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SURGERY

Medialized, Muscle-Splitting Approach for Posterior Lumbar Interbody Fusion

Technique and Multicenter Perioperative Results

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Study Design. Retrospective, multicenter study of perioperative results

Objective. The purpose of this study was to describe the surgical technique for medialized posterior lumbar fusion as well as present preliminary complication and treatment results from a multicenter retrospective study.

Summary of Background Data. Posterior exposures remain the most commonly performed approaches for spinal fusion. Conventional open posterior exposures, however, have relatively high exposure-related morbidity and postoperative infection rates. Less invasive exposures for transforaminal and anterior (lateral) interbody fusion have been widely used over the past decade, but the need for bilateral posterior exposure has challenged the development of less invasive exposures for direct posterior approaches for lumbar fusion.

Methods. Consecutive patients treated with minimally invasive spine (MIS) posterior lumbar interbody fusion with medialized cortical bone trajectory pedicle screw and rod fixation were identified from four sites in the United States. Of the 138 patients identified, 61% of patients were treated for degenerative spondylolisthesis at 167 levels, most commonly at L4–5 (62%). Perioperative treatment, complication, and reoperation data were collected to describe early feasibility of the approach.

Results. Mean total operative time was 135 minutes with an average of 236 mL of blood loss. Mean total postoperative length of hospital stay was 2.6 days, with 25% of patients discharged on the same day or within 23 hours of surgery. Total perioperative complication rate in 138 patients was 10.1% (14/138) with three related reoperations. Intraoperative complications included five (3.6%) instances of incidental durotomy, without any progression to persistent cerebrospinal fluid leaks. Nine (6.5%) postoperative complications occurred, including one L5 vertebral body fracture, two pulmonary embolisms, one deep vein thrombosis, one urinary tract infection one instance of urinary retention, two superficial surgical site infections, and one patient with persistent pain at 6 months postoperative. Three (2.2%) reoperations were performed, one for revision of the L5 vertebral body fracture, and two for wound debridement. No instances of postoperative radiculitis or neurological injury were observed.

Conclusion. Medialized, muscle-sparing posterior exposures with specialized instrumentation can be performed in patients with degenerative lumbar pathology with low surgical morbidity and blood loss and a short length of postoperative hospital stay.

Key words: cortical, cortical bone trajectory, interbody, lumbar, medialized, minimally invasive, mini-open, MIS, multifidus, pedicle, posterior lumbar interbody fusion, posterior, screw, sparing.

Level of Evidence: 4

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Posterior lumbar interbody fusion (PLIF) and posterolateral fusion (PLF) are the most common approaches for treating a variety of degenerative lumbar spinal conditions. The conventional open exposure used in PLIF has been associated with elevated rates of complications, most notably new postoperative radiculopathies or nerve injury and surgical site infections.[1] In addition, the paraspinal—particularly the multifidus—muscles are sacrificed, which has been associated with decreased trunk function as well as poorer outcome and long-term prognosis.[2–8] Maintaining the integrity of the segmental insertions (tendinous attachments) of the multifidus in spine surgery is of such importance that it has been proposed as the criteria between minimally invasive and nonminimally invasive posterior approaches, regardless of incision size.[9,10]

PLIF has lagged, relative to other minimally invasive spine (MIS) approaches, in the development of less invasive exposures due to the requirement for a central

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decompression, bilateral intervertebral cage placement and, along with conventional PLF, the use of standard lateral-to-medial bilateral pedicle screw and rod fixation requiring a wide exposure to the transverse processes for complete decompression and interbody and/or posterior fusion. With the proliferation of MIS techniques for transforaminal lumbar interbody fusion (TLIF), bilateral posterior exposures were not initially considered able to be performed in a less invasive fashion. The introduction of the cortical bone trajectory for the placement of medialized bilateral pedicle screw and rod fixation[11–15] has changed the requirement for a wider exposure in posterior fusions and has led to the development of several MIS direct posterior approaches.[15,16]

The purpose of this study was to describe technical considerations for MIS posterior fusion with cortical bone trajectory pedicle screw and rod fixation as well as to evaluate operative feasibility and perioperative (complication) results in a consecutive series of MIS PLIF patients as part of a multicenter study.

MATERIALS AND METHODS

Surgical Technique

The surgical technique for medialized posterior interbody fusion (MIS PLIF). The patient positioned prone on a radiolucent operating table and prepped and draped in a conventional manner. Fluororadiography in true anteroposterior and lateral views are obtained at the operative level. A single, medialized posterior incision and muscle-splitting corridor is developed. Posterior musculature is retracted, not resected, with maintenance of the insertions of the multifidus. The exposure is extended to the lateral borders of the facet joints (Figures 1 and 2), preserving both the lateral superior articular facet and the neurovascular complex, which enters from lateral to medial. Complete or partial facetectomies and laminectomies are then performed to allow access to the disc space without neural retraction. Release of the facets also allows for better segmental lordosis correction. Additional partial or hemilaminectomies could be performed at the operating surgeon's discretion. Two interbody grafts are placed near or on each of the lateral borders of the ring apophysis. This lateralized interbody grafting allows for intervertebral access without the need for neural retraction. The ability to place the cage laterally nearer to the apophyseal ring also theoretically resists subsidence by resting on cortical rather than cancellous bone. The use of lordotic cages also may be able to increase lordosis through the placement of taller, sagittally tapered cages without endplate violation, using an insert and rotate technique.[17–19] Cortical bone trajectory, medial-to-lateral, pedicle screws are then placed under fluororadiographic guidance (Figure 2). The technique for cortical bone trajectory pedicle screw placement has been previously

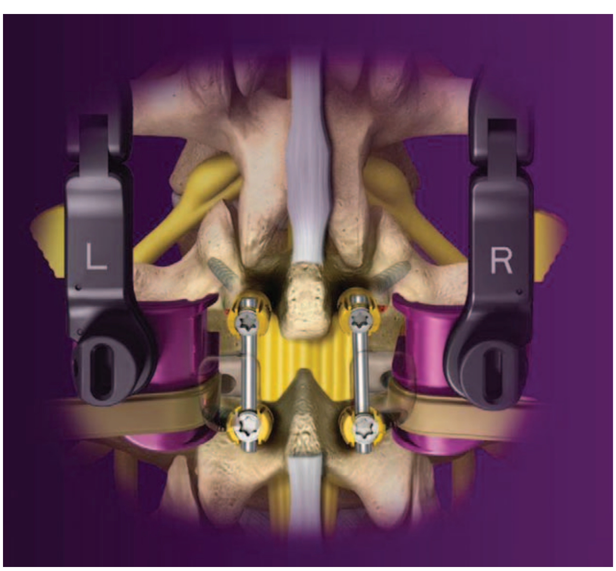

Figure 1. Illustration showing surgical exposure and cortical bone trajectory, medial-to-lateral pedicle screw, and rod fixation in MAS PLIF.

Figure 2. Intraoperative photograph showing surgical exposure and cortical bone trajectory, medial-to-lateral pedicle screw, and rod fixation in MAS PLIF. (**A**), and the closed incision following MAS PLIF (**B**).

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described,[14,15] but is performed by identifying the superior most lateral edge of the pars and moving 3 to 5 mm medial to identify the screw entry point (Figure 3). For the cephalad screw, it is important to avoid the adjacent facet capsule and make the entry point slightly inferior. Typically, a 5.5–6.5 mm diameter, 35 mm length screw is placed with approximately a 15° medial to lateral trajectory and an approximately 30° interior to superior trajectory for the cephalad screw with a less steep trajectory for the caudal screw, limiting the surgical exposure required (Figure 3). Intraoperative neuromonitoring can be used in these cases with free-run electromyography, evoked electromyography during screw placement, and/or somatosensory-evoked potentials throughout. Degenerative lumbar and lumbosacral pathology can be treated with this approach, although significant deformity or trauma may be better treated with an alternative approach. Case images are included in Figure 4.

Study Design

A retrospective study of perioperative results following MIS PLIF was undertaken on 138 consecutive patients between 2010 and 2014 from four surgeons at four sites in the United States as part of an institutional review board approved study. Inclusion criteria for the study required treatment with MIS PLIF (MAS PLIF, NuVasive, Inc., San Diego, CA) at one or two levels between L1–2 and L5–S1. Demographic, surgical, and complication data were collected at baseline, intraoperative, perioperative (<6 weeks), 6 weeks, and 6 months.

Statistical analysis included descriptive statistics, one-way analysis of variance, and chi-squared tests. All analyses were performed using JMP version 12 (SAS Institute, Cary, NC) and significance was accepted for $P < 0.05$.

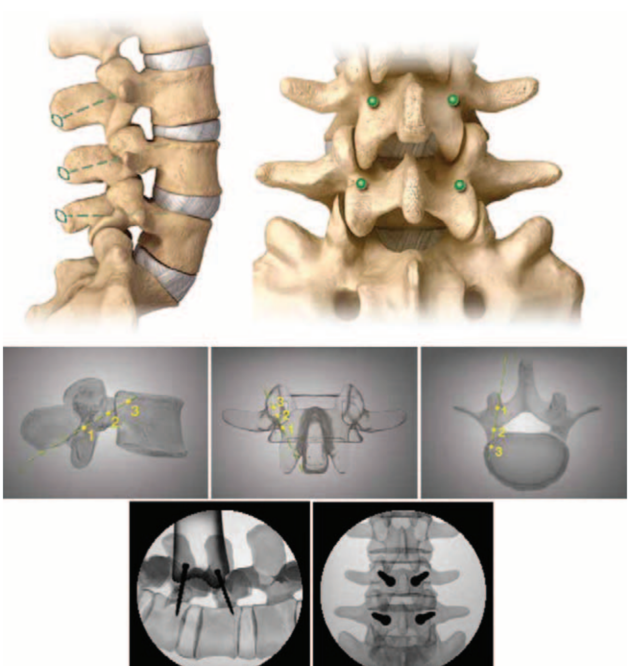

Figure 3. Illustrations showing trajectory and placement of cortical bone trajectory pedicle screw placement.

Patient Sample

A total of 138 patients treated with MIS PLIF met inclusion criteria and were included in the study. Mean age was 54.8 years (range 21–88) and 46% were men. Average body mass index (BMI) was 29.5 kg/m^2 (range 18.2–50.5) and 2% had undergone prior lumbar discectomies at levels outside of index or adjacent levels treated with MIS PLIF. Cumulative surgical indications included degenerative disc disease in 62 (45%) patients and Grade I or Grade II spondylolisthesis in 84 (61%) patients. Preoperatively, 48 (35%) patients had neurologic deficits and all patients presented with low back pain and unilateral or bilateral leg pain. All demographic and baseline patient information are presented in Table 1.

RESULTS

A total of 167 levels were treated (average 1.2 per patient) at one or two levels between L3–4 and L5-S1. Interbody cages were filled with a combination of allograft and autograft. Cortical bone trajectory pedicle screw and rod fixation was used in all cases. Mean total operative time was 134.9 minutes (range 66–259 minutes), estimated blood loss was 236.9 mL (range minimal–1000 mL), and length of postoperative hospital stay was 2.6 days (range 0–9 days). One quarter (25%) of patients were discharged within 23 hours (same day or the next morning postoperative) of surgery. Complete surgical and treatment information is presented in Table 2.

In a comparison of one- and two-level procedures, operative time was longer in the two-level group (132 *vs.* 148 minutes) and there was more blood loss (220 *vs.* 299 mL).

Complications

Five (3.6%) incidental durotomies occurred, all of which were treated uneventfully with no further sequelae (*e.g.*, cerebrospinal fluid leak). There were no reports of postoperative radiculitis or other neurological injuries. Perioperative complications included one L5 vertebral body fracture, two pulmonary emboli, one proximal deep vein thrombosis, one instance of urinary tract infection, and one episode of urinary retention. Postoperative superficial wound infections occurred in two (1.4%) patients. Three (2.2%) patients underwent reoperation within 30 days postoperative: two for wound debridement and one for revision of an L5 vertebral body fracture and subsequent implant subsidence. One of the infections was in an obese woman with type 2 diabetes who was treated and seen in the office 2 weeks postoperative without any sign of infection. The patient then traveled out of state where she presented to the emergency room for wound drainage. A wound vac was placed at that time, and it was subsequently removed by the initially treating surgeon along with a formal irrigation and debridement. One patient experienced persistent pain at 6 months due to suspected prolonged union and was

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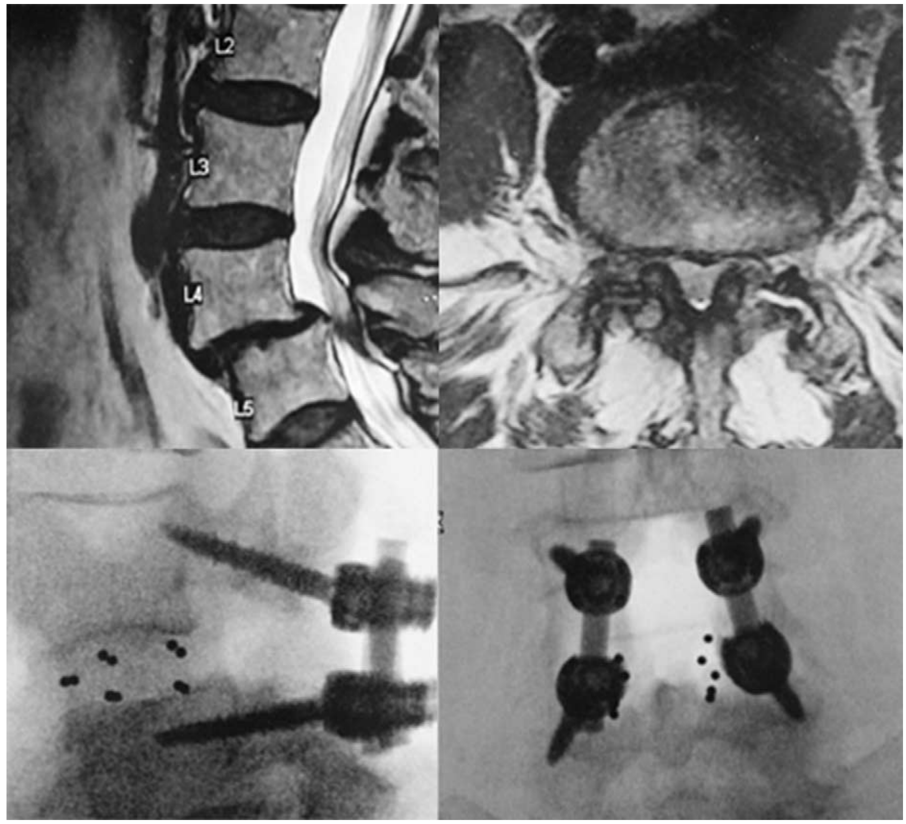

Figure 4. Magnetic resonance imaging (MRI) and fluororadiographs showing treatment of L4–5 degenerative spondylolisthesis with MAS PLIF.

prescribed a bone growth stimulator. The other infection was in a 50-year-old woman with a BMI of 44.6 treated at L5-S1 who had prolonged postoperative hospitalization (9 days), despite an uneventful surgery and early recovery. The patient developed a superficial wound infection followed by cellulites, which was irrigated and debrided and resolved without further sequelae. The vertebral body fracture occurred in a 77-year-old woman with a BMI of 30.7 treated at L4–5 for a Grade I spondylolisthesis. Within 2 weeks postoperative, there was cage subsidence, which evolved into an L5 burst fracture. Two reoperations were performed for reinstrumentation from L3 to the sacrum with standard pedicle screws and iliac bolts. By 6 months postoperative, the patient had no further adverse events and her preoperative low back pain had improved from 5/10 to 1/10. Complications are included in Table 3.

Of the 14 total complications that were observed, five (36%) occurred in the 29 (21%) two-level fusion procedures. These complications included four instances of dural tear and one pulmonary embolism. All three thromboembolic events occurred at one institution, which suggests a potentially patient higher risk profile from that regional population.

TABLE 1. Demographics and Baseline Patient Information

	n = 138
Age (yr)—mean ± SD	54.8 ± 12.6
Male—n (%)	63 (45.6)
Body mass index (kg/m^2)—mean ± SD	29.5 ± 7.2
Prior lumbar surgery—n (%)	3 (2.2)
Primary diagnosis—n (%)	
Degenerative disc disease	62 (45)
Spondylolisthesis	84 (61)
Grade 1	62 (44.9)
Grade 2	16 (11.6)
Unknown	6 (4.3)
Stenosis	
Central	73 (52.9)
Foraminal	66 (47.8)
Subarticular	17 (12.3)
Neurological deficit—n (%)	49 (35.5)

n indicates number of patients; SD, standard deviation.

DISCUSSION

Medialization of posterior exposures for lumbar interbody fusion has several potential advantages including the lessening of procedure-related morbidity and the maintenance of posterior musculature and their neurovascular supply, in particular the preservation of the tendinous attachments of the multifidus muscle, which has been associated with improved clinical and functional outcomes.[2–7,9,10,20]

Complications in the current series were relatively few and major complications were rare. Five patients

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TABLE 2. Surgical and Treatment Information

	n = 138
Levels treated per patient—mean	1.2
Levels treated—n (%)	
L3–4	13 (9.4)
L4–5	86 (62.3)
L5-S1	68 (49.3)
Number of levels treated—n (%)	
One	109 (79.0)
Two	29 (21.0)
Additional decompression—n (%)	35 (25.4)
Operating time (min)—mean ± SD	134.9 ± 36.6
Estimated blood loss (mL)—mean ± SD	236.9 ± 175.8
Length of stay (days)—mean ± SD	2.6 ± 1.5
Postoperative discharge day—n (%)*	
Zero (same day)	6 (4.3)
One	28 (20.2)
Two	34 (24.6)
Three	38 (27.5)
Four	22 (15.9)
Five or more	9 (6.5)

*n = 137.
n indicates number of patients; SD, standard deviation.

experienced intraoperative dural tears and, postoperatively, thirteen complications occurred. Those related to the surgical procedure included two (1.4%) instances of superficial surgical site infection and one L5 vertebral body fracture, all three of which required reoperation for resolution. No instances of new postoperative radiculitis or neural injury were seen in this series. In comparison with historical literature, Okuda *et al*[1] reported on 251 patients treated with open PLIF with bilateral facetectomy at one or two levels in similar distributions to the current study and found a perioperative complication rate of 18%. Dural tears occurred in 19 patients and seven patients had screw malpositioning. Postoperatively, 8.4% (21) of patients had new postoperative neural deficits, including 19 motor and two

TABLE 3. Complications Following MAS PLIF

	n = 138
Intraoperative—n (%)	
Dural tear	5 (3.6)
Perioperative—n (%)	
Pulmonary embolism	2 (1.4)
Deep vein thrombosis	1 (0.7)
Urinary retention	1 (0.7)
Urinary tract infection	1 (0.7)
Wound infection	2 (1.4)
L5 fracture with implant subsidence	1 (0.7)
Six months postoperative—n (%)	
Persistent pain, possible prolonged union	1 (0.7)

n indicates number of patients.

sensory complications. Of those, 32% of deficits were classified as slight, 47% as severe, and 21% were permanent. In 2009, Rihn *et al*[21] reported on 119 patients treated with single-level open TLIF for degenerative spinal pathology. In this series, 55 (46%) complications occurred in 40 (34%) patients. There was an 11% incidence of new postoperative radiculitis, 5% infection rate, and 10% reoperation rate. In further evidence of the clinical, and related economic, benefit of MIS compared to open posterior fusion procedures, Rampersaud *et al*[22] performed a cost-utility analysis of MIS *versus* open PLIF. In this study, the authors found 200 *versus* 798 mL blood loss for MIS compared to open PLIF, 0% and 17% transfusion rates, and 10.8% and 29.3% complication rates, respectively. These perioperative results were markedly similar to the findings of the current study and, in the study by Rampersaud *et al*,[22] these clinical benefits in the MIS cohort translated to 4-year modeled cost/quality-adjusted life year ratios of $37,720 for the MIS and $67,510 for the open cohorts. This translated to nearly twice the cost effectiveness for the MIS compared to open group.

In further evidence of the incremental benefits of MIS posterior exposures for lumbar fusion, a high-quality systematic literature review by Goldstein *et al*[23] was performed examining clinical and economic differences between MIS and open TLIF and PLIF. In this review, 45 high-quality studies directly comparing MIS *versus* open TLIF or PLIF were included, with 3472 MIS patients and 5924 open patients. The authors found that operative time ranged to 45% longer to 63% shorter for the MIS compared in the MIS group to open groups, blood loss ranged from 16% to 89% less in the MIS Group than the open group, and length of stay decreased 15% to 64% for the MIS cohort. Back and leg pain was similarly improved between MIS and open patients, as was disability (Oswestry Disability Index) and quality of life (SF-36 physical and mental component score and EQ-5D). Nonunions ranged from 0% to 16.7% in the MIS studies compared to 0% to 7.9% in the open cohort with complications ranging from 0% to 40% in the MIS and 0% to 52% in the open cohort. In nine studies that also included economic analyses, nearly all studies showed cost-effectiveness benefits in the MIS cohorts.

The morbidity and perioperative results from these reports are largely corroborated in the findings from the current study with MIS PLIF and cortical trajectory pedicle screw and rod fixation. Mid- to long-term outcomes were not able to be collected from the current series, although results from the published literature suggest the equivalence of MIS and open exposures, in general.

The ability to use medialized exposures in posterior fusions is dependent upon the use of medialized fixation. In this series, cortical bone trajectory pedicle screw and rod fixation was used without any related morbidity. From a biomechanic and clinical perspective, cortical pedicle screws have been found to be largely equivalent to traditional pedicle screw and rod fixation in the presence of, particularly bilateral, interbody spacers.[24–29] The screw trajectory decreases the risk of injury to neural structures, by passing

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away from the existing nerve roots. In this series, no instance of nerve injury was observed. With respect to the potential for adjacent facet impingement with this posterior construct, this is avoided by the placement of the cephalad screws in the previously described inferior-to-superior trajectory, remaining distant from the adjacent facets. In the case of potential misplacement of the cortical screws, although none were observed in this series, the likelihood for neural impingement is theoretically lower than in conventional pedicle screw placement as the general trajectory of cortical screws into the vertebral bodies is away from nerve roots and the cauda equina. In a direct comparison of traditional to cortical bone trajectory pedicle screws in PLIF, Lee *et al*[30] found that cortical pedicle screws resulted in similar clinical and radiographic outcomes and represent a reasonable alternative to conventional lateral-to-medial pedicle screw and rod fixation in PLIF. There is a learning curve to the adoption of this technique, particularly as it relates to the placement of the pedicle screw and rod constructs. The cases included in this series are inclusive of learning curve patients for all of the investigators and a relatively low rate of complication and favorable perioperative variables were observed, suggesting that there is not a significant learning curve in adoption of this procedure.

Weaknesses of the current study include the retrospective nature of the data collection, which has been known to underestimate certain variables, including complications. While follow-up time points studied were appropriate in determining initial feasibility, long-term outcomes are not yet available to be assessed for this specific procedure.

CONCLUSION

These multicentric results support the feasibility of a less-invasive approach for posterior lumbar fusion in the treatment of common lumbar degenerative pathologies. This approach employs traditional principles of direct decompression with rigid interbody and pedicle fixation but avoids many of the morbidities commonly associated with traditional open posterior exposures. In addition, this technique compares favorably to published reports of traditional open PLIF with respect to operative time, blood loss, postoperative length of stay, and overall complications. It is of significance that there were no reports of postoperative radiculitis or neurological injury in these patients, common problems following open PLIF. These results validate the minimal morbidity and technical reproducibility of the MIS PLIF procedure. Additional studies are needed to quantify long-term clinical and radiographic outcomes.

➢ Key Points

- ❑ Conventional, open approaches remain the most common approaches for lumbar spinal fusion, despite elevated procedural-morbidity, particularly infections and neural injuries, which challenge their continued use in modern healthcare.
- ❑ A multifidus-sparing, medialized exposure for posterior fusion has been introduced with cortical bone trajectory, medial-to-lateral, bilateral pedicle screw, and rod fixation. This report examines the technique and perioperative results of using this less-invasive medialized exposure.
- ❑ In 138 patients treated with medialized posterior lumbar interbody fusion at four centers in the United States, mean total operative time, blood loss, and hospital stay were 135 minutes, 236 mL, and 2.6 days. Same or next-day discharge occurred in 25% of cases. The overall perioperative complication rate was 10.1% and reoperations were performed in three instances. No instances of postoperative radiculitis or neurological injury were observed.
- ❑ These initial results suggest that the medialized approach and instrumentation for posterior lumbar fusion can be successfully performed with low procedural morbidity, even during learning curve of adoption. Longitudinal studies are needed to further evaluate patient clinical results and fusion outcomes using this approach.

References

1. Okuda S, Miyauchi A, Oda T, et al. Surgical complications of posterior lumbar interbody fusion with total facetectomy in 251 patients. *J Neurosurg Spine* 2006;4:304–9.
2. Kim DY, Lee SH, Chung SK, et al. Comparison of multifidus muscle atrophy and trunk extension muscle strength: percutaneous versus open pedicle screw fixation. *Spine* 2005;30:123–9.
3. Fan SW, Hu ZJ, Fang XQ, et al. Comparison of paraspinal muscle injury in one-level lumbar posterior inter-body fusion: modified minimally invasive and traditional open approaches. *Orthop Surg* 2010;2:194–200.
4. Fan S, Hu Z, Zhao F, et al. Multifidus muscle changes and clinical effects of one-level posterior lumbar interbody fusion: minimally invasive procedure versus conventional open approach. *Eur Spine J* 2010;19:316–24.
5. Bresnahan LE, Smith JS, Ogden AT, et al. Assessment of paraspinal muscle cross-sectional area following lumbar decompression: minimally invasive versus open approaches. *J Spinal Disord Tech* 2013; Epub ahead of print.
6. Wang TY, Pao JL, Yang RS, et al. The adaptive changes in muscle coordination following lumbar spinal fusion. *Hum Mov Sci* 2015;40:284–97.
7. Regev GJ, Lee YP, Taylor WR, et al. Nerve injury to the posterior rami medial branch during the insertion of pedicle screws: comparison of mini-open versus percutaneous pedicle screw insertion techniques. *Spine* 2009;34:1239–42.
8. Ward SR, Tomiya A, Regev GJ, et al. Passive mechanical properties of the lumbar multifidus muscle support its role as a stabilizer. *J Biomech* 2009;42:1384–9.
9. Kim CW, Siemionow K, Anderson DG, et al. The current state of minimally invasive spine surgery. *Instr Course Lect* 2011;60: 353–70.
10. Kim CW. Scientific basis of minimally invasive spine surgery: prevention of multifidus muscle injury during posterior lumbar surgery. *Spine* 2010;35 (26 suppl):S281–6.
11. Kojima K, Asamoto S, Kobayashi Y, et al. Cortical bone trajectory and traditional trajectory–a radiological evaluation of screw-bone contact. *Acta Neurochir (Wien)* 2015;157:1173–8.

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12. Phan K, Hogan J, Maharaj M, et al. Cortical bone trajectory for lumbar pedicle screw placement: a review of published reports. *Orthop Surg* 2015;7:213–21.
13. Glennie RA, Dea N, Kwon BK, et al. Early clinical results with cortically based pedicle screw trajectory for fusion of the degenerative lumbar spine. *J Clin Neurosci* 2015;22:972–5.
14. Mobbs RJ. The ''medio-latero-superior trajectory technique'': an alternative cortical trajectory for pedicle fixation. *Orthop Surg* 2013;5:56–9.
15. Berjano P, Damilano M, Ismael M, et al. Minimally invasive PLIF with divergent, cortical trajectory pedicle screws. *Eur Spine J* 2015;24 (suppl 5):654–5.
16. Gautschi OP, Garbossa D, Tessitore E, et al. Maximal access surgery for posterior lumbar inter body fusion (PLIF) with divergent, cortical bone trajectory (CBT) pedicle-screws: a good option for minimize spine access and maximize the field for nerve decompression. *J Neurosurg Sci* 2015.
17. Grant JP, Oxland TR, Dvorak MF. Mapping the structural properties of the lumbosacral vertebral endplates. *Spine* 2001;26:889–96.
18. Closkey RF, Parsons JR, Lee CK, et al. Mechanics of interbody spinal fusion. Analysis of critical bone graft area. *Spine* 1993;18:1011–5.
19. Vaidya R, Sethi A, Bartol S, et al. Complications in the use of rhBMP-2 in PEEK cages for interbody spinal fusions. *J Spinal Disord Tech* 2008;21:557–62.
20. Liu H, Wu W, Li Y, et al. Protective effects of preserving the posterior complex on the development of adjacent-segment degeneration after lumbar fusion: clinical article. *J Neurosurg Spine* 2013;19:201–6.
21. Rihn JA, Patel R, Makda J, et al. Complications associated with single-level transforaminal lumbar interbody fusion. *Spine J* 2009;9:623–9.
22. Rampersaud YR, Gray R, Lewis SJ, et al. Cost-utility analysis of posterior minimally invasive fusion compared with conventional open fusion for lumbar spondylolisthesis. *SAS J* 2011;5: 29–35.
23. Goldstein CL, Phillips FM, Rampersand YR. Comparative effectiveness and economic evaluations of open versus minimally invasive posterior or transforaminal lumbar fusion: a systematic review. *Spine* 2016; Epub ahead of print.
24. Cheng WK, Inceoglu S. Cortical and standard trajectory pedicle screw fixation techniques in stabilizing multisegment lumbar spine with low grade spondylolisthesis. *Int J Spine Surg* 2015; 9:46.
25. Wray S, Mimran R, Vadapalli S, et al. Pedicle screw placement in the lumbar spine: effect of trajectory and screw design on acute biomechanical purchase. *J Neurosurg Spine* 2015;22:503–10.
26. Calvert GC, Lawrence BD, Abtahi AM, et al. Cortical screws used to rescue failed lumbar pedicle screw construct: a biomechanical analysis. *J Neurosurg Spine* 2015;22:166–72.
27. Xu G, Fu X, Du C, et al. Biomechanical comparison of monosegment transpedicular fixation with short-segment fixation for treatment of thoracolumbar fractures: a finite element analysis. *Proc Inst Mech Eng H* 2014;228:1005–13.
28. Baluch DA, Patel AA, Lullo B, et al. Effect of physiological loads on cortical and traditional pedicle screw fixation. *Spine* 2014;39: E1297–1302.
29. Perez-Orribo L, Kalb S, Reyes PM, et al. Biomechanics of lumbar cortical screw-rod fixation versus pedicle screw-rod fixation with and without interbody support. *Spine* 2013;38:635–41.
30. Lee GW, Son JH, Ahn MW, et al. The comparison of pedicle screw and cortical screw in posterior lumbar interbody fusion: a prospective randomized noninferiority trial. *Spine J* 2015;15:1519–26.

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