
SRS-30			
Pain	3.8	3.2	3.1
Function	4.4	3.3	3.6
SF-36			
Bodily pain	79.5	41.7	66.2
General health	82.2	61.6	59.2

Abbreviations: ASF, anterior spinal fusion; PSF, posterior spinal fusion; SF, Short Form; SRS, Scoliosis Research Society.

Multiple regression analysis was performed to assess the independent estimated effect of age, surgery type, lumbar curve, and lumbar lordosis on patient outcomes. The multiple regression analysis of SRS pain scores revealed a significant age effect ($P < .05$), with a coefficient of -0.035 per year. Surgery type was also a significant independent predictor of pain scores ($P < .05$), with an estimated effect of 1.68 for ASF surgery compared with the PSF procedure. Preoperative lumbar lordosis was shown to be an independent predictor of SRS satisfaction ($P < .05$), having an estimated effect of -0.026 per degree, with patients with preoperative hypolordosis having better rates of satisfaction with surgery. Age was also found to be an independent predictor of SF-36 physical function score ($P < .05$), with an estimated effect of -1.78 per year. None of these predictors demonstrated a statistically significant independent effect on SF-36 bodily pain, general health, vitality, mental health, social function, role-physical, or role-emotional scores; there was also no independent

predictor of SRS mental health scores found through multiple regression analysis.

Outcomes were compared between patients whose fusions preserved mobile segments versus those who were fused to the structural thorax or sacrum. Five patients (3 female and 2 male) had fusions with cephalad levels that extended to the structural thorax (T10-T11), with an average age of 51.4 years. Thirty-three patients (25 female and 8 male) had fusions with nonthoracic proximal levels (T12 or lower), with an average age of 66.1 years. The patient group that was fused to the structural thorax had an average SRS pain score of 3.7, SRS functional score of 4.0, SRS mental health score of 4.4, SRS self-image score of 4.3, and SRS overall satisfaction score of 4.4. In contrast, the group maintaining proximal mobile segments demonstrated lower scores, with an average SRS pain score of 3.2 (not significant [NS]), SRS functional score of 3.3 ($P < .05$), SRS mental health score of 3.9 ($P = .054$), SRS self-image score of 3.4 ($P < .05$), and SRS overall satisfaction score of 3.6 (NS). Controlling for age, there were no clinical outcome score differences between the group fused to the structural thoracic spine compared with the group fused below T11.

Seventeen patients (13 female and 4 male), with an average age of 67.3 years, had fusions with caudal levels that extended to the sacrum. Twenty-one patients (15 female and 6 male), with an average age of 61.7 years, had fusions with distal levels that maintained a mobile segment. The patient group that was fused to the sacrum had an average SRS pain score of 3.3, SRS functional score of 3.4, SRS mental health score of 3.9, SRS self-image score of 3.4, and SRS overall satisfaction score of 3.6. For the same group, the average SF-36 bodily pain score was 49.6, the SF-36 general health score was 64.8, the SF-36 vitality score was 58.4, the SF-36 mental health score was 75.5, the SF-36 social function score was 71.1, the SF-36 physical function score was 52.2, the SF-36 role-physical score was 50.0, and the SF-36 role-emotional score was 76.6. In contrast, the group maintaining distal mobile segments demonstrated an average SRS pain score of 3.3, SRS functional score of 3.5, SRS mental health score of 4.0, SRS self-image score of 3.7, and SRS overall satisfaction score of 3.9. In this group, the average SF-36 bodily pain score was 47.4, the SF-36 general health score was 62.6, the SF-36 vitality score was 49.2, the SF-36 mental health score was 70.4, the SF-36 social function score was 75.6, the SF-36 physical function score was 49.2, the SF-36 role-physical score was 48.6, and the SF-36 role-emotional score was 74.5. None of the differences in outcomes between the two groups were statistically significant.

Figs. 1–3 illustrate case examples. Case 1 is a patient who underwent combined anterior and posterior surgery with extension of fusion to the pelvis. Case 2 is a patient who underwent posterior-only surgery with fusion to L5.

Perioperative complications seen in the PSF group include dural tears (n = 4), infections (urinary tract infection [UTI] [n = 1], line sepsis [n = 1], and wound infection [n = 1], and neurologic complications (worsened lower extremity pain or weakness [n = 3], urinary retention [n = 1], and altered mental status [n = 1]). Complications seen in the combined ASF/PSF surgery group were infections (UTI [n = 1] and *Clostridium difficile* colitis [n = 1]) and neurologic complications (lateral femoral cutaneous nerve palsy [n = 1] and altered mental status [n = 1]) (Table 3).

Discussion

The surgical management of adult scoliosis is challenging, and results are variable. Age and surgical approach are important independent determinants of postoperative pain, with younger patients treated with anterior surgery reporting less postoperative pain than older patients treated with posterior surgery. Age is also an important independent predictor of postoperative function. The role of comorbidities is well established as an important determinant of postoperative health-related quality of life [25]. In this series, data on comorbidities were incomplete and not included in the analysis. This series includes data on postoperative health status, with limited data on absolute changes in health status as a result of surgery. Controlling for age, patients with anterior approaches had less postoperative pain than patients with posterior approaches. Patients who are candidates for an anterior approach are fundamentally different than patients who are treated with posterior-only or combined procedures. Specifically, patients treated with anterior-only surgery had limited degenerative changes at the lumbosacral junction and limited preoperative pain. Therefore, this study does not support the hypothesis that surgical approach is an important determinant of outcome of surgery. Future investigation, including a randomized prospective trial

Fig. 1. Case 1: a 52-year-old woman with degenerative scoliosis and progressive deformity. She complained of primarily axial pain and an inability to stand upright, with limited radicular pain or neurogenic claudication.

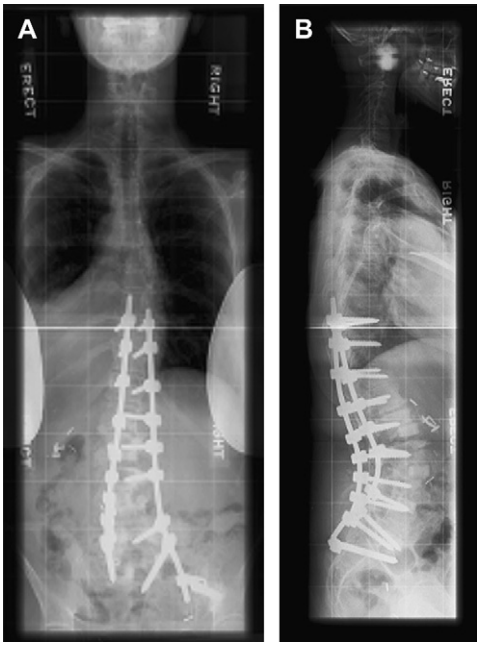

Fig. 2. Case 1: in the same patient as in Fig. 1, surgery included an L2-S1 ASF, followed by a T10-S1 PSF with iliac fixation. After surgery, the patient had good improvement of her spinal alignment, and she was extremely satisfied with her ability to stand upright and improvement of her back pain.

or a matched cohort study, may better address the relation between surgical approach and clinical outcomes.

Regarding change in health status, the data available in this study were limited to the last seven questions of the SRS-29 instrument, which ask patients to evaluate change in pain, function, appearance, and social role in comparison with their recollection of their preoperative status. Patients self-reported improvement of pain more often than improvement of function after surgery. Clinic chart notes and the assessments of the surgeons whose patients were included in this study (DSB, SSH, and SHB) suggested a much higher rate of improvement of pain and function in these patients than the self-assessment questionnaire results. There were many examples of patients reporting an improvement of their preoperative pain and being limited by a different type or pattern of pain at follow-up. Similarly, in the domain of function, many patients had improvements of functional limitations, including neurogenic claudication and back-related disability, but were limited at follow-up by factors that included hip and knee pathologic findings or cardiorespiratory conditions. More complete data on preoperative pain and function scores and more specific questions on pain patterns and functional limitations would be useful in accurately assessing the impact of surgery on domains of health-related quality of life, including pain and function.

Regarding specific radiographic variables and outcome, previous studies have demonstrated a significant correlation between global sagittal alignment and health-related quality of life. Glassman and colleagues [26] demonstrated that pain and function were compromised in patients with no prior surgery and a positive global sagittal balance of more than 4 cm. Postoperative pain and function did not correlate highly with any radiographic variable. Schwab and colleagues [27] demonstrated significantly increased pain and functional limitation in adults with scoliosis with combined hypolordosis (Cobb angle $\geq 35^\circ$ and end plate obliquity $> 25^\circ$ compared with patients with lumbar lordosis $> 55^\circ$ and L3 obliquity $< 15^\circ$). Low correlations existed between pain measured by visual analog scale (VAS) and individual radiographic parameters, however, including lumbar lordosis, end plate obliquity,

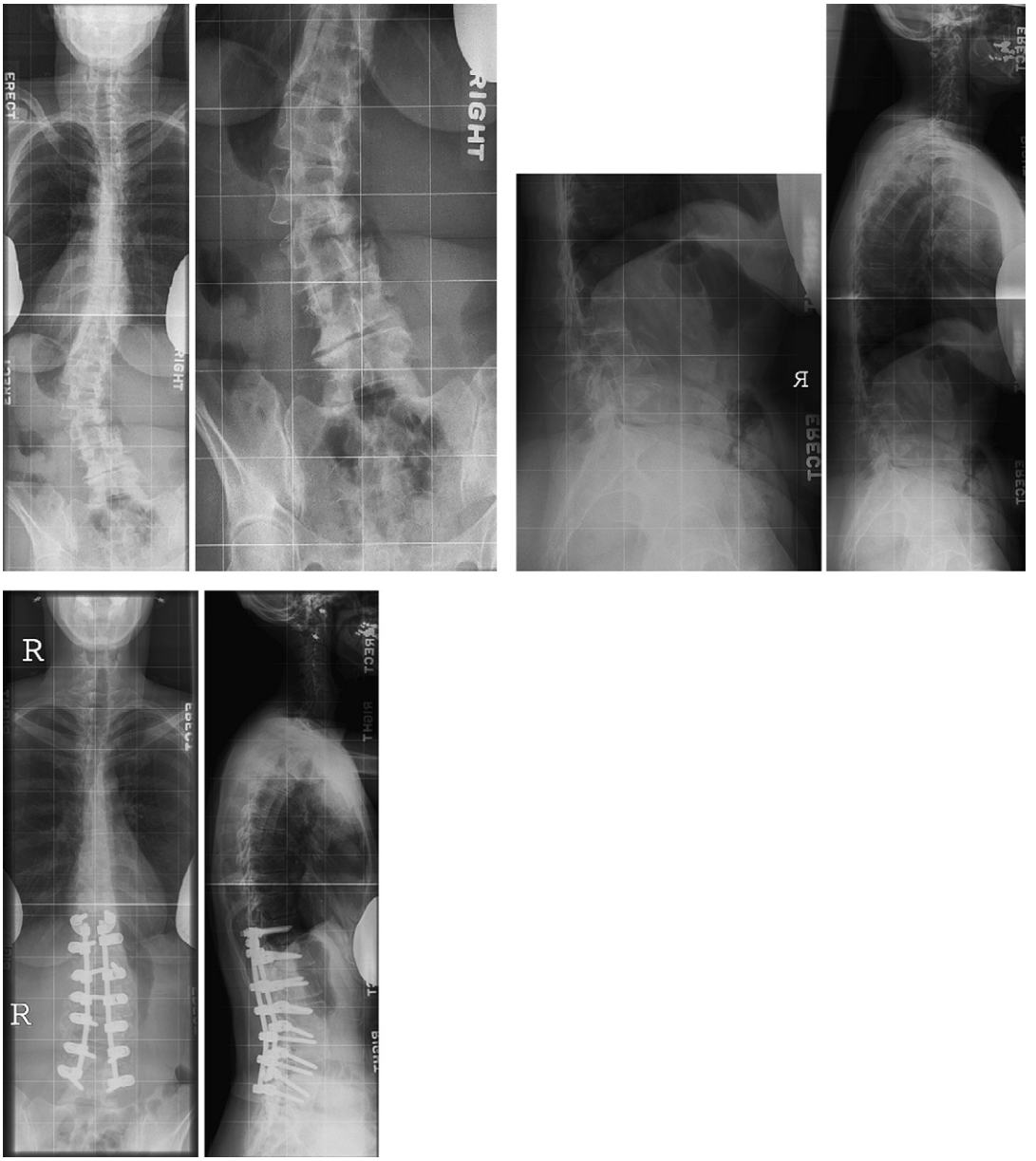

Fig. 3. Case 2: a 72-year-old woman with chronic obstructive pulmonary disease and non–insulin-dependent diabetes mellitus. The patient presented with neurogenic claudication and limited axial pain. Treatment involved a limited posterior-only fusion of the spine from T11-L5. She has not developed symptomatic degeneration at L5-S1 in 6 years of follow-up.

thoracolumbar kyphosis, curve pattern, sagittal pelvic tilt, plumb line offset, and age [28]. The radiographic variable that was most significant in this study was preoperative lumbar lordosis. Patients with less lumbar lordosis before surgery reported higher rates of satisfaction with surgery than patients with greater preoperative lordosis. Absolute postoperative lumbar lordosis and overall sagittal balance had a low correlation with clinical outcomes in this small series.

Operative options for the management of degenerative scoliosis include decompression only or decompression with an instrumented fusion. The population of patients with degenerative scoliosis

Table 3
Complications

Perioperative complications	PSF	ASF/PSF
Dural tears	4	—
Infections		
Urinary tract infection	1	1
Clostridium difficile	1	1
Line sepsis	1	—
Wound infection	1	—
Neurologic complications		
Worsened lower extremity pain or weakness	3	—
Lateral femoral cutaneous nerve palsy	—	1
Urinary retention	1	—
Altered mental status	1	1

Abbreviations: ASF, anterior spinal fusion; PSF, posterior spinal fusion.

presenting to a surgeon for care includes elderly patients with significant comorbidities. Surgical strategies that may involve less invasive approaches are useful in these patients and may limit complications and perioperative morbidity [29]. Guidelines for a less invasive operation being an adequate approach are not well established. The role of decompression only for adult degenerative scoliosis is not addressed in this study. Surgery for spinal stenosis is the most common reason for spine surgery in the elderly population [30]. Previous authors have reported that the presence of scoliosis in patients with spinal stenosis is associated with significantly worse outcomes in nonoperative and operative care [31–35]. Frazier and colleagues [34] demonstrated a clear association between preoperative spinal deformity and poor outcomes in decompressive surgery, whether or not concurrent fusion was performed. Hansraj and colleagues [36] reported similar good outcomes in patients with typical stenosis and atypical stenosis, including degenerative scoliosis, and those with atypical scoliosis were treated with decompression and arthrodesis. Overall, rates of fusion in spine surgery have increased significantly in the past decade [37]. The reasons for an increase in arthrodesis rates are multifactorial and are likely to include recognition of improved outcomes in the setting of segmental instability [38–42]. There is a limited role for decompression of the spine without arthrodesis in patients with degenerative scoliosis. The authors' indications for decompression without arthrodesis in degenerative scoliosis include a predominance of radicular pain without disabling axial pain, stenosis in the central zone, lateral recess or extraforaminal zone without foraminal stenosis, radicular symptoms on the convex side of the deformity, and an intact pars interarticularis and facet joint. The authors' surgical approach is a minimally invasive unilateral approach to the motion segment with sparing of the interspinous ligament, pars interarticularis, and facet integrity.

Decompression of the spine with concurrent arthrodesis has been advocated by most authors in the management of stenosis with scoliosis in the lumbar spine [18,33,43–46]. Previous studies on the operative management of degenerative scoliosis with inclusion of health-related quality-of-life data have been limited. Albert and colleagues [47] reported significant improvements in SF-36 scores in domains of physical function, social function, bodily pain, and perceived health change in 55 adults treated surgically for spinal deformity. The authors report that such factors as age, fusion levels, and complications do not affect outcomes at an average of 12 months after surgery. Shapiro and colleagues [48] identified 16 adults with progressive scoliosis, back pain, and spinal stenosis treated with a combined anterior and posterior approach. Sixty-nine percent of patients reported a significant improvement in pain, and 10 patients experienced major complications, 8 of whom required revision surgery. Zubriggen and colleagues [49] reported outcomes on 30 patients with degenerative scoliosis treated with decompression and segmental fixation. Twenty (67%) of 30 patients required further surgery within 3 years, including 13 patients with implant loosening. Despite the high reoperation rate, most patients self-reported their postoperative health status as good or excellent. Marchesi and Aebi [50] reported the results of surgical management of 27 patients with degenerative scoliosis using the AO-internal fixator and Cotrel-Dubousset instrumentation. The authors report a 50% improvement in coronal curves, with a limited change in sagittal balance of the spine. Four patients had a postoperative flatback deformity, and all had significant postoperative pain. Ten of 27 patients had implant breakage at an average follow-up of 4 years, and 5 patients had major complications. More than 80% of patients reported satisfactory improvement of pain and walking tolerance. Aebi [14] reports improved results with more contemporary instrumentation systems. Grubb and colleagues [51] reported on the results of surgical care for 25 patients with

degenerative scoliosis and demonstrated significantly worse results compared with adults with idiopathic scoliosis, including a higher rate of complications (40% versus 29%) and worse clinical outcomes, such as satisfaction with treatment. An important observation in the population with degenerative scoliosis is the high nonunion rate (30.4%), which accounts for significant late deterioration in pain and function and a revision rate of 36% within 4 years. Pseudarthroses were associated with posterior-only surgery to the sacrum in the patients with degenerative scoliosis.

Previous studies have offered little guidance regarding specific strategies for surgical management of patients with degenerative scoliosis. Simmons [16] recommended decompression with short instrumentation and concave distraction in patients with degenerative scoliosis with minimal rotational deformity (type 1) and longer instrumentation with rod derotation in patients with degenerative scoliosis superimposed on preexisting idiopathic scoliosis (type 2). The authors' cohort of patients with degenerative scoliosis spans a spectrum of severities that are not easily classifiable as type 1 or 2, and this article is intended to report clinical and radiographic outcomes with specific surgical strategies in patients with degenerative scoliosis. The results of this series of patients offer insight into specific strategies regarding the choice of fusion levels and the role of anterior and posterior surgery.

Regarding the choice of a caudad fusion level, Grubb and colleagues [7] and Kostuik [52] have emphasized the importance of identifying a pain generator in choosing a lower end vertebra and specifically avoiding fusion to a painful motion segment. Previous studies have demonstrated that long fusions to L5 may be unreliable and susceptible to subsequent advanced degeneration below the fusion, with loss of sagittal global compensation and compromised clinical outcome [53,54]. Extension of fusions to the pelvis have also been associated with increased perioperative complications and compromise in function, however [55]. In this series, the indications to extend a fusion to the pelvis included advanced degenerative changes apparent on plain radiographs, lumbosacral obliquity, and a clinical indication of pain from the lumbosacral motion segment. Discography was rarely used to determine fusion level, and MRI evidence of disc degeneration alone was not an indication for extension of fusion to the pelvis. The authors demonstrated no measurable difference in postoperative health status between patients fused to the pelvis and those with mobile segments in the lower lumbar spine. Thirteen patients were fused to L5; only one of these patients required extension of the fusion to the sacrum for pain, and no patient had significant sagittal plane decompensation during the follow-up period. There were two postoperative wound infections in patients fused to the sacrum and none in the group of patients fused to L5. The fusions included in this series were relatively short, and only 2 of the patients fused to L5 had a cephalad fusion level in the thoracic spine. The complications with late decompensation and subsequent advanced degeneration reported in fusions from the thoracolumbar spine to L5 were not observed in this series with shorter fusions, and the strategy of maintaining mobility at L5-S1 is demonstrated to be reliable in this series.

The choice of cephalad levels for fusion in deformity surgery is an important decision point in surgical strategies for degenerative scoliosis [56]. Lee and colleagues [57] reported a high rate of progressive kyphosis above fusions for idiopathic scoliosis and identified a preoperative kyphosis of greater than 5° as a risk factor for adjacent level kyphosis. In contrast, Mooney and Kaelin [58] reported no cases of proximal junctional kyphosis in a small series of 10 patients with short posterior fusions to T11, T12, and L1. Entebar and Cahill [59] suggest that rigid fixation of the spine at multiple levels for the management of degenerative instability may increase the risk of adjacent segment failure. Swank and colleagues [60] reported that fusions to the sacrum with an upper instrumented vertebra at L1 or L2 had poor clinical outcomes and a high rate of mechanical failure. In this series, 6 of 33 patients fused below T11 required cephalad extension of their fusion for adjacent segment degeneration or proximal kyphosis. None of the 5 patients fused to T10 or T11 required proximal extension of the fusion. A surgical strategy in which the cephalad extent of the fusion did not encompass the entire measured curve by Cobb end plates did not increase the rate of revision surgery for adjacent segment complications. This series demonstrates that extending surgical fusion and fixation to the structural thoracic spine may lead to a lower rate of revision surgery than maintaining mobile segments at the thoracolumbar junction.

The role of combined anterior and posterior surgery for adult degenerative scoliosis has not been well defined. Simmons [18] recommends a combined anterior and posterior approach or

posterior-based osteotomies in patients with a fixed kyphosis that is not passively correctable on extension films. Grubb and colleagues [51] identify the importance of a circumferential arthrodesis at L5-S1 in fusions to the sacrum in degenerative scoliosis. Aebi [14] identified a limited capacity to improve lumbar lordosis in degenerative scoliosis using segmental instrumentation without osteotomies. Hasegawa and Homma [61] describe a multilevel posterior lumbar interbody fusion technique for one-stage correction and circumferential arthrodesis. Those authors acknowledge a limited ability to improve lordosis, however, especially at L4-S1, and a high rate of adjacent segment symptomatic degeneration above circumferentially fused segments. In that series, only 4 patients had a combined anterior and posterior approach for deformity correction. The current authors' indications for a combined anterior and posterior approach to the spine in degenerative scoliosis include long fusions (above L1) to the sacrum, correction of a fixed lumbosacral obliquity, fixed kyphosis, large rigid coronal plane deformity, and osteoporosis or compromise in fixation to S1.

The operative management of degenerative scoliosis remains challenging and characterized by significant variability in approaches. This study demonstrates that improvement of pain is more reliable than improvement of function in adults with degenerative scoliosis. Comorbidities and recall bias may limit the changes in health status observed in this series. Future investigations with complete data on comorbidities and preoperative health status and back-specific outcomes questions should be useful to determine the impact of surgery on health-related quality of life in patients with degenerative scoliosis. Short fusion to L5 for degenerative adult deformity is a reliable strategy with a low revision rate. Fusion to levels below the cephalad Cobb level also seem to be reliable and may support an approach for doing less surgery in patients with adult degenerative scoliosis. Fusion to the structural thoracic spine did have a lower revision rate than fusion to T12 or to the upper lumbar spine, however. Future studies, including matched cohort analysis of similar curves and randomized prospective studies, should be useful in providing an evidence-based approach to the choice of fusion levels.

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