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Lateral Lumbar Interbody Fusion for the Correction of Spondylolisthesis and Adult Degenerative Scoliosis in High-Risk Patients: Early Radiographic Results and Complications

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ABSTRACT

Background: Lateral lumbar interbody fusion (LLIF) is not associated with many of the complications seen in other interbody fusion techniques. This study used computed tomography (CT) scans, the radiographic gold standard, to assess interbody fusion rates achieved utilizing the LLIF technique in high-risk patients.

Methods: We performed a retrospective review of patients who underwent LLIF between January 2008 and July 2013. Forty-nine patients underwent nonstaged or staged LLIF on 119 levels with posterior correction and augmentation. Per protocol, patients received CT scans at their 1-year follow-up. Of the 49 patients, 21 patients with LLIF intervention on 54 levels met inclusion criteria. Two board-certified musculoskeletal radiologists and the senior surgeon (JZ) assessed fusion.

Results: Of the 21 patients, 6 patients had had previous lumbar surgery, and the cohort's comorbidities included osteoporosis, diabetes, obesity, and smoking, among others. Postoperative complications occurred in 12 (57.1%) patients and included anterior thigh pain and weakness in 6 patients, all of which resolved by 6 months. Two cases of proximal junctional kyphosis occurred, along with 1 case of hardware pullout. Two cases of abdominal atonia occurred. By CT scan assessment, each radiologist found fusion was achieved in 53 of 54 levels (98%). The radiologists' findings were in agreement with the senior surgeon.

Conclusion: Several studies have evaluated LLIF fusion and reported fusion rates between 88%-96%. Our results demonstrate high fusion rates using this technique, despite multiple comorbidities in the patient population. Spanning the ring apophysis with large LLIF cages along with supplemental posterior pedicle screw augmentation can enhance stability of the fusion segment and increase fusion rates.

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INTRODUCTION

As the spine ages, disc degeneration with resulting instability often occurs. Patients can present with a wide spectrum of instability, from 1-level spondylolisthesis to multilevel degenerative scoliosis. Adult degenerative scoliosis (ADS) is a common problem in the United States.[1-4] Asymmetric degeneration and instability can lead to spondylolisthesis, sagittal malalignment, and coronal malalignment, all of which can cause back pain and neurologic compromise from spinal stenosis. In a majority of the cases, back pain is the presenting complaint.[1-5]

Once nonoperative measures have failed, surgery can be indicated to correct the sagittal and coronal imbalances and decompress the spinal stenosis, offering relief of both the patient's back and leg symptoms. Although multiple techniques have been reported for the correction of degenerative lumbar pathology, both the anterior and posterior spinal columns must be addressed to fully address the pathology.[6]

Interbody spinal fusion was initially described using an anterior lumbar interbody fusion (ALIF)

technique or a posterior approach using either the posterior lumbar interbody fusion (PLIF) technique or transforaminal lumbar interbody fusion (TLIF) technique.[7-10] More recently, a less invasive lateral lumbar interbody fusion (LLIF) technique has been described using cages inserted through a direct lateral transpsoas approach.[9,10] This approach reportedly has an increased biomechanical advantage along with decreased risk of complications seen with other interbody techniques.[7,8,11]

The primary goal of interbody fusion is to achieve a solid arthrodesis. Secondary goals can include deformity correction and indirect spinal canal decompression. Standard x-rays, flexion-extension x-rays, computed tomography (CT) scans, and magnetic resonance imagining (MRI) can be used to assess fusion. Recently, CT scans have been shown to have greater intraobserver and interobserver reliability in assessing bony fusion compared with other modalities.[12,13]

Increased age, smoking, poor bone quality, obesity, previous surgery, and multilevel procedures are risk factors associated with increased perioperative complications, including infection and pseudarthrosis.[14] Biomechanical stability also has been shown to influence fusion rates.[15,16] Spanning the ring apophysis with large LLIF cages along with supplemental posterior pedicle screw augmentation can enhance stability of the fusion segment and increase fusion rates.

Few studies have used CT scans, the radiologic gold standard, to assess fusion achieved using the LLIF technique.[17] In this article, we present our early radiographic results of fusion and complications for the correction of lumbar degenerative conditions, including spondylolisthesis and ADS, after LLIFs with oversized lateral cages and posterior pedicle screw augmentation in high-risk patients.

METHODS

After institutional review board approval, a retrospective review of a single surgeon's (JZ) hospital records at a single institution from January 2008 to July 2013 was performed. All patients who underwent LLIF by the senior author during this time period for any diagnosis and who received their scheduled CT scan 1 year postoperation were included. No patients were excluded because of age, smoking history, history of diabetes, bone mineral density, body mass index (BMI), history of previous surgery, or number of levels fused. All patients had been treated nonoperatively with activity modification, nonsteroidal antiinflammatory drugs, physical therapy, and/or steroid injections prior to undergoing LLIF. Patients' office and hospital charts, preoperative and postoperative radiographs, and 1-year postoperative CT scans were reviewed.

Forty-nine patients who underwent fusion on 119 levels utilizing the LLIF technique were identified during this review time period. Of those initially identified, 21 patients with LLIF intervention on 54 levels had reached the 1-year postoperation date and received their follow-up CT scan.

Eleven patients had the diagnosis of ADS and 10 patients had spondylolisthesis with or without stenosis. All patients in this cohort had back pain with leg symptoms. LLIF levels included 3 1-level procedures, 7 2-level procedures, 8 3-level procedures, 2 4-level procedures, and 1 5-level procedure. Anatomical levels instrumented with LLIF included 1 T12-L1, 3 L1-L2, 11 L2-L3, 18 L3-L4, and 21 L4-L5. In this cohort, all patients were augmented with posterior pedicle screw instrumentation.

Although the same technique for interbody cage placement and posterior instrumentation was used for all patients, some patients required a greater number of levels to be fused laterally. Also, some patients required more extensive osteotomies posteriorly to correct their deformity. Patients with scoliosis had their lateral interbody procedure approached through the concavity of the curve to minimize the size of the skin incision. For patients without a scoliotic curve, we approached the spine from the patient's left lateral side. The vascular structures are more anterior relative to the psoas muscle on the patient's left side and tend to provide a safer corridor to the lateral lumbar spine than the patient's right side. The skin incision was made obliquely, oriented in line with the ribs. The musculature was split individually for each level. Secondary to the orientation of the disc spaces, a single muscular dissection could be used to access multiple levels. A transpsoas approach through a tubular retractor was used to gain access to the operative levels. Intraoperative neuromonitoring (mechanomyography [MMG] or electromyography [EMG]) was employed to monitor the lumbar plexus. The starting point for all lateral procedures was midaspect of the disc at the junction of zones 2 and 3 according to the Uribe et al method.[18] After complete discectomy and endplate preparation, the contralateral superior and inferior annulus was released with a Cobb elevator. Bullet distractors were inserted to assess optimal length and height of the cages and confirmed with fluoroscopy. Cage lengths were oversized by 5 mm to ensure the ring apophysis was spanned. All cages were lordotic and 19 mm wide, anterior to posterior. Infuse (Medtronic; bone morphogenetic protein [BMP], 2 mg per level) wrapped around Mastergraft (BioHorizons; hydroxyapatite and beta-tricalcium phosphate) strips was

Table 1. Patient Characteristics

Variable	Value
Mean age, years	66.6
Sex	16 female, 5 male
Mean body mass index	27.9
Diagnosis	
Adult degenerative scoliosis	11
Spondylolisthesis ± spinal stenosis	10
Pseudarthrosis	1
Lateral instrumented levels	
T12-L1	1
L1-L2	3
L2-L3	11
L3-L4	18
L4-L5	21
Blood loss (avg)	
Lateral stage, mL	201.5
Posterior stage, mL	1267

placed inside the chambers of the polyetheretherketone lateral cages. Cage placement was confirmed with intraoperative fluoroscopy to ensure that the ring apophysis was bridged and the endplates were not violated.

When 3 or more LLIFs had to be performed, a staged approach was used and the posterior pedicle screw instrumentation was performed 2 days after the index LLIF procedure. In this study's cohort of patients, staged posterior fusion was performed in 11 patients (37 levels). The other 10 patients were fused posteriorly during the same LLIF anesthesia session. Posterior fusion was carried out from T3-ilium in 1 patient, T5-ilium in 1 patient, T9-ilium in 1 patient, T10-ilium in 4 patients, T12-ilium in 1 patient, L1-S1 in 1 patient, L2-S1 in 2 patients, L3-S1 in 1 patient, L4-S1 in 1 patient, L3-L5 in 6 patients, and L4-L5 in 2 patients. Laminectomies were performed in 6 patients and Smith-Petersen osteotomies were performed in 6 patients.

Posterior instrumentation with unilateral (2 patients, both L4-L5 single-level fusions) or bilateral pedicle screws and rods was performed with either a minimally invasive surgery (MIS) percutaneous or an open technique. Unilateral pedicle screw augmentation was performed with the patient still in the lateral decubitus position. The patient was positioned prone for the placement of all bilateral pedicle screws, either in an open or an MIS percutaneous fashion. In cases where the fusion extended to the sacrum or ilium (11 patients, 52%), the L5-S1 disc space was fused using a TLIF technique because the iliac crest and neurovascular structures prevent LLIF at this level. Rods were precontoured and placed either in an open fashion using direct visualization or in an MIS percutaneous fashion using the screw towers extending out of the skin as a guide.

Finally, prior to closing, all cases were augmented with vancomycin powder. Each lateral case was augmented with 1 g vancomycin powder and each posterior case was augmented, based on the size, with 500 mg to 2 g of vancomycin powder.

As a part of our postoperative protocol, CT scans with coronal, sagittal, and axial thin-cut (1 mm) reconstruction images were obtained on all operative levels at 1 year postoperation. The CT scans were assessed for the presence of fusion and bridging bony trabeculae traversing the entire operative disc space from endplate to endplate, either through or adjacent to the implant. Two independent board-certified musculoskeletal radiologists and the senior surgeon assessed each CT scan for fusion.

RESULTS

Five males and 16 females were identified. The average age was 66.6 years (range, 42-83 years). Average height and weight were 166 cm (range, 150-183 cm) and 78.14 kg (range, 49-110 kg), respectively. The average BMI was 27.9 (range, 19.7-43.9). Patient characteristics are listed in Table 1.

Comorbidities are listed in Table 2. The patient cohort included 2 active smokers (9.5%) and 10 former smokers (47.6%). Four patients had diabetes mellitus (19.1%), 9 patients had osteopenia (42.9%), and 5 patients had osteoporosis (23.8%). Thirteen patients (61.9%) were overweight (BMI >25) and 8 patients (38.1%) were obese (BMI >30). Six patients had had previous lumbar surgeries (28.6%).

Blood loss was calculated for each surgery. Blood loss averaged 201.5 mL for single-stage or stage 1 of the surgeries, including the LLIF portion of the procedure. Blood loss for the second stage, including MIS or open posterior augmentation along with open

Table 2. Medical Comorbidities

Comorbidity	Number of Patients (%) n=21
Smoking	
Current	2 (9.5)
Former	10 (47.6)
Never	9 (42.9)
Diabetes mellitus	4 (19.1)
Osteoporosis	5 (23.8)
Osteopenia	9 (42.9)
Obesity	8 (38.1)
Hypertension	17 (80.9)
Coronary artery disease	5 (23.8)
Rheumatoid arthritis	1 (4.8)

Table 3. Postoperative Complications

Complication	Number of Patients Affected (%) n=21	Comment
Anterior thigh pain/weakness	6 (28.6)	Resolved as early as postoperative day 2, and all resolved by 6 months
Proximal junctional kyphosis	2 (9.5)	Both cases required revision
Hardware failure	1 (4.8)	One hardware pullout in a patient with osteoporosis
Abdominal atonia	2 (9.5)	One resolved at 6 months, and 1 continues
Dural tear	1 (4.8)	Previous lumbar surgery

osteotomies, laminectomies, and/or iliac screw placements, averaged 1,267 mL. Total operative time averaged 312.9 minutes (range, 114-617 minutes) for the single stage/lateral stage procedures and 446.5 minutes (range, 219-626 minutes) for the second stage of the staged procedures.

Complications occurred in 12 patients (57.1%) (Table 3). The most common complication was anterior thigh pain and weakness on the ipsilateral side of the approach in 6 patients (28.6%). Three of these 6 patients had anterior thigh pain (14.3%) that resolved within 3 months. Two patients had postoperative quadriceps weakness (9.5%); 1 patient had 4/5 motor strength that resolved within 3 months; and the other patient had 3/5 motor strength that resolved within 6 months.

One dural tear was encountered in a patient who had had previous posterior lumbar decompression surgery. Proximal junctional kyphosis requiring surgical revision was observed in 2 patients (9.5%), both of whom had osteoporosis. Abdominal atonia was observed in 2 patients (9.5%) who both had multilevel procedures performed for ADS. One patient's atonia resolved within 6 months; the other's has yet to resolve. Hardware failure occurred in a patient with osteoporosis. No vascular injury, ileus, infection, deep vein thrombosis or pulmonary embolism, urinary tract infection, or other medical complications occurred in any patient.

Both independent radiologists' assessments were in agreement; they found that 53 of 54 levels (98%) demonstrated definitive solid fusion evidenced by continuous bridging bony trabeculae from endplate to endplate (Figure 1). One 77-year-old male patient with a history of osteoporosis, diabetes, and 2 previous lumbar surgeries had a 1-level L4-L5 LLIF performed that did not achieve the bridging trabeculae. Fusion was visualized cranially and caudally at the endplate graft interface, but continuous bridging bony trabeculae from endplate to endplate was not seen on a single CT image. No evidence of radiolucent lines, pseudarthrosis, moderate subsidence, or catastrophic endplate failure was detected. This finding was in agreement with the senior author's assessment.

Figure 2 illustrates a common patient's preoperative and postoperative x-rays.

DISCUSSION

As the spine degenerates, it can become unstable. Patients can present with a spectrum of instability from 1-level spondylolisthesis to multilevel degenerative scoliosis. To address the pathology, spinal fusion is often indicated. Anterior column support and fusion and posterior instrumented fusion have been shown to have advantages over posterior instrumented fusion alone.[15,16] Additionally, in patients with ADS, the spinal deformity can be rigid and may require both anterior and posterior column attention to fully address and correct the pathology.[16]

ADS is thought to develop as a result of asymmetric degeneration of the spine. Defined as a spinal curvature greater than 10 degrees, ADS most commonly occurs in the lumbar spine.[19-21] A vast majority of patients present with pain as their main complaint.[22,23] Although nonoperative treatment is the initial management in most cases,[5] if this treatment fails, selective patients have seen significant improvement in their back and leg pain, along with their quality of life, with surgical correction.[24,25]

The goals of surgery for spondylolisthesis and ADS are to restore the spinal alignment to a more anatomical position and to alleviate neural compression. Maintenance of this revised spinal alignment can be accomplished using a number of different fusion techniques. Anterior column procedures can include discectomies, ligamentous releases, corpectomies, and interbody fusions to realign and fuse the spine. Posterior procedures can include decompressive laminectomies, corrective osteotomies, and interbody fusion, along with various types of instrumentation.

Interbody fusion for degenerative spinal conditions has increased in popularity since its modern introduction by Lane and Moore in 1948.[26] Originally proposed for anterior approaches, interbody fusion

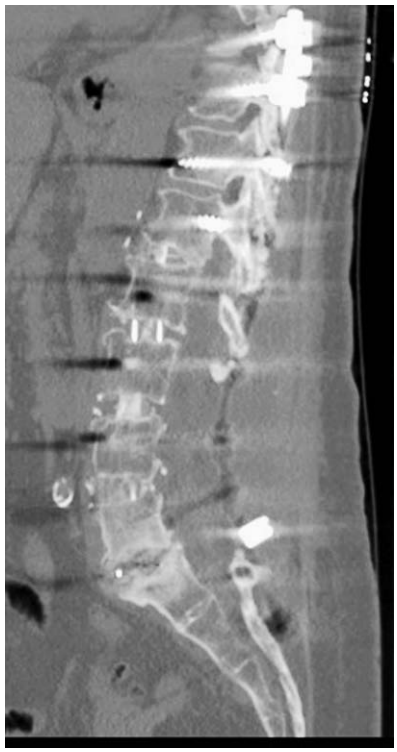

Figure 1. Postoperative computed tomography scan of a patient with 4-level lateral fusion and posterior instrumentation showing bridging trabeculae at each interbody level.

has since been described using posterior approaches (PLIF) and transforaminal approaches (TLIF). Reported fusion rates among the ALIF, PLIF, and TLIF techniques vary between 80%-98%.[27-30] More recently, LLIF, described by Bergey et al[31] and Ozgur et al,[32] allows for interbody fusion while avoiding some of the potential complications inherent to the other techniques.

The lateral transpsoas interbody fusion technique offers several advantages over the other interbody techniques. Gaining access to the spine through a less invasive transpsoas approach avoids retroperitoneal structures such as the ureter, sympathetic chain, and major vascular structures, all of which are notably endangered by the anterior spinal approach.[7,8] Moreover, a transpsoas approach avoids perineural fibrosis, the risk of dural tears, and injuries to the thecal sac and nerves when performing posterior interbody fusion using the PLIF and TLIF techniques.[8,11,30]

Improved stability can also be obtained from the LLIF cages themselves because they are much larger and wider than PLIF and TLIF cages. Wider interbody cages have the potential benefit of support from the stronger apophyseal ring and may lead to less subsidence and more stability.[33] Larger cages also offer more space and surface area for bone graft incorporation, potentially leading to higher fusion rates. Additionally, the LLIF approach preserves the anterior longitudinal ligaments and posterior longitudinal ligaments that provide inherent stability.

The lateral transpsoas approach to interbody fusion is not without limitations.[10,32,34] The iliac crest prohibits lateral access to the L5-S1 level so it cannot be addressed using this direct lateral approach. Additionally, a high-riding iliac crest can often block lateral access to the L4-L5 level, requiring ALIF, PLIF, or TLIF techniques to achieve interbody fusion. In a similar fashion, the ribs can obstruct access to the T12-L1 and L1-L2 levels. Preoperative lateral radiographs can often identify these access limitations.

An inherent limitation to this approach is direct psoas muscle trauma from the retractor and its proximity to the lumbar plexus. Whether the etiology is psoas muscle trauma or nerve irritation and injury, anterior thigh dysesthesias and/or quadriceps weakness can result.[10,31,32,35] Using MMG and EMG neuromonitoring during transpsoas LLIF procedures is critical to decrease the risk of neurologic injury resulting from direct nerve trauma or stretch.[36]

The goals of any spinal surgery are to relieve compression, eliminate instability, and correct deformity to a more anatomical spinal alignment. When spinal fusion is required, interbody fusion has been shown to help achieve a solid arthrodesis.[17,37,38] The senior surgeon began using the LLIF technique for selected spinal pathology in 2008. A standard intraoperative and postoperative protocol was established that includes a 1-year postoperative CT scan to assess fusion.

Our study is one of the few studies that includes all patients undergoing LLIF, regardless of risk factors. No patients were excluded despite previous surgical history, smoking history, bone density, diabetes, or BMI. Additionally, multilevel procedures were included in the data.

All of the patients in this study had an LLIF procedure performed with a similar technique used for each lateral procedure. In this study cohort, a wide range of posterior osteotomies was performed in addition to the standard posterior instrumentation, depending on the pathology addressed. Many of the cases were complex and required multilevel procedures. Six cases involved multiple posterior osteotomies to realign the spine. Additionally, 6 patients had had previous lumbar surgery that was revised with our procedure. Our patient population included patients who were diabetic, obese, or smokers or who had osteopenia or osteoporosis. Most patients had multiple risk factors. One patient was a former smoker, obese, and diabetic. The

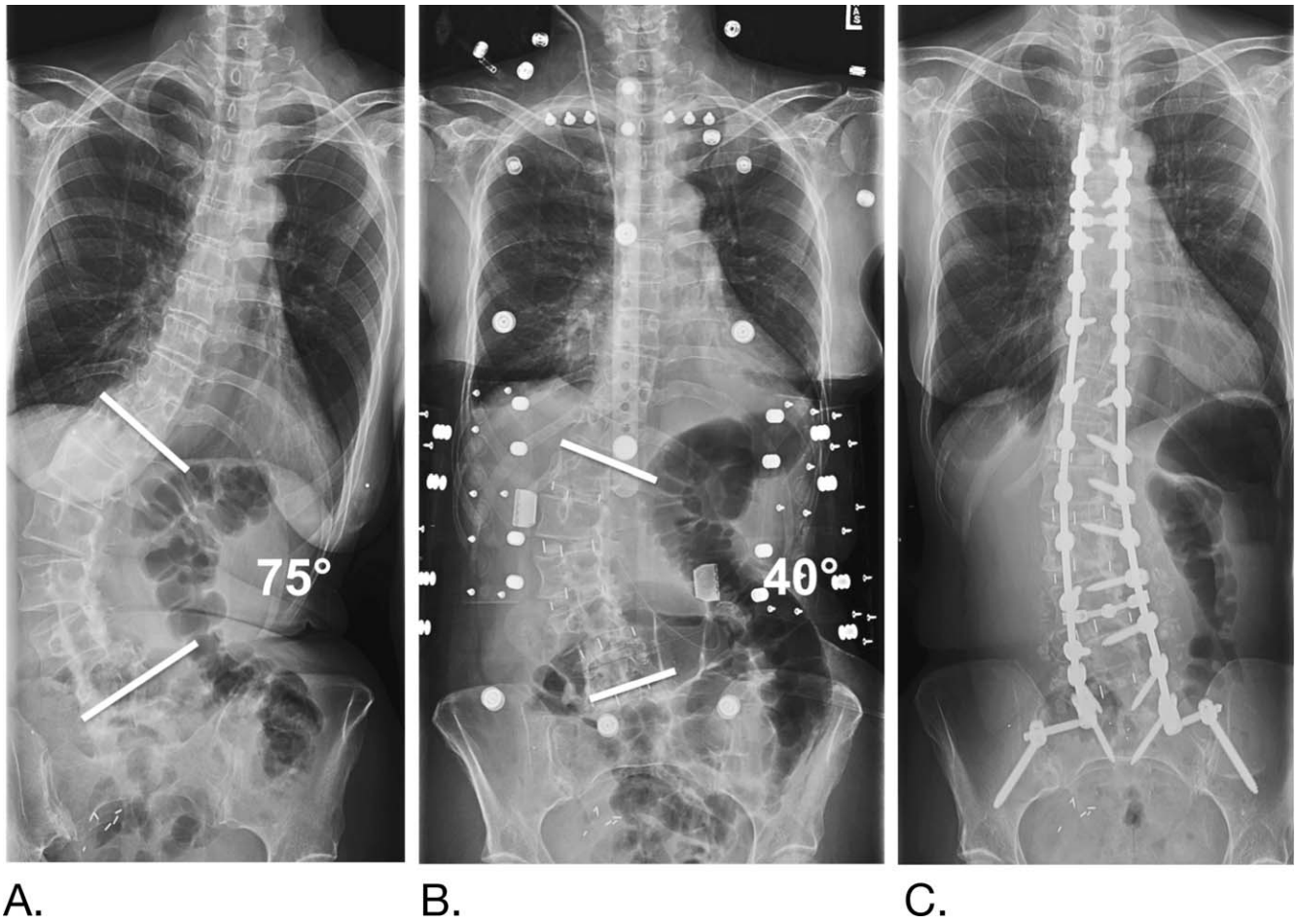

Figure 2. A: Preoperative x-ray of a patient with degenerative lumbar scoliosis showing a 75-degree lumbar scoliotic curve with lateral spondylolisthesis at L4-L5. B: X-ray of the same patient after the lateral (first) stage of the 2-stage procedure. The curve has been reduced to 40 degrees with the lateral procedures alone. C: X-ray of the same patient after the posterior instrumentation stage of the procedure. The scoliotic curve has been almost fully corrected. The sagittal balance has also been restored although it cannot be seen in this view.

patient underwent a 2-level fusion procedure and achieved a solid fusion.

Another unique feature of our study is the involvement of 2 board-certified musculoskeletal radiologists for independent evaluation of fusion. Each radiologist independently and blindly assessed fusion, both agreeing that all but 1 level showed solid fusion (98%). Although both radiologists felt that this 1 level was fused, it did not demonstrate the solid, contiguous bridging trabeculae spanning from endplate to endplate on a single CT slice. Pseudarthrosis and/or radiolucencent lines were not evident above or below the cage and the cage endplate interfaces showed evidence of fusion. The patient who did not experience fusion was a 77-year-old male with a history of diabetes and osteoporosis, a BMI of 25.9, and 2 previous surgeries, including an L4-L5 microdiscectomy and subsequent L4 decompressive laminectomy, who presented with continued back and leg pain. He underwent a left L4-L5 LLIF with bilateral posterior MIS percutaneous L4-L5 pedicle screws. To date, his leg and back pain have resolved, but he occasionally complains of pain over his left sacroiliac joint.

Our fusion results with this technique are equal to the reported LLIF fusion rates of 88%-96%.[17,36,37] We feel our high fusion rate, despite performing multilevel procedures in elderly patients with a history of previous surgeries, smoking, diabetes, osteopenia or osteoporosis, and/or obesity, is multifactorial. Complete discectomy and meticulous endplate preparation without violation are key, especially in revision cases. Stabilization of the fusion segment is critical and we oversize the length of our lateral cages by 5 mm to provide stability. We ensure each cage spans the ring apophysis, the strongest portion of the vertebral endplate located at the outer rim of the endplate. Multiple studies

have demonstrated the posterolateral cortical ring apophysis to be the strongest area of the vertebral endplate.[39,40] Zavatsky et al have shown in a biomechanical study that spanning the ring apophysis with a lateral cage not only increases the load to failure of the endplate by greater than 30%, but it also can mitigate the effects of osteoporotic bone or accidental endplate decortications.[33] Additionally, because posterior pedicle screw instrumentation further stabilizes the construct to aid in fusion, we augment our constructs posteriorly with pedicle screws, especially in patients with poor bone quality. Our patient population experienced no cases of frank pseudoarthrosis or catastrophic subsidence.

Several studies have evaluated LLIF fusion rates but only 1 previous study used CT scans to evaluate fusion in all patients.[17,38] Most studies describe using a combination of radiographs and CT scans to evaluate fusion, which is not the radiographic gold standard to assess fusion. Because the use of CT to evaluate fusion for interbody fusion procedures has been shown to have greater interobserver and intraobserver reliability,[15] we chose this imaging modality to assess fusion.

We had complications in 12 patients (57.1%) in this cohort. Anterior thigh pain and weakness was the most common complication and occurred in 6 patients (28.6%). All thigh symptoms resolved within 6 months postoperation. Because this study cohort encompasses many patients treated earlier in our experience with the LLIF technique, a learning curve could have contributed to our results. Additionally, the use of MMG is thought to have decreased the incidence of lumbar plexus injuries; no cases of quadriceps weakness have occurred since we began using MMG in 2010. In the 2 cases of quadriceps weakness in this cohort, EMG was exclusively utilized to monitor the lumbar plexus. The inherent psoas trauma associated with this approach may have contributed to the anterior thigh symptoms observed, especially in multilevel procedures. Multilevel procedures result in increased psoas trauma and can result in anterior thigh symptoms associated with startup pain when the patient stands up from a sitting position secondary to the firing of the psoas muscle with this activity. In our patient cohort, all 5 patients who had anterior thigh symptoms had multilevel procedures performed. Two patients had a 2-level procedure performed, 2 patients had a 3-level procedure, and 1 patient had a 5-level procedure performed.

Other complications included hardware pullout in an 83-year-old male with osteoporosis requiring proximal extension of his fusion. Proximal junctional kyphosis occurred in 2 patients, both of whom had osteoporosis and required extension of their fusion cranially. Two female patients had postoperative abdominal atonia on the side of the lateral approach. In 1 patient, the abdominal tone returned 6 months postoperation and the atonia is still present in the other patient at 1 year postoperation. Injury to the T11 and T12 nerves can occur with dissection through the external and internal oblique muscles, possibly explaining this atonia complication. Stretch injuries often result in neuropraxia and the atonia can resolve with time. Transection or overdistraction of these nerves can result in more permanent sequelae.

Blood loss in the second stage of our surgeries averaged 1,267 mL (range, 400-3,600 mL). The large amount of blood loss in the second stage resulted from the complex open posterior procedures performed in 3 patients. T3-ilium, T5-ilium, and T9-ilium open posterior spinal fusion procedures were performed, all of which required a large open dissection and multiple osteotomies.

No cases of infection occurred in our study, despite performing these procedures in 6 revision cases (28.6%), 4 diabetic patients (19.1%), 8 obese patients (38.1%), 2 current smokers (9.5%), and 10 patients with a recent smoking history (47.6%). Vancomycin powder is routinely placed in the deep and superficial layers of the anterior and posterior closure. The rate of infection has been shown to dramatically decrease with the placement of vancomycin powder in surgical spinal wounds.[41-43]

Approximately 2 mg of BMP was placed around Mastergraft and placed in each lateral interbody cage. We do not feel that BMP radiculitis contributed to our thigh complications secondary to the timing of the onset of symptoms. All cases of anterior thigh pain occurred immediately postoperation, most likely secondary to injury to the lumbar plexus or genitofemoral nerve. Direct psoas muscle trauma may also have been a contributing factor because most of the anterior thigh pain occurred when the psoas muscle contracted as patients rose from a sitting position. BMP radiculitis often has a delayed onset, beginning days to weeks postoperation. Furthermore, we did not experience any catastrophic subsidence that can be caused by osteolysis from BMP. Although minor subsidence was not directly measured, no cases of moderate or catastrophic subsidence occurred. The lack of catastrophic subsidence could be a result of the lower dose of BMP utilized at each level, spanning the strong ring apophysis with the lateral cage, or supplementing the construct posteriorly with pedicle screws.

Our study has several limitations. One of the major limitations is the retrospective nature of this review. Additionally, no randomization or control group was employed; however, all patients who underwent LLIF and posterior pedicle screw augmentation were included. One of the strengths of this study is that we included all patients without regard to previous spinal surgery or comorbidities. Additionally, a single surgeon used the same technique for the interbody preparation, cage sizing and placement, graft material utilization, and posterior augmentation and achieved successful fusion in a high-risk patient population.

CONCLUSION

Our preliminary results demonstrate a high fusion rate in LLIF that compares to or exceeds the published data from other LLIF studies and other interbody fusion techniques (ALIF, PLIF, and TLIF). Spanning the ring apophysis with large LLIF cages and supplemental posterior pedicle screw augmentation are thought to be key factors in successful fusion, especially in high-risk patients, as they can enhance stability of the fusion segment. We will continue data collection and CT scan assessment on these patients and all other patients operated on in our consecutive series and will report future data.

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