Adjacent-segment disease in 511 cases of posterolateral instrumented lumbar arthrodesis: floating fusion versus distal construct including the sacrum

Clinical article

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Object. The aim of this study was to study the long-term outcomes of patients undergoing instrumented posterior fusion of the lumbar spine.

Methods. The authors present 511 patients who underwent instrumented arthrodesis for lumbar degenerative disease over a 23-year period at a single institution. Patients underwent follow-up for an average of 39.73 ± 46.52 months ($\pm$ SD) after the index lumbar arthrodesis procedure.

Results. The average patient age was 59.45 ± 13.48 years. Of the 511 patients, 502 (98.24%) presented with back pain, 379 (74.17%) with radiculopathy, 76 (14.87%) with motor weakness, and 32 (6.26%) with preoperative bowel/bladder dysfunction. An average of 2.04 ± 1.03 spinal levels were fused. Postoperatively, patients experienced a significant improvement in back pain ($p < 0.0001$) and radiculopathy ($p < 0.0001$). Patients with fusions excluding the sacrum (floating fusions) were statistically more likely to develop adjacent-segment disease (ASD) than those with fusion constructs ending at S-1 distally ($p = 0.030$) but were less likely to develop postoperative radiculopathy ($p = 0.030$). In the floating fusion cohort, 31 (12.11%) of 256 patients had cephalad ASD, whereas 39 (15.29%) of 255 patients in the lumbosacral cohort had cephalad ASD development; this was not statistically different ($p = 0.295$). This suggests that caudad ASD development in the floating fusion cohort is due to the added risk of an unfused L5–S1 vertebral level. Because of the elevated risk of symptomatic radiculopathy but lower risk of ASD, patients in the lumbosacral fusion cohort had a reoperation rate similar to those undergoing floating fusions ($p = 0.769$).

Conclusions. In this paper, the authors present one of the largest cohorts in the Western literature of patients undergoing instrumented fusion for degenerative lumbar spine disease. Patients who had floating lumbar fusions were statistically more likely to develop ASD over time than those who had lumbosacral fusions incorporating the S-1 spinal segment, but were less likely to experience postoperative radicular symptoms. Additional prospective studies may more clearly delineate the long-term risks of instrumented posterolateral fusions of the lumbar spine. (<http://thejns.org/doi/abs/10.3171/2013.12.SPINE13789>)

KEY WORDS • adjacent-segment disease • arthrodesis • instrumented fusion • lumbar spine • surgery • floating lumbar fusion • back pain

POSTERIOR lumbar fusion is a common surgical procedure performed for a number of clinical indications in the lumbar spine, including degenerative conditions such as spondylolisthesis,^{1,5,6,10,12,15} scoliosis,^{8,9,14,20,24,25} and degenerative disc disease,^{2–4,18,25,26,35,40,41} as well as others such as tumor, infection,⁴⁶ and trauma.^{31,44,45,47,48} As the number of patients who have received lumbar fusions over the past 10–20 years has increased in number, new clinical entities now face the spine surgeon, including the relative contribution of L5–S1 fusion toward long-term outcomes.^{7,23,27,30,32,38,39,42,43}

Abbreviations used in this paper: ASD = adjacent-segment disease; BMP = bone morphogenetic protein.

The L5–S1 spinal segment is a transitional junction between the mobile lumbar spine and the fused sacral promontory. Biomechanically, it represents an area of increased stress, commensurate with the fact that it is a common site for degenerative spondylolisthesis and is one of the most common sites for symptomatic degenerative disc disease development. As instrumented fusion itself creates a discontinuity in the number of mobile vertebral segments in the lumbar spine, its role in affecting L5–S1 biomechanics remains unclear.^{13,22,28,29,34} Thus, although some studies demonstrate increased adjacent-segment disease (ASD) after floating fusion, others have shown that including L5–S1 in the fusion construct appears to be protective against ASD development.^{16,17,21}

Adjacent-segment disease after posterolateral lumbar fusion

To better understand the natural history of degenerative spinal disease progression after instrumented fusion, we present a series of 511 patients who received posterior lumbar instrumented fusion for degenerative etiologies at a single institution in the past 23 years. We summarize the preoperative, perioperative, and long-term postoperative outcomes of these patients. In addition, we compare the likelihood of ASD development as a function of fusion location.

Methods

Data were obtained for all patients undergoing instrumented lumbar arthrodesis for the treatment of degenerative lumbar disease at our institution over a 23-year period from 1990 to 2013. Arthrodesis procedures performed for oncology, infection, trauma, scoliosis, and rheumatological pathology were excluded. Patients with metabolic bone diseases and those undergoing interbody fusion, circumferential fusion, or thoracolumbar fusion were excluded as well. In conducting the study, we retrospectively reviewed clinical notes, operative narratives, and radiology reports. Given that this is a retrospective study, we invariably lost to follow-up some patients who moved away from the region or sought the services of other surgeons. When possible, we attempted to mitigate this factor through telephone calls to inquire about the patients' functional status and surgical history since our last follow-up.

Demographic information, such as age and sex; comorbidities, such as obesity, smoking, hypertension, diabetes, coronary artery disease, and osteoporosis; and presenting symptoms manifested by the patients, such as low-back pain, radiculopathy, weakness, sensory deficits, bowel and bladder dysfunction, were collected and documented for all patients. Intraoperative and perioperative data, such as the number of levels in the arthrodesis construct, intraoperative blood loss, hospitalization length, iatrogenic durotomies, CSF fistula, deep venous thrombosis, pulmonary embolism, infection, hematoma, wound dehiscence, discharge to rehabilitation facilities, reoperations, and instrumentation failure, were also obtained from the medical record. It should be noted that in this series, bone morphogenetic protein (BMP) was used primarily in an off-label manner. Continuous values were compared using the t-test, while binary outcomes were compared using the chi-square test.

Results

Patient Population

Between 1990 and 2013, a total of 511 patients underwent instrumented lumbar arthrodesis for the treatment of degenerative lumbar disease. The average age for this cohort was 59.45 ± 13.48 years ($\pm$ SD), and 254 patients (49.71%) were male (Table 1). Sixty-six patients (12.92%) had diabetes, 17 (3.33%) were osteoporotic, 40

TABLE 1: Preoperative characteristics of all patients undergoing lumbar instrumented fusion for degenerative spinal disease*

Parameter	Value†			p Value‡
	Total Instrumented	Floating Fusion	Lumbosacral Fusion	
no. of cases	511	256	255	
mean age in yrs	59.45 ± 13.48	61.94 ± 12.85	56.96 ± 13.65	<0.001
male sex	254 (49.71)	115 (44.92)	139 (54.51)	0.030
comorbidities				
diabetes	66 (12.92)	36 (14.06)	30 (11.76)	0.439
hyperlipidemia	68 (13.31)	35 (13.67)	33 (12.94)	0.808
COPD	4 (0.78)	2 (0.78)	2 (0.78)	0.997
coronary artery disease	62 (12.13)	40 (15.63)	22 (8.63)	0.015
osteoporosis	17 (3.33)	9 (3.52)	8 (3.14)	0.812
obesity	40 (7.83)	17 (6.64)	23 (9.02)	0.317
actively smoking	81 (15.85)	41 (16.02)	40 (15.69)	0.919
hypertension	179 (35.03)	89 (34.77)	90 (35.29)	0.605
depression	47 (9.20)	21 (8.20)	26 (10.20)	0.436
presenting symptoms				
back pain	502 (98.24)	249 (97.27)	253 (99.22)	0.094
radiculopathy	379 (74.17)	186 (72.66)	193 (75.69)	0.434
motor weakness	76 (14.87)	44 (17.19)	32 (12.55)	0.141
sensory deficits	75 (14.68)	37 (14.45)	38 (14.90)	0.886
bowel/bladder dysfunction	32 (6.26)	16 (6.25)	16 (6.27)	0.991

* COPD = chronic obstructive pulmonary disease.

† Values are the number of patients (%) unless indicated otherwise. The mean value is presented as $\pm$ SD.

‡ Values in boldface are statistically significant.

(7.83%) were morbidly obese, and 81 (15.85%) were active smokers at the time of surgery. A total of 502 patients (98.24%) presented with back pain and 379 patients (74.17%) presented with radiculopathy. Preoperative radiculopathy occurred primarily at the L-4, L-5, and/or S-1 levels. Seventy-six patients (14.87%) presented with motor weakness, 75 patients (14.68%) had sensory deficits, and 32 patients (6.26%) had preoperative bowel/bladder dysfunction.

Intraoperative Characteristics

An average of 2.04 ± 1.03 spinal levels were fused in each patient (Table 2). Bone morphogenetic protein was used in 246 patients (48.14%). Autograft was used in 400 patients (78.28%), while autograft with supplemental allograft was used in 282 patients (55.19%). The median blood loss was 650 ml (interquartile range 400–1000 ml). The majority of patients (450 [88.06%]) underwent concomitant laminectomy as part of their procedure, but only 170 patients (33.27%) also had discectomy. Twenty-seven patients (5.28%) had an intraoperative durotomy during the surgery.

Perioperative Characteristics

Perioperatively, the average length of stay was 6.22 ± 4.60 days (Table 3). Thirteen patients (2.54%) experienced a postoperative CSF leak. Eleven patients (2.15%) developed a wound infection that required operative intervention. Four patients (0.78%) experienced deep venous thrombosis, and 5 (0.98%) experienced pulmonary embolism. Fifty-one patients (9.98%) were discharged to rehabilitation.

Postoperative Outcomes

The average follow-up was 39.73 ± 46.52 months. During this period, 212 patients (41.49%) experienced continued or recurrent back pain (Table 4), and 148 patients (28.96%) experienced continued or recurrent radiculopathy. Forty-one (8.02%) and 31 (6.11%) patients

had recurrent or continued motor or sensory deficits, respectively. Sixteen patients (3.13%) had continued bowel/bladder dysfunction. The cumulative rate of ASD development over time was 15.66% (80 patients). Adjacent-segment disease was defined as radiographic evidence of degeneration at the adjacent level with clinical symptoms necessitating revision surgery. Following univariate logistical regression analysis, social and medical variables (including smoking, osteoporosis, and depression) did not statistically affect the likelihood of ASD ($p = 0.440$, $p = 0.369$, and $p = 0.490$, respectively). The overall pseudarthrosis rate was 10.76% (55 patients). In total, the rate of reoperation due to nonimprovement or worsening of symptoms was 22.50% (115 patients).

Floating Versus Lumbosacral Fusions

Among the 511 patients undergoing instrumented lumbar fusion, 256 patients (50.10%) received floating fusions, defined as those involving spinal levels L-1 through L-5. In contrast, 255 patients (49.90%) received a lumbosacral fusion that included the sacrum distally (Table 5). Regarding preoperative prognostic factors, the floating fusion cohort was statistically older ($p < 0.001$) and included a greater number of patients with coronary artery disease ($p = 0.015$), while the lumbosacral fusion cohort had a statistically higher male prevalence ($p = 0.030$) (Table 1). There was no statistical difference in the number of patients who received BMP, autograft, or allograft between either of these cohorts (Table 2). Although the floating fusion cohort was statistically more likely to undergo laminectomy ($p = 0.020$) and discectomy ($p = 0.016$), the lumbosacral fusion cohort had a statistically larger number of spinal levels fused ($p < 0.001$). While 49 patients (19.14%) in the floating fusion cohort developed ASD requiring reoperation, only 31 patients (12.16%) in the lumbosacral fusion cohort developed symptomatic ASD ($p = 0.030$). Despite having higher rates of ASD development, patients who underwent floating fusion had a lower incidence of postoperative radicular symptoms than those undergoing lumbosacral fusion ($p = 0.030$), as

TABLE 2: Intraoperative characteristics of patients undergoing instrumented arthrodesis due to degenerative spinal disease*

Parameter	Value†			p Value‡
	Total Instrumented	Floating Fusion	Lumbosacral Fusion	
no. of patients	511	256	255	
mean no. of levels fused $\pm$ SD	2.04 ± 1.03	1.64 ± 0.82	2.44 ± 1.06	<0.001
BMP	246 (48.14)	117 (45.70)	129 (50.59)	0.269
autograft	400 (78.28)	197 (76.95)	203 (79.61)	0.467
allograft	282 (55.19)	135 (52.73)	147 (57.65)	0.264
median blood loss in ml (IQR)	650 (400–1000)	600 (362.5–975)	700 (500–1000)	
incidental durotomy	27 (5.28)	8 (3.13)	19 (7.45)	0.029
laminectomy	450 (88.06)	234 (91.41)	216 (84.71)	0.020
discectomy	170 (33.27)	98 (38.28)	72 (28.24)	0.016

* IQR = interquartile range.

† Values are number of patients (%) unless noted otherwise.

‡ Values in boldface are statistically significant.

Adjacent-segment disease after posterolateral lumbar fusion

TABLE 3: Perioperative characteristics of patients undergoing instrumented fusion for lumbar degenerative spinal disease*

Parameter	Value†			p Value‡
	Total Instrumented	Floating Fusion	Lumbosacral Fusion	
no. of patients	511	256	255	
mean length of stay in days ± SD	6.22 ± 4.60	5.95 ± 4.67	6.51 ± 4.53	0.197
CSF leak	13 (2.54)	4 (1.56)	9 (3.53)	0.158
DVT	4 (0.78)	3 (1.17)	1 (0.39)	0.317
PE	5 (0.98)	4 (1.56)	1 (0.39)	0.179
wound infection	11 (2.15)	6 (2.34)	5 (1.96)	0.766
pneumonia	4 (0.78)	2 (0.78)	2 (0.78)	0.997
hematoma	3 (0.59)	1 (0.39)	2 (0.78)	0.560
wound dehiscence	5 (0.98)	0 (0.00)	5 (1.96)	0.024
myocardial infarction	3 (0.59)	2 (0.78)	1 (0.39)	0.565
death	1 (0.20)	1 (0.39)	0 (0.00)	0.318
paraplegia	1 (0.20)	1 (0.39)	0 (0.00)	0.318
discharge to rehab	51 (9.98)	30 (11.72)	21 (8.24)	0.189

* DVT = deep venous thrombosis; PE = pulmonary embolism; rehab = rehabilitation.

† Values are the number of patients (%) unless noted otherwise.

‡ The value in boldface is statistically significant.

well as a lower incidence of pseudarthrosis ($p = 0.113$), although the latter did not reach statistical significance.

Discussion

Through the emergence of newer spinal instrumentation techniques and improved imaging modalities, the prevalence of lumbar arthrodesis has continued to increase in the past few decades.^{19,21,34} With the rising numbers of patients undergoing instrumented lumbar fusion, the spinal surgeon must be able to recognize and effectively treat long-term postoperative sequelae such as ASD. Although earlier literature considers ASD a rare entity, more recent case series involving larger patient populations and longer follow-up times reveal that ASD can routinely occur in more than 20% of the population over a 10-year span.^{7,14,30,33,37}

TABLE 4: Postoperative characteristics of patients undergoing instrumented lumbar fusion for degenerative spinal disease

Parameter	Instrumentation*
no. of cases	511
mean total follow-up time in mos ± SD	39.73 ± 46.52
back pain	212 (41.49)
radiculopathy	148 (28.96)
motor symptoms	41 (8.02)
sensory symptoms	31 (6.11)
bowel/bladder dysfunction	16 (3.13)
total reop rate	115 (22.50)
reop for ASD	80 (15.66)

* Values are presented as the number of patients (%) unless noted otherwise.

There is considerable controversy over the pathophysiology of ASD.²⁷ Biomechanical studies have supported the increased prevalence of degenerative disease adjacent to the site of bony fusion. Lee and Langrana showed that there is heightened stress at the facet joints of L3–4 and L4–5 after lumbosacral arthrodesis.²⁹ Axelsson et al. assessed adjacent segments with the use of radiographic analysis and found hypermobility in the juxtaposed segment.⁴ The findings of these studies suggest that instrumented fusion can produce adverse consequences on the integrity of natural biomechanical forces. Commensurate with these findings, we found a significant portion of patients—more than 15%—who developed ASD over a mean time of approximately 40 months. Of note, in this paper, we defined ASD as radiographic disease

TABLE 5: Comparison of intraoperative and postoperative variables of patients undergoing floating versus lumbosacral fusion

Parameter	No. of Patients (%)		p Value*
	Floating Fusion	Lumbosacral Fusion	
no. of cases	256	255	
reop for ASD	49 (19.14)	31 (12.16)	0.030
postop back pain	109 (42.58)	103 (40.39)	0.616
postop radiculopathy	63 (24.60)	85 (33.33)	0.030
postop motor symptoms	20 (7.81)	21 (8.24)	0.860
postop sensory symptoms	17 (6.72)	14 (5.51)	0.570
pseudarthrosis	22 (8.59)	33 (12.94)	0.113
total reop rate	59 (23.05)	56 (21.96)	0.769

* Values in boldface are statistically significant.

with appropriate clinical symptoms requiring reoperation. This definition may underestimate the incidence of symptomatic ASD as some patients elect not to undergo surgery.

In the lumbar spine, some have hypothesized that floating fusions may give rise to higher incidences of ASD, due to the relative instability of the rostral lumbar spine relative to the caudal lumbosacral spine. In an in vitro biomechanical model, Quinnell and Stockdale demonstrated that lumbar floating fusion causes disproportionate transfer of forces caudad to the fusion construct, whereas discs cephalad to the instrumentation were less likely to be affected.³⁶ Thus, Disch et al. showed that of 102 patients who received lumbar fusions, 20% of patients who received lumbosacral fusions developed ASD, whereas 46% of those who received floating lumbar fusions developed ASD.¹¹ This outcome was clinically significant, as Oswestry Disability Index scores were significantly higher for those with ASD than those without ASD.

Our findings are consistent with this observation, as 49 patients (19.14%) in the floating fusion cohort developed ASD requiring reoperation, whereas only 31 patients (12.16%) in the lumbosacral fusion cohort developed symptomatic ASD ($p = 0.030$). Thus, patients receiving posterior instrumented fusion not including the L5–S1 level may be at heightened risk for ASD development. An alternative explanation for this observation may be the fact that fusion of the L5–S1 spinal segment eliminates the possibility of ASD development caudally, as the sacral spine is fused developmentally. Indeed, a closer examination of our patients revealed that 100% of the 31 patients who developed ASD in the L5–S1 fusion cohort had cephalad ASD development. In contrast, 10 (20.4%) of 49 patients who developed ASD in the floating fusion cohort had caudad ASD development (Fig. 1).

We wondered whether the rate of caudad ASD development influenced the rate of cephalad ASD development in patients with floating fusions. Thus, we eliminated those patients who developed caudad ASD and only compared the rates of cephalad ASD. In the floating fusion cohort, 31 (12.11%) of 256 patients had cephalad ASD, whereas 39 (15.29%) of 255 patients in the lumbosacral cohort had cephalad ASD development. This was not statistically different ($p = 0.295$). These data suggest that caudad ASD development in the floating fusion cohort is due to the added risk of an unfused L5–S1 vertebral level. That is, because the rostral incidence did not statistically differ between the two cohorts, caudad ASD in the floating cohort likely accounts for the increased incidence of ASD.

Because we included patients receiving both single- and multilevel fusions in our analysis, we wanted to examine the rates of ASD development as a function of the number of levels fused. Among patients undergoing single-level fusions, 20% developed ASD, whereas 13.0% of patients undergoing multilevel fusions (≥ 2 levels) developed ASD. This trended toward but did not reach statistical significance ($p = 0.081$), suggesting that the rates of ASD development in the lumbar spine may be related to the number of fused vertebral segments.

Fig. 1. Comparison of percentage cephalad ASD development as a function of lumbosacral versus floating fusion.

Of note, among patients with cephalad ASD after multilevel fusions, the L2–3 level degenerated in 97.3% of cases. Similarly, among patients with cephalad ASD after single-level fusions, the L3–4 level degenerated in 77.4% of cases. While the specified levels may have an intrinsically higher rate of degeneration, the increased rate of cephalad ASD at L2–3 after multilevel fusions and L3–4 after single-level fusions is likely due to the higher prevalence of first-time operations at the L3–5 and L4–5 levels, respectively.

Interestingly, although lumbosacral fusions seem to be associated with lower incidence of ASD development, patients undergoing floating fusions nevertheless experienced better outcomes in terms of radiculopathy ($p = 0.030$). This was true even though preoperatively there was no statistical difference between the incidence of radiculopathy in the floating versus lumbosacral fusion cohorts ($p = 0.434$). In fact, following a logistical regression of the lumbosacral fusion cohort, postoperative radiculopathy and pseudarthrosis were statistically correlated ($p < 0.001$). Thus, although patients receiving noninterbody lumbosacral fusions are less disposed to ASD, they are at heightened risk of postoperative radiculopathy and pseudarthrosis. Because of this, our total reoperation rate was statistically the same ($p = 0.769$).

Conclusions

In this paper, we present one of the largest cohorts of patients undergoing instrumented fusion for lumbar spinal disease of degenerative etiology. Our results demonstrate that patients undergoing instrumented fusion have statistically significant improved back pain ($p < 0.001$) and radiculopathy ($p < 0.001$) postoperatively. Patients who had floating lumbar fusions were statistically more likely to develop ASD over time than those who had lumbosacral fusions incorporating the L5–S1 spinal segment.

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Because the rostral incidence did not statistically differ between the 2 cohorts, caudal ASD in the floating cohort likely accounts for the increased incidence of ASD. Although the heightened risk of ASD increased the reoperation rate in the floating cohort, the increased rate of postoperative radiculopathy contributed to reoperations in the lumbosacral cohort. Thus, the total reoperation rate is statistically the same. Additional prospective studies may more clearly delineate the potential risk of ASD development as a function of fusion location, as well as long-term outcomes of instrumented posterolateral fusion.

Disclosure

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Author contributions to the study and manuscript preparation include the following. Conception and design: Witham, M Bydon, Xu. Acquisition of data: M Bydon, Xu, Santiago-Dieppa, Macki. Analysis and interpretation of data: M Bydon, Xu, Santiago-Dieppa, Macki, Wolinsky. Drafting the article: M Bydon, Xu, Santiago-Dieppa. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Witham. Statistical analysis: M Bydon, Xu, Santiago-Dieppa, Macki. Administrative/technical/material support: Witham, M Bydon, Sciubba, Wolinsky, A Bydon, Gokaslan. Study supervision: Witham, A Bydon, Gokaslan.

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