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SURGERY

Upper Instrumented Vertebral Fractures in Long Lumbar Fusions

What Are the Associated Risk Factors?

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Study Design. A retrospective comparative study.

Objective. To investigate the risk factors associated with upper instrumented vertebral (UIV) fractures in adult lumbar deformity.

Summary of Background Data. Long segment lumbar fusions may lead to junctional failures. The purpose of this study was to determine factors associated with junctional failures.

Methods. Twenty-seven consecutive patients from 2001 to 2008 with minimum 4 levels fused, lower instrumented vertebra (LIV) of L5 or S1, upper instrumented vertebra of T10 or distal, and no previous surgery proximal to the instrumentation were retrospectively reviewed. We describe the UIV angle, the sagittal angle of the upper instrumented vertebra with the horizontal. Patients were divided into 3 groups: group 1, 7 patients with UIV fractures; group 2, 6 patients with other proximal failures; and group 3, 14 patients with no proximal complications.

Results. The mean number of levels fused was 5.7 (4–7), 5.2 (4–8), and 6.2 (4–8); mean age was 64.1, 61.8, and 64.1, and mean body mass index was 33.5, 30.0, and 31.6 for groups 1, 2, and 3, respectively ($P > 0.05$). Osteotomies were performed in 5 of 7 in group 1, 1 of 6 in group 2, and 5 of 14 in group 3. Mean follow-up was 26.3 months. The average intraoperative UIV angle (UIV0) and immediate postoperative UIV angle (UIV1) were 18.6°/15.4° for group 1, 5.7°/5.3° for group 2, and 10.3°/7.1° for group 3 ($P < 0.05$). Surgical revision rates were higher in group 1 (71%) compared with groups 2 (50%) and 3 (43%). Eight of 11 (73%) patients with upper instrumented vertebra of L1 or L2 had either UIV fracture or other proximal failure compared with 5 of 16 (31%) in patients with upper instrumented vertebra of T10, T11, or T12.

Conclusion. Our series of long lumbar fusions had a high long-term complication and revision rate. A high UIV angle on intraoperative lateral radiograph was strongly associated with UIV fractures. UIVs of L1 or L2 had a higher rate of adjacent segment or UIV failure.

Key words: upper instrumented vertebra, adjacent segment failure, long lumbar fusions, fracture. **Spine 2012;37:1407–1414**

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Long lumbar instrumented fusions have been described for various conditions, including degenerative lumbar scoliosis, adolescent idiopathic scoliosis, sagittal imbalance, degenerative spondylolisthesis, and in revision cases such as pseudarthoses.[1–9] Spinal stabilization is often indicated in these circumstances as a means of alleviating pain, preventing spinal instability, and avoiding progression of the deformity.[1,3,7,10–12]

High rates of proximal failures have been described[2,3,5–8,13–15] with long lumbar fusions. Such failures include proximal segment degeneration, screw failure in the upper instrumented vertebra, adjacent vertebral compression fractures, and adjacent vertebral subluxations, as well as severe disc degeneration leading to proximal junctional kyphosis.[1,3,7,8,13] The majority of these complications are treated surgically with decompression or proximal extension of the instrumentation, often to the upper thoracic spine.[1–3,15]

Many theories have been used to explain these high rates of failures. Fused lumbar segments may increase stress and motion at the adjacent unfused segments accelerating degeneration of these segments and/or inducing instrumentation failure.[5,16–22] As such, various authors have stressed the importance of stopping instrumentation adjacent to stable segments with normal sagittal, coronal, and axial alignment.[3,23] Others advocate to extend instrumentation to T10 or proximal as the rib cage provides increased stability.[3,14] However, studies that have addressed this issue have found no significant difference in rates of proximal failure based solely on the level of the upper instrumented vertebra.[2,6] Other factors contributing to proximal junctional failures include increased age, osteopenia, preoperative comorbidites, thoracoplasty, male sex, preoperative kyphosis adjacent to the upper instrumented vertebra, rigid implant systems, preoperative hyperkyphotic thoracic alignment, post-operative sagittal imbalance, sagittal imbalance associated with hip and knee degeneration, and acute corrections of sagittal malalignment.[1,3,6,7,13,24]

We identified a common occurrence of upper instrumented vertebral (UIV) fracture in a large number of our cases. In retrospect, we noted a high sagittal angle of the upper instrumented vertebra in the majority of these cases. The purpose of this series was to investigate causes of proximal junctional failure including the effect of the sagittal UIV angle.

MATERIALS AND METHODS

Following Research Ethics Board approval, a retrospective review was performed on 27 consecutive patients who underwent long-segment lumbar fusion from 2001 to 2008. All surgeries were performed by the senior author at Toronto Western Hospital. Inclusion criteria consisted of patients who had a minimum of 4 lumbar levels of posterior instrumented spinal fusion, distal level of L5 or distal, proximal level of T10 or distal, and no previous thoracic procedures proximal to the upper instrumented vertebra. All constructs were pedicle screw constructs that extended to or beyond the region of the main pathology. Local autograft bone graft without the use of bone graft substitutes or extenders was used for fusion.

Clinical and radiographical data were collected by a spine surgeon, a resident, and a research assistant who were not directly involved in the care or surgical treatment of the patients. Patient demographics of age, sex, and body mass index (BMI) were measured. The number of previous spinal surgeries and total number of levels fused were also noted.

Radiographical assessment, including all preoperative, intraoperative and postoperative imaging, was measured. After the final instrumentation was completed, an intraoperative cross-table lateral radiograph was obtained before closure. The sagittal UIV angle was measured off this cross-table lateral film. The angle was measured from the inferior end plate of the upper instrumented vertebra to the horizontal (Figure 1). A lordotic angle was considered a positive UIV angle, and a kyphotic angle was given a negative UIV value. A neutral UIV angle is one in which the end plate is perfectly parallel with the horizon. All patients were placed on a Jackson Table with 4 posts. A best effort was made with the Jackson Table to position the patients parallel to the floor to obtain the best quality intraoperative radiographs.

The initial predischarge postoperative standing film was considered as the initial postoperative film. The clinical outcome was assessed using the Oswestry Disability Index (ODI).[25] All patients were followed for a minimum of 24 months or until revision surgery or death.

The patients were divided into 3 groups on the basis of outcome. Group 1 consisted of 7 patients who sustained UIV fractures postoperatively (Figure 2). Group 2 consisted of 6 patients who had other proximal complications (proximal vertebral fractures, disc herniations, proximal instrument failure or loosening, or other forms of proximal junctional kyphosis) (Figure 3). Group 3 consisted of 14 patients without proximal complications (Figure 4).

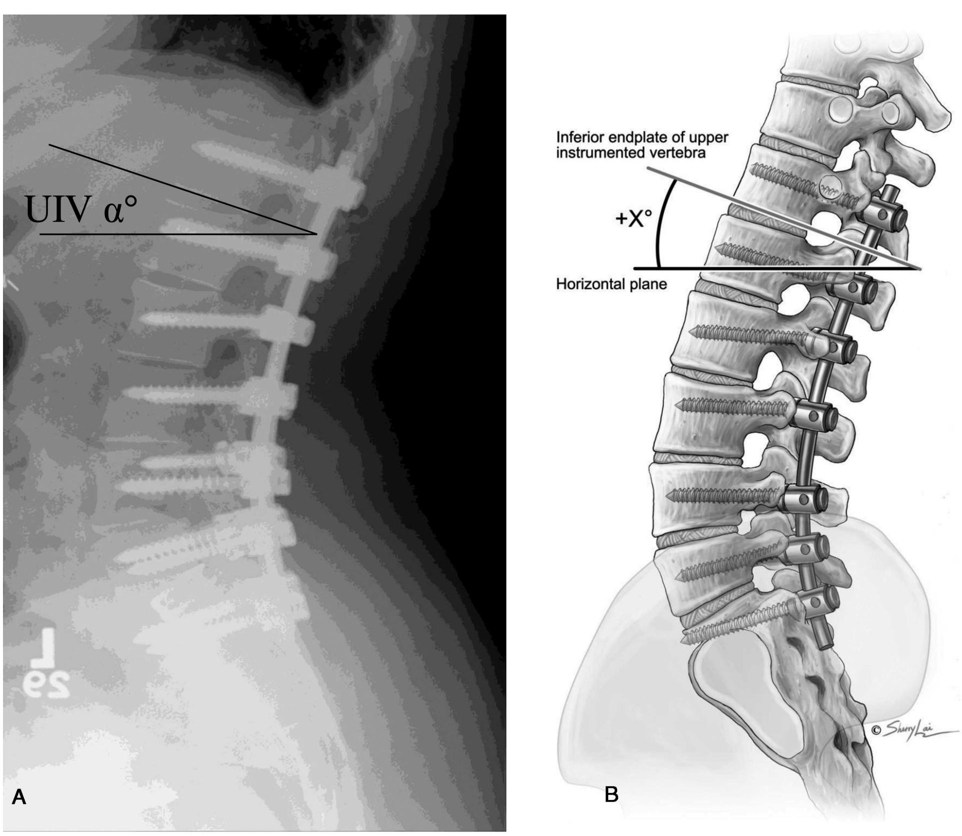

Figure 1. The UIV angle. Actual measurement **(A)** and schematic image **(B)** of a positive UIV angle. For explanations, see text. UIV indicates upper instrumented vertebral.

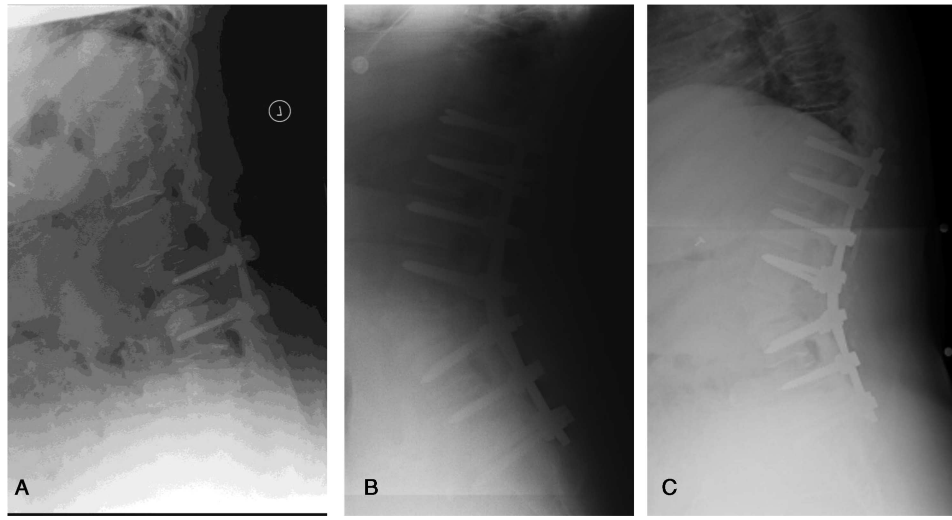

Figure 2. A patient with an upper instrumented vertebral fracture. **(A)** Preoperative image. **(B)** Intraoperative image showing posterior T11 to S1 fusion with pedicle subtraction osteotomy at L3 level. **(C)** Postoperative standing image, demonstrating a fracture of the superior end plate of T11. The patient underwent revision surgery.

Statistical analysis was performed using the SAS software to process the data within the General Linear Models (GLM procedure; SAS Institute Inc., Cary, NC).

RESULTS

Patient Demographics and Radiological and Clinical Outcomes

The majority of patients underwent surgery for degenerative kyphosis, scoliosis, or both. In group 1, there were 3 patients with degenerative scoliosis, 3 with degenerative kyphosis, and 1 with post-traumatic kyphosis. In group 2, there were 3 patients with degenerative scoliosis, 1 with degenerative spondylolisthesis with proximal degeneration, and 2 with adult idiopathic scoliosis. Group 3 consisted of 12 patients with degenerative deformities (7 with scoliosis, 4 with kyphosis, and 1 with spondylolisthesis), 1 with adult idiopathic scoliosis, and 1 with post-traumatic kyphosis (Table 1).

There were 3 men and 4 women in group 1, 1 man and 5 women in group 2, and 7 men and 7 women in group 3. There were no significant differences between the groups in mean age (64.1 yr in group 1, 61.8 yr in group 2, and 64.1 yr in group 3), mean BMI (33.5 in group 1, 30.0 in group 2, and 31.6 in group 3), levels fused (5.7 [4–7] in group 1, 5.2 [4–8] in group 2, and 6.2 [4–8] in group 3), or previous spinal surgeries (1.7 [0–3] in group 1, 1.5 [0–2] in group 2, and 0.8 [0–2] in group 3 [$P > 0.05$]).

The mean follow-up was calculated on the basis of the date of final follow-up or until the patient underwent revision or died. The mean length of follow-up was 25.7 (7–54) months for group 1, 27.5 (15–46) months for group 2, and 26.1 (1–83) months for group 3. All surviving patients who were not revised had a minimum follow-up of 24 months in group 1, 37.7 months in group 2, and 46.5 months in group 3. The mean interval between the index surgery and revision or death was 26.0 in group 1, 17.3 in group 2, and 10.8 in group 3. There was 1 death in group 1 and 2 deaths in group 3.

All 7 patients in group 1 sustained a fracture of the upper instrumented vertebra, 1 of whom was also associated with a delayed deep wound infection. Group 2 had 3 patients with

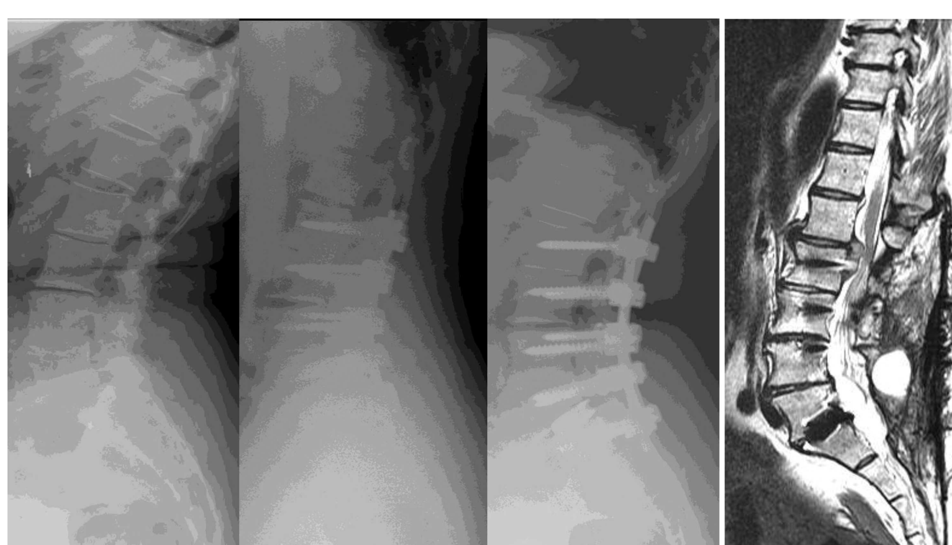

Figure 3. A patient with a large proximal disc herniation. **(A)** Preoperative image. **(B)** Intraoperative image showing posterior L2 to S1 fusion. **(C)** Postoperative standing image. **(D)** Postoperative magnetic resonance image demonstrating a large L1–L2 disc herniation above the construct. The patient underwent revision surgery.

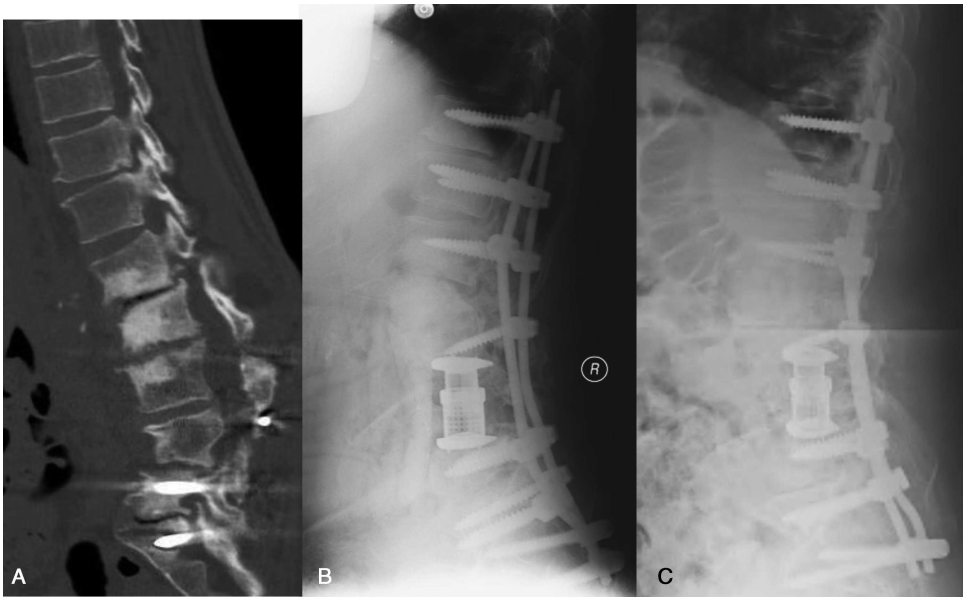

Figure 4. A patient without proximal complications. **(A)** Preoperative sagittal computed tomographic scan demonstrating lumbar kyphotic deformity following anterior and posterior fusions. **(B)** Intraoperative lateral radiograph showing posterior T12 to pelvis fusion with L2 pedicle subtraction osteotomy. Note, patient underwent previous L4 cage insertion on index procedure. **(C)** Postoperative standing image.

fractures of the vertebra proximal to the upper instrumented vertebra, 1 case of disc herniation at the level proximal to the upper instrumented vertebra, 1 case of progressive degenerative kyphosis proximal to the construct, and 1 case of adjacent segment kyphosis associated with a pseudarthrosis and loose proximal instrumentation. Group 3 had no proximal failures; however, there was 1 case of deep infection, 3 cases of pseudarthrosis, and 1 case of distal degeneration in a patient with L5 as lower instrumented vertebra (LIV).

Effect of UIV Angle on Proximal Failures

The UIV angle highly correlated with developing a fracture of the upper instrumented vertebra. The average intraoperative UIV angle (UIV0) was 18.6° in group 1, 5.7° in group 2, and 10.3° in group 3. This difference was significant between group 1 and group 2 (P = 0.0005) and between group 1 and group 3 (P = 0.01) and nonsignificant between groups 2 and 3 (P = 0.068). When comparing the UIV fracture group (group 1) with all other patients, there was a statistically significant association between the UIV0 and the incidence of UIV fractures (P = 0.002). Similarly, the average immediate postoperative UIV angle (UIV1) was 15.4° in group 1, 5.3° in group 2, and 7.1° in group 3. This difference was significant between group 1 and group 2 (P = 0.0048) and between group 1 and group 3 (P = 0.0147) but not between groups 2 and 3 (P = 0.31). Again, the association between the UIV1 and the incidence of UIV fractures was significant (P = 0.005). The differences between UIV1 and UIV0 were small and nonsignificant among the 3 groups, indicating that the intraoperative UIV angle was a good predictor of the postoperative upright measurement.

Five out of 7 (71%) patients with UIV fracture underwent revision surgery. Two other patients were symptomatic but were not offered additional surgery because of comorbidities: 1 patient had a postoperative myocardial infarction and the other had an inoperable brain tumor. Six of the 7 fractures occurred prior to the first postoperative visit (6–8 wk postoperation).

Effect of Osteotomy on Proximal Failure

In this series, patients undergoing 3-column osteotomies had a 50% (5 of 10) risk of UIV fracture. Interestingly, these 5 patients sustained UIV fractures and not other forms of proximal junctional failure. In these 5 patients, the UIV was T11 in 3 cases, T12 in 1 case, and L1 in 1 case, with a mean UIV angle of 21°. In the 5 osteotomy patients who did not develop UIV fracture, the upper instrumented vertebra was T11 in 2 cases and T12 in 3 cases, with a mean UIV angle of 10.8°.

Effect of Choice of Upper Instrumented Level on Proximal Failure

Constructs with upper instrumented vertebra of T10, T11, or T12 developed proximal junctional failures in 31% of cases (5 of 16) compared with 73% (8 of 11) of constructs with upper instrumented vertebra of L1 or L2. The surgical revision rate was similar with 50% (8 of 16) of patients with distal thoracic upper instrumented vertebra undergoing revision compared with 55% (6 of 11) of patients with upper lumbar upper instrumented vertebra, because revisions were required for other complications including pseudarthrosis and infection (Table 2).

Effect of Choice of Lower Instrumented Level

The lower instrumented level was L5 in 3 patients, S1 in 10, and pelvis in 14 cases. Iliac wing screws were not placed in patients who already had previous solid fusions at L5–S1. There was no correlation between the lower instrumented level and proximal complications (P = 0.85 for UIV fracture, P = 0.54 for other proximal failures, and P = 0.86 for all proximal complications combined). Two of the 3 patients with L5 as the distal level developed symptomatic L5–S1 degeneration requiring revision with distal extension of their fusions.

TABLE 1. Comparison of the Clinical and Radiological Data Between the Study Groups

	UIV Fracture, Group 1	Other Proximal Failures, Group 2	No Proximal failures, Group 3
	n = 7	n = 6	n = 14
Diagnosis			
Degenerative deformity	6	4	12
Post-traumatic kyphosis	1	0	1
Adult idiopathic scoliosis	0	2	1
Age (yr)—mean (range)	64.1 (55–74)*	61.8 (39–76)*	64.1 (23–80)*
Sex			
Male	3 (43%)	1 (17%)	7 (50%)
Female	4 (57%)	5 (83%)	7 (50%)
BMI—mean (range)	33.5 (21.0–43.4)*	30.0 (20.0–42.6)*	31.6 (22.2–46.1)*
Number of previous spinal surgeries	1.7 (0–3)*	1.5 (0–2)*	0.8 (0–2)*
Levels fused	5.7 (4–7)*	5.2 (4–8)*	6.2 (4–8)*
Osteotomies			
PSO	4	0	4
VCR	1	0	1
SPO	0	1	0
UIV			
T10	0	1	2
T11	3	0	4
T12	1	0	5
L1	2	3	3
L2	1	2	0
LIV			
L5	1	0	2
S1	3	2	5
Pelvis	3	4	7
Revisions (post–index surgery)	n = 5 (71%)	n = 3 (50%)	n = 6 (43%)
UIV angle 0—mean (range)	18.6 (3–26)†	5.7 ([−2]–14)†	10.3 (0–21)†
UIV angle 1—mean (range)	15.4 (4–26)†	5.3 ([−8]–16)†	7.1 ([−5]–16)†
UIV angle difference—mean (range)	−3.2 ([−10]–3)	−0.4 ([−11]–6)	−3.2 ([−18]–11)
Preoperative ODI, mean (range)	55.2 (42–70)*	49.2 (18–74)*	53.1 (22–76)*
Postoperative ODI, mean (range)	50.9 (42.2–62.2)*	44.3 (28.9–56)*	48.3 (0–73.3)*
Length of follow-up (mo)	24.0	37.7 (31–46)	46.5 (26–83)
Surviving and nonrevised	n = 1	n = 3	n = 6
Length of follow-up (mo)	26.0 (7–54)	17.3 (15–21)	10.8 (1–19)
Revised or died	n = 6	n = 3	n = 8

**P* ≥ 0.05.*

†P < 0.05 (see text for specific values).

UIV indicates upper instrumented vertebral; BMI, body mass index; PSO, pedicle subtraction osteotomy; VCR, vertebral column resection; SPO, Smith Petersen Osteotomy, LIV, lower instrumented vertebra; ODI, Oswestry Disability Index.

TABLE 2. Relationship Between the UIV Level and the Incidence of UIV Fractures, Other Proximal Complications, and the Patients Undergoing Revision Surgery

	UIV Fracture (Mean UIV Angle)	Other Proximal Failures (Mean UIV Angle)	Total Proximal Failures (%)	Revision Surgery (%)
T10, T11, and T12 (n = 16)	n = 4 (20.3°)	n = 1 (−2.0°)	n = 5 (31)	n = 8 (50)
L1 and L2 (n = 11)	n = 3 (16.3°)	n = 5 (7.2°)	n = 8 (73)	n = 6 (55)
Total (n = 27)	n = 7 (18.6°)	n = 6 (5.7°)	n = 13 (48)	n = 14 (52)

UIV indicates upper instrumented vertebral.

The third patient who developed a UIV fracture, however, was diagnosed with an inoperable brain tumor and died 17 months post–index surgery without a revision. In contrast, 50% of the patients with LIV at S1 or pelvis underwent revisions (5 of 10 and 7 of 14 patients, respectively). The mean time to revision was 17.5 months for L5, 26.8 months for S1, and 13.6 months for pelvis. For patients with LIV of S1, 4 of the 5 (80%) revisions were for proximal failures compared with 4 of 7 (57%) of the patients with the pelvis as the LIV ($P > 0.05$).

Effect of Lordosis

The initial postoperative lumbar lordosis (LL) was 44.3° (14°–61°) in group 1, 41.3° (16°–57°) in group 2, and 36.5° (15°–50°) in group 3. The mean difference between the pelvic incidence (PI) and the LL was 10.6° in group 1, 20.8° in group 2, and 15.4° in group 3. There were no statistically significant differences between the PI and the LL or the difference in the PI and LL between the groups (Table 3).

Clinical Outcome

The 3 groups were similar with regard to the mean preoperative ODI (55.2, 49.2, and 53.1 for groups 1–3, respectively) and postoperative ODI (50.9, 44.3, and 48.3 for groups 1–3, respectively). The difference between the preoperative and postoperative ODI was small and nonsignificant among the groups. Across the whole study population, we found a positive correlation between the preoperative and postoperative ODI (Pearson correlation coefficient 0.78, $P = 0.0003$). The ODI did not significantly correlate with age, BMI, number of previous spinal surgeries, or number of levels fused.

TABLE 3. Measurements of Immediate Postoperative Values of PI, LL, and Difference in PI–LL Among the 3 Groups

Groups (n)	PI	LL	Difference (PI–LL)
1 (7)	54.9° (40°–72°)	44.3° (14°–61°)	10.6° (−3°–26°)
2 (6)	62.2° (46°–76°)	41.3° (16°–57°)	20.8° (9°–47°)
3 (14)	51.9° (40°–72°)	36.5° (15°–50°)	15.4° (1°–29°)

$P > 0.05$ among all groups.

PI indicates pelvic incidence; LL, lumbar lordosis.

Effect of Coronal Balance

All patients had coronal balance within 5 cm of the central sacral line (13.1 mm in group 1, 9.2 mm in group 2, and 7.9 mm in group 3). All fusions were stopped at upper instrumented vertebrae with level vertebrae in the coronal plane without significant rotation. There was no correlation between proximal failures and coronal balance.

DISCUSSION

In this study, we found that patients undergoing 4 or more levels of lumbar fusions with high UIV sagittal angles had an increased risk of UIV fractures. The majority of these fractures occurred prior to the first postoperative visit. We think that the UIV sagittal angle is an important intraoperative consideration in determining the appropriate UIV level.

Although the UIV angle influenced proximal failure by UIV fracture, the choice of UIV level influenced the overall rate of proximal junctional failure. We noted adjacent segment disc herniations, chronic adjacent disc degeneration, and fractures proximal to the upper instrumented vertebra in 6 of our 27 patients with low UIV angles. We identified the level of the upper instrumented vertebra to be a significant factor. Fusions with upper instrumented vertebra of T10 to T12 had a proximal junctional failure rate of 31% (5 of 16) compared with a proximal failure rate of 73% (8 of 11) in fusions with upper instrumented vertebra of L1 or L2. Swank *et al*[14] observed a similar trend, with 7 of 20 patients requiring revision surgery after receiving a long lumbar fusion to L1 or L2. Only 2 of these patients had good or excellent clinical results.[14] As well, Shufflebarger et al[3] described a 50% rate of proximal adjacent segmental failures for fusions extending to L1 or L2 as well as to T11 or T12. This was in comparison with the 14% rate for fusions extending to T9 or T10.[3] Watanabe *et al*[1] reviewed 10 patients with proximal vertebral complications after long construct fusions. They described 2 groups: 1 group (n = 5) with UIV fractures and another (n = 5) with proximal vertebral subluxation. They identified age, osteopenia, BMI, preoperative comorbidities, and severe global sagittal imbalance as risk factors for proximal junctional fracture. In addition, marked correction of sagittal malalignment was considered a risk factor of UIV collapse followed by adjacent vertebral subluxation. Their conclusions were limited by their small numbers. In their series, no fusions were stopped in the lumbar spine. Their series had a higher rate of preoperative global sagittal imbalance and a greater number of segments fused (mean of 10 and 7 levels in their 2 groups compared with 5.7, 6.2, and 5.2 in our 3 groups).

The illustrative cases demonstrated in the Watanabe[1] study further supports the importance of the UIV sagittal angle. Their case with a UIV fracture had a UIV angle over 20°, whereas their case with adjacent segment fracture had a UIV angle less than 10° at the early postoperative standing radiograph. We think that their conclusion regarding correction of the sagittal alignment with osteotomies as risk factor for UIV fracture is more related to the high UIV angle created by the osteotomy as opposed to the correction itself. In our series, osteotomies were not a significant risk factor as we consciously fused to a more proximal level upper instrumented vertebra after having some early failures with such patients.

Intraoperatively, we now routinely check the UIV sagittal angle, with a conscious effort to fuse to a neutrally angled vertebra. Because the intraoperative radiograph is obtained in a prone patient in the operating room, there are inherent differences between this radiograph and the one obtained with the patient standing. These include the possibility that the operating room table is not completely level, the technician may not have obtained the radiograph parallel to the floor, and the patient is not standing. Despite these considerations, we found the difference in the UIV angle between the first standing radiograph and the intraoperative shoot-through film to be a mean of 3.2° in group 1, 0.4° in group 2, and 3.2° in group 3. Although the odd patient had larger differences, we think that as a whole the intraoperative shoot-through film provides valuable information on the UIV sagittal angle. Care must be taken to ensure that the upper instrumented vertebra is visible on intraoperative imaging. From this study, we think that the use of the intraoperative shoot-through lateral radiograph provides information in the operating room that surgeons can use to influence their intraoperative decision making on fusion levels.

We noted a high surgical revision rate in our series of 51.9% (14 of 27). These included revisions for infection (2), proximal junctional failures (8), and pseudarthrosis (4). We attribute the high failure rate to a multitude of factors. The most important is the lack of creating adequate sagittal balance among the 3 groups. With the mean PI of 54.9° (40°–76°) in our 27 patients, we would estimate that we would require an LL that measured within 10° of the measured PI.[26] The measured PI–LL was well below this in our groups, measuring 15.4° (1°–29°) in group 3 with no proximal failures and 20.8° (9°–47°) in group 2 which sustained proximal failures but not UIV fractures. Interestingly, group 1, the UIV fracture group had the best balance with a PI–LL of 10.6° (−3° to 26°). This further implicates the high UIV angle as the primary factor in this type of proximal failure. The low LL relative to PI may account for the high revision rate and poor ODI scores in this series. Other factors contributing to the high failure rate include a high rate of revision procedures, in which adding on adjacent segment degeneration was a major indication for surgery, long follow-up, high reliance on local bone graft, and in retrospect, poor choice of fusion levels. We think that the lessons we learned from this series will help minimize our complications and revision rates going forward.

Like other studies, this series is limited by the small numbers. Nevertheless, we think that our conclusions related to fusion levels and the UIV sagittal angle are significant findings. A multicenter setting based on this study's results may help further validate these findings and other findings in this study to provide surgeons with a better understanding in choosing appropriate fusion levels for their patients with degenerative lumbar conditions.

CONCLUSION

Our series of long lumbar fusions had a high long-term complication and revision rate. Although undercorrection of the sagittal balance in this series may have contributed to some of the poor outcomes, a high sagittal angle (mean, 18.6°) of the upper instrumented vertebra relative to the horizontal (UIV angle) on intraoperative lateral shoot-through radiographs and postoperative standing radiographs was strongly associated with early fractures of the upper instrumented vertebra. On the basis of the findings of this study, we recommend that long lumbar fusions should not be stopped at proximal levels with a high sagittal UIV angle.

➢ Key Points

- ❑ The angle of the upper instrumented vertebra relative to the horizontal in the sagittal plane is termed the "UIV angle."
- ❑ In this series, a high UIV angle was associated with fractures of the upper instrumented level.
- ❑ The fracture of the upper instrumented vertebra was noted within 8 weeks of surgery in 6 of 7 patients.
- ❑ Fracture of the upper instrumented vertebra occurs with high UIV angle despite a PI minus LL difference that approximates normal.

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