

Long Term Durability of Minimal Invasive Posterior Transforaminal Lumbar Interbody Fusion: A Clinical and Radiographic Follow-up

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Abstract

Background Context: Both open and minimal invasive lumbar fusion surgery (MIS) are used to treat patients with degenerative spinal pathologies. Open lumbar fusion surgery studies have reported excellent short term safety and long term clinical outcomes. MIS has shown excellent safety and short term clinical success, but there is very little information on its long term clinical durability.

Purpose: The purpose of this study was to document the long term clinical durability and safety of patients treated with minimal invasive surgery – transforaminal lumbar interbody fusion (MIS TLIF). Secondary purposes were to evaluate the clinical outcomes of patients receiving fusion in two sequential lumbar disc segments (2-level) as compared to a single level lumbar disc segment (1-level), and as an aside, to determine whether or not there were any differences in clinical outcomes in patients treated over the age of 60 years as compared to those under 60 years.

Study Design: This study was a retrospective review of prospective collected outcomes data.

Patient Sample: One hundred sixty nine consecutive patients, with either isolated single level or two level lumbar intervertebral segment pain manifested by back pain alone or back pain with leg pain associated with a primary diagnosis of degenerative spondylolisthesis, massive disc herniation, lumbar stenosis, recurrent disc herniation after failed laminotomy/laminectomy, axial intervertebral disc collapse, or isolated degenerative disc/joint disease.

Outcomes Measures: Hospital stay time, return to work time, Oswestry Disability Index (ODI), numeric pain scores, pain medicine (narcotic) use, fusion status, and reoperation rate.

Methods: Patients treated with 1-2 level MIS TLIF were evaluated based on clinical outcomes, reoperation rates, and fusion status out to an average of 49 months postoperative (range, 36-60 months). Effect of the number of levels fused, patient age, and worker compensation status on outcome was also assessed.

Results: Average surgery times were 183 minutes, with no difference between older and younger patients. Hospital stay averaged 15 hours with a median return to work time of 8 weeks. Return to work for patients working prior to surgery was 97%. ODI improved 36% at the first follow-up and was 41% at 49 months postoperative. Eighty-six percent of patients reached a 20% clinical improvement in ODI at the last follow-up. Every primary diagnostic group increased significantly over time. VAS pain scores improved in a similar pattern as ODI. Patients with 2 level fusions improved comparably in both ODI and VAS scores as 1 level fusion patients. Worker compensation patients improved in both ODI and pain scores, although a little less than non-workers compensation patients. Neither smoking, nor obesity status impacted clinical outcomes. Narcotic use for spine related pain went from 100% to 31% 6 months postoperative. Fusion rates were 96% at the 1-year follow-up. When reviewing surgical

revisions as a consequence of surgical technique, and omitting unanticipated adverse events, 99% of patients maintained a successful fusion at their last average follow-up.

Conclusion: The results of this study support the long-term clinical effectiveness of MIS TLIF for varying diagnoses. These results suggest that those undergoing 1 or 2 level lumbar fusions improve equally, and that older patients do well with MIS surgery long term. Reoperation rates were acceptable, with excellent surgical durability at 49 months.

Keywords: minimal invasive spine surgery, SEXTANT, multi level, Lumbar fusion, Oswestry Disability Index, work comp

Introduction

Nearly 300,000 lumbar fusions are performed annually in the United States (Katz 2006).

Degeneration of the intervertebral disc and lumbar spine from aging or excess motion can cause segmental instability, disc herniation, acquired spondylolisthesis or symptomatic degenerative disc disease (DDD), which can be indications for lumbar fusion surgery (Slosar, 2002).

Both open and minimal invasive lumbar fusion surgery (MIS) have been used to treat patients with degenerative spinal pathologies successfully when medical management fails (Glassman et al. 2006, Schwender et al. 2005). Open lumbar fusion surgery (anterior, posterior, posterolateral) studies have reported excellent short term safety (Burkus et al. 2002, Glassman et al. 2006, Dawson et al. 2009) and long term clinical outcome success (Atlas et al. 2005, Chang et al. 2005, Weinstein et al. 2009). However, there is less safety and short term outcome data for MIS (Schwender et al. 2005, Rouben 2007, Park et al. 2008), and very little long term outcome data (Rouben 2009). Some of the earliest work with MIS has been with the transforaminal lumbar interbody fusion (TLIF) procedure. MIS TLIF is a surgical technique that can be performed with multiple small incisions, requiring little if any neural retraction and provides for excellent intradiscal space preparation. MIS TLIF is intended to reduce para-spinous soft tissue injury that can occur with muscle stripping, tearing, cutting and retraction that occurs with open lumbar fusion procedures (Foley et al. 2002).

MIS TLIF studies has demonstrated low surgical complication rates, decreased blood loss, short hospital stays, and early restoration of function (Schwender et al. 2005, Park et al. 2008, Starkweatehr et al. 2008). It is unclear if the outcomes seen short-term are maintained several

years postoperative. With limited health care resources available, it is increasingly important to treat patients with durable long lasting interventions. Thus, the purpose of this study was to document the long term clinical durability and safety of patients treated with MIS TLIF. Secondary purposes were to evaluate the clinical outcomes of patients receiving MIS TLIF fusions to two sequential lumbar disc segments (2-level) as compared to a single level lumbar disc segment (1-level), and as an aside, to determine whether or not there were any differences in clinical outcomes in patients treated over the age of 60 years as compared to those under 60 years.

Methods

Following IRB review, consecutive records of patients receiving MIS TLIF between 2002-2006 were analyzed. Patients were tracked (diagnosis, patient reported outcomes, radiographs, surgical data) as part of a standard of care in a typical community practice. Data collection occurred at the preoperative visit as well as the post-operative 3, 12, and 24 month intervals. In addition, patients were seen at yearly visits after that.

Inclusion criteria for patients to undergo a MIS TLIF procedure in this review, included with isolated single or two level lumbar intervertebral segment pain manifested by back pain alone or back pain with leg pain associated with a primary diagnosis of 1) degenerative spondylolisthesis, 2) massive disc herniation (lateral, foraminal, etc.), 3) lumbar stenosis (lateral, central, etc.), 4) recurrent disc herniation after failed laminotomy/laminectomy, 5) axial intervertebral disc collapse, or 6) isolated degenerative disc/joint disease.

To be included in the study patients had to have matching preoperative and minimum 3yr postoperative ODI and VAS pain scores, and matching preoperative and minimum 3yr postoperative imaging studies. Several of these patients also had data 4yr and 5 yr postoperative. Study exclusion criteria included: scoliosis $> 10^0$, treatment for traumatic fracture, obesity (> 400 lbs), spondylolisthesis $> \text{Grade II}$, preoperative symptomatic lumbar segment disease in excess of two levels, or psychological factors preventing follow-up, or failed lumbar fusion. Several of these patients were reported in an earlier series on the short term surgical results of MIS (Schwender et al. 2005, Rouben 2007).

All patients had failed a minimum 3 months of conservative medical management prior to surgery, which included supervised physical therapy (PT), epidural injections, exercise, and/or oral medicinals. Diagnosis was made following physical exam, acquisition of plain lumbar x-ray films, and magnetic resonance imaging (MRI). In addition, selective facet injections, discography/computer tomography (CT), and/or myelography/CT were often adjunctively used to clarify and confirm the legitimacy of the diagnosis and surgical qualifications. Since this was a retrospective analysis of prospectively collected data, no power analysis was completed, but all consecutive eligible patients meeting inclusion criteria were included.

Preoperative demographic data captured included age, gender, smoking status, body mass index (BMI), and indication/diagnosis used for treatment.

Pre and postoperative outcomes data collected included: Oswestry Disability Index (ODI) (Fairbank et al. 2000), a 100 point visual analog pain scale (VAS), pain related narcotic use, and

patient work status. Radiographic measures assessed included fusion status. Fusion was defined as an absence of radio-lucent lines covering >50% of either implant, translation of ≤ 3 mm on flexion–extension radiographs, and continuous trabecular bone growth connecting the vertebral bodies on CT scan cut (Suk et al. 1997; Christensen et al. 2001). Any postoperative adverse event necessitating revision surgery was tracked as well.

Prior to surgical incision, C-ARM fluoroscopic images were obtained intra-operatively to adequately map the positions of the pedicles. An initial incision was made of the posterior lumbar spine, about 40-50 mm, from the midline and beginning at the most cephalad pedicle to be contained in the fusion to the most caudad pedicle. The incision was made deep to, but not through, the superficial fascia of the muscle. A PAK™ (Medtronic Spinal and Biologics, Memphis, TN) needle was inserted through the fascia, passing between the muscle fibers directly to and into the medullary canal of each pedicle. A Steinman pin was then inserted through the center of the PAK™ needle into the body of the vertebrae. The PAK™ needle was then removed. The Steinman pin was over drilled with a cannulated 4.5mm drill point and a 5.5mm pedicle bone tap that was inserted into the pedicle to a point approximately 50% into the vertebral body. Each tap was then tested by passing 15 amps of electrical current into the tap. If no aberrant electrical response was noted, then a 95% confidence of pedicular continuity was assumed (Glassman et.al. 1995). The taps were removed and the contra-lateral pedicle screws were inserted. Initially the Sextant I™ and after that, the Sextant II™ pedicle screw-rod construct (Medtronic Spinal and Biologics, Memphis, TN) was used (Figures 1-2). An additional stab incision was then made cephalad on the contra-lateral side, through which the Sextant™ rod was percutaneously inserted through but between the muscle fibers, connecting

with the indwelling pedicle screws. The caudal screw was then locked to the rod. Flexible Steinman pins were placed in the ipsi-lateral drilled pedicles for subsequent insertion of pedicle screws at the end of the case. A Steinman pin was then inserted through the ipsi-lateral wound, docking on the facet joint at the level of the surgery. Using the Minimal Exposure Tubular Retractor (METRx™) (Medtronic Spinal and Biologics, Memphis, TN) system, serial dilations were made to create a muscle sparing surgical corridor (Foley et al. 1997), progressively to a 26 mm diameter operative final tube. A total facetectomy was completed, resecting from lateral to medial using a high-speed drill and/or Kerrison ronguers. The resected bone was later used for interbody fusion graft material. Identification of the inter-pedicular annulus (to be resected), the exiting nerve root (to be protected), and the translating nerve root (to be protected) was made. A discectomy was then performed through the ipsilateral tubular operative retractor. Distraction of the disc space was then performed and held by temporarily locking the contra-lateral rod to the cephalad screw. Following endplate preparation, an interbody, implantable, cage was provided in the form of either a titanium, poly-ether-ether ketone (PEEK) or Hydrosorb Cage (Medtronic Spinal and Biologics, Memphis, TN) implant. Cages were filled with locally harvested autologous bone with rhBMP-2 (Medtronic Spinal and Biologics, Memphis, TN). The contra-lateral rod-screw construct was released, compressed, and locked at the cephalad end. Ipsilateral screws were inserted, a connecting rod was inserted, compressed and locked as previously described. For any bi-lateral cases, once the facetectomy was completed on one side, the Sextant™ construct was placed through initial side, but not locked. The other side was then addressed. Once the disc work was completed on the initial side, the contra-lateral Sextant™ construct was locked and then inserted on the ipsi-lateral side.

Perioperative surgical information collected included, surgery time (skin to skin), estimated blood loss, levels fused, complications, graft material, c-arm radiation exposure time, and hospital stay duration. All patients committed and agreed, pre-operatively, to participation in the same mandated, regimented, and supervised rehabilitative therapy protocol initiated seven days after surgery.

Dichotomous variables were assessed by the Chi Square method. Changes from baseline and postoperative were tested with a one way (time) ANOVA with repeated measures. When comparing 1 versus 2 level fusion outcomes or older versus younger patient outcomes, a two way (group x time) ANOVA with repeated measures was used. If significant main effects were found, student t-tests were used to determine location of pair wise difference. An alpha level $p < 0.05$ was considered significant. SPSS (Version 11.0, Chicago, IL) was used for statistical analysis.

Results

Patient indications and demographics are presented in Tables 1-2. There were a total of 169 patients meeting the study inclusion criteria. The primary indication for treatment was isolated single level or two level lumbar intervertebral segment pain manifested by back pain alone (n=29, 17%), leg pain alone (n=58, 34%) or back pain with equal leg pain (n=82, 49%). The most common primary diagnosis was recurrent disc herniation following either failed laminectomy/discectomy (n=53), with massive disc herniation (n=41) representing the second most common diagnosis. Most patients had additional secondary diagnoses. Forty-five patients required two- level fusions, whereas 124 patients required one-level fusions. All surgeries were completed by the authors (D.R. and M.C.). There were more female patients (n=96) than male

patients (n=73), and the average age was 44.5 years (range, 17-73). There were 12 patients 60 years or greater. There were a total of 14 (8 %) workers compensation patients and 94 (56%) patients were smokers. Fifty-eight patients were not working prior to surgery (34%) and they were either full time students, retired, or disabled at the time of surgery.

Surgical results are listed in Table 3. Average surgery time was 183 minutes (range, 90-390), with patients treated for massive disc herniation having the lowest mean surgical time (151 minutes). There were no differences in surgical time between older and younger patients (200 vs. 182 minutes, p=ns). There were 1.3 average levels fused during surgery. There were 21 bilateral fusion cases. For one level fusions, levels treated included L2-L3 (n=4), L3-L4 (n=8), L4-L5 (n=35), and L5-S1 (n=77). For two-level fusions, levels treated included L2-L4 (n=3), L3-L5 (n=7), and L4-S1 (n=35). Surgical blood loss averaged 171 cc (range, 50-750). Patients with two-level fusions (218 cc) had a little greater blood loss than one-level fusion patients (154 cc) (p< 0.001). There was little difference in blood loss in older and younger patients (218 vs. 168 cc, p=ns). Exposure to operative radiation averaged 189 seconds (range, 50-445 seconds). Mean hospital stay was 15 hours, with the shortest surgery time for the massive disc herniation group. There was a non-significant difference in postoperative hospital stay for older patients as compared to younger patients (25 vs. 14 hours, p=ns), mainly due to Medicare in-patient hospital stay requirements. Ninety-one percent of all patients (154/169) were discharged in 24 hours or less hours following surgery. The longest hospital patient stay was 3 days. Following surgery, 97% of patients who were working immediately prior to surgery returned to work. Return to work time averaged 11 weeks, with a median time of 8 weeks. Fifty-seven percent of workers compensation patients returned to work after surgery. The mean time to work for worker compensation patients was 17 weeks, with a median time of 18 weeks.

Follow-up intervals included 3, 12, 24, and 49 (range, 36-60 months) months postoperative. The mean improvement in ODI at each postoperative time ranged from 40-46% when compared to preoperative scores ($p<0.001$) (Figure 3). At 12 months, 24 months, and 49 months postoperative, 89, 88, and 86% of patients had an ODI change score of at least 20% following surgery. ODI improved significantly after surgery in all diagnostic groups ($p<0.001$) and was maintained at the last follow-up (Table 4). Subanalysis showed that those patients who had 5 year follow-up, 86% (56/65) maintained at least a 20% improvement in ODI following surgery as compared to preoperative scores. Further subanalysis for ODI showed better improvements in ODI for those patients undergoing 2-level as compared to 1-level lumbar fusion (Table 5). Those patients 60 years and older had comparable changes compared to younger patients at all time points following surgery (Table 6). ODI improved for workers compensation patients ($p<0.001$), with a mean change of 34% at 2 years, being maintained at their last average follow-up of 50 months. There were no differences in outcomes between smokers and non-smokers, or between obese ($BMI > 30 \text{ kg/m}^2$) and non-obese at any time point ($p=ns$), although all groups improved over time.

VAS pain scores improved post operatively at all time points (Figure 1, $P<0.001$). The average improvement was 39% at the initial follow-up, which was maintained during the last follow-up (42%) ($P<0.001$). Every diagnostic subgroup improved in a similar pattern (Table 3, $P<0.001$). When reviewing VAS changes in those with multiple levels treated and single levels (Table 5, $p<0.05$), older patients and younger patients (Table 6, $p=ns$), and workers compensation patients, each group had a significant improvement following surgery ($P<0.001$). There were no group differences for VAS when comparing smokers and non-smokers or obese and non-obese ($p=ns$).

Narcotic use for spine pain relief was used by all patients prior to surgery. At 6 months postoperative, this number had decreased to 31% ($p < 0.05$). When reviewing fusion success, 96% of patients reached fusion by 1 year as assessed by CT scan.

The overall rate for repeat surgery was 14.2%. The most common event was removal of painful pedicle screws (7.6%). In every case of painful screw removal, the patient either complained of hyper sensitive incisional wound pain within the initial six weeks, or sustained a subsequent trauma directly to their back manifesting very soon thereafter with complaints of hypersensitive incisional wound pain. There were 3 instances in which a fusion was required to an adjacent level because of painful symptoms (1.8%). There was 1 pseudoarthrosis (0.6%) and 1 staph infection (0.6%) requiring repeat surgery. One patient (0.6%) had a postoperative fall and fractured their pedicles at L4 requiring repeat surgeries. All patients requiring reoperation were treated successfully. When reviewing surgical revisions as a consequence of surgical technique, and omitting unanticipated adverse events, 99% of patients maintained a successful fusion at their last average follow-up (49 months).

Discussion

The TLIF procedure has been used early on by Harms et al. (1982, 1998) and more recently by others (Schwender 2005, Rouben 2007, 2009, Isaacs 2005). In comparison to posterolateral surgery, TLIF creates greater fusion area, enhanced fusion blood supply, access for medial and lateral decompression, and optimal restoration of disc height (Branch 2000). The TLIF approach allows for access to the disc space without need for significant retraction of the nerve root or sacral sac. As compared to PLIF procedures, TLIF procedure allows preservation of the posterior longitudinal ligament complex as well as other supporting bony and ligamentous

supporting structures, which are frequently disrupted during surgery. The addition of minimal invasive surgery allows comparable results as open procedures, but with less traumatic injury. In the current study, the authors successfully performed MIS TLIF in 169 patients. The MIS procedure allowed a small amount of blood loss, with a hospital stay average of 15 hours. Hospital stay numbers were lower than other reported literature (Schwender 2005, Burkus 2005, Park 2008) of 2-3 days suggesting quick recoverability, and a procedure that utilizes less resources, and beneficial from a payer standpoint. There were no significant adverse events during surgery. Median return to work was 8 weeks for those working prior to surgery. Return to work data are better than most open surgery data, with laparoscopic fusion being close to these study results with a median time of 89 days (12.5 weeks) (Burkus 2003). These data suggest that patients recover quickly from MIS surgery.

The primary outcome metric, ODI improved significantly following surgery, and was maintained at each follow-up. Recent work suggests that a 18.8-point net improvement in ODI or a 36.8% improvement is a substantial clinical benefit (Glassman et al. 2008). When reviewing individual patient data, 65% of patients had a minimum change score of 36% at any given post surgical time point, suggesting a significant number of patients were helped by the intervention. Significant improvements in ODI were seen within each diagnosis group. Those patients that had reached 5 year postoperative, had a mean change score of greater than 40% suggesting maintenance of disability improvement. Part of the reason for the large change could have been related to the level of disability prior to surgery, and a large range of available improvement. When performing subanalysis, a similar improvement was maintained for elderly patients, those with 1 vs. 2 level fusions, workers compensation patients, and those who smoked. This suggests

that patients typically seen in a community practice can be treated with success. When comparing these results to other literature, our results are comparable. Schwender et al. (2005) found a change of 32% for ODI following MAST TLIF, with an average follow-up of 22.6 months. They also used the SextantTM and METRxTM system similar to this study. Jang et al. (2005) found a smaller clinical improvement for ODI (25.5%) at 19 month following MAST TLIF in an older population. When compared to open TLIF, authors from the SPORT Trial found a 24 % improvement in ODI at 2 years following surgery in patients with degenerative spondylolisthesis (Weinstein et al. 2007). As compared to large non-randomized series of open TLIF/posterior lumbar fusions, representative of typical practice patterns, our results are equally as impressive as the 2yr change scores in younger patients (22.9%)(Glassman et al. 2006) or in older patients (16.4%)(Glassman et al. 2007) . However, this study is the first to report long term clinical success for MIS TLIF. In total, our data suggests that patients treated with MIS TLIF have excellent, durable improvements in ODI over an extended period of time.

All patients surgically treated had either back or leg pain prior to surgery. Pain severity was assessed with a 100 point VAS pain scale. The average improvement was 31% at the initial follow-up, and was maintained at each subsequent follow-up including the 49 month postoperative visit. When reviewed on a per patient basis, 86%, 83%, and 75% of patients had a minimum 30% improvement at 12 months, 24 months, and 49 months postoperative, suggesting surgical relief of pain over time. Improved pain control was supported by a reduction in pain medication use. By 6 months post surgery, only 31% of patients were using narcotics for back pain. A reduction in the use of pain medications would also reduce overall health care costs, very important in a time of reduced resource availability. A secondary reason for less pain

would potentially be from the elimination of secondary iliac crest bone graft harvest, and the small surgical incision. No iliac crest was harvested during study, as only local bone was used with rh-BMP-2.

When subanalysis was performed those patients treated with multi level disease, elderly patients, workers compensation patients, and those who were smokers had clinical significant improvements in pain scores as well. These data support the idea that patients in a typical clinical practices presenting with multiple comorbidities can receive pain relief with MIS TLIF surgery. These data also suggest that pain relief can be maintained long term. These results are comparable to what has been reported for MIS TLIF surgery (Schwender et al. 2005), as well open TLIF/posterior lumbar fusions surgery (Ekman 2005).

By 1 year postoperative, 96% of patients were fused via CT. Although 14.2% of patients required a second operation during the follow-up, a majority of these reoperations were not related to surgical technique or implant failure. The most common reason for repeat surgery was removal of painful screws, which was a result of hypersensitivity to incisional wound pain within the first six weeks, or occurred following trauma to the wound area. The major adverse event requiring revision was a staph infection. This patient required a revision surgery and was treated with antibiotics successfully. When reviewing those patients who had revisions due to surgical technique or unanticipated adverse events, 99% of patients maintained surgically intact fusions at the 49 month follow-up, suggesting that fusion surgery provided adequate stability and fixation.

Although there are many advantages to MIS surgery, the procedure does have challenges. There is a learning curve that must be mastered before technical proficiency can be achieved. In addition, placement of percutaneous pedicle screws requires the surgeon to be able to accurately interpret AP and lateral fluoroscopic images to safely insert these devices (Schwender 2005).

There were a few limitations to this study. First, this was not a randomized controlled trial with a comparator group. The authors of this study perform MIS surgery as their standard of practice, and do not perform open surgery procedures. Since this was a single center study, no open surgical patients were available for comparison. However, patient selection was consecutive, and allowed tracking longitudinally over 5 years. Future studies should compare head to head comparisons between MIS and open procedures. Secondly, only one reviewer was used for postoperative CT analysis for fusion status. Although a study limitation, strict criteria was used to assess fusion assessment. Furthermore, assessment of fusion was a secondary outcome in the study, and the primary focus was on patient reported outcomes and durability over time.

In conclusion, MIS TLIF surgery for the treatment of degenerative pathologies was maintained long term, as assessed by ODI, VAS and reoperation rate. Patients, who were older, had multi level pathologies, who were workers compensation, or who had comorbidities responded well to surgical treatment. Fusion status was 96% by 1 year. Overall, MIS TLIF appears to be a safe and effective treatment. Future studies should evaluate the benefit of MIS TLIF versus Open TLIF.

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Table 1. Patient Indications

Primary Diagnosis	N	Primary Back Pain (n)	Primary Leg Pain (n)	Equal Back/Leg Pain (n)
Recurrent Disc Herniation	53	0	21	32
Massive Disc Herniation	41	0	20	21
Degenerative Spondylolisthesis	35	26	0	9
DDD/DJD	19	1	15	3
Axial Intervertebral Disc Collapse	12	0	0	12
Lumbar Stenosis	9	2	2	5
Total	169	29	58	82

Degenerative Disc Disease (DDD); Degenerative Joint Disease (DJD)

Table 2. Patient Demographics (Mean \pm SD)(Range)

Diagnosis	Age, Range (y)	M/F	BMI, Range (kg/m ²)	Smokers (n/total, %)	2 Level Fusions (n/total, %)
Recurrent Disc Herniation	44.2 \pm 10.3 (17-62)	19/34	30.1 \pm 6.7 (19.9-48.1)	28/53, (53%)	11/53, (21 %)
Massive Disc Herniation	40.6 \pm 8.1 (25-67)	19/22	28.9 \pm 7.6 (18.3-62.0)	25/41, (61%)	7/41, (17%)
Degenerative Spondylolisthesis	46.6 \pm 12.8 (17-73)	16/19	28.2 \pm 4.7 (19.9-38.2)	21/35, (60%)	2/35, (6%)
DDD/DJD	44.2 \pm 10.7 (18-63)	8/11	33.0 \pm 7.9 (22.4-58.0)	9/19, (47%)	18/19, (95%)
Axial Intervertebral Disc Collapse	51.7 \pm 10.2 (33-72)	6/6	31.4 \pm 7.8 (23.8-46.0)	7/12, (58%)	0/12, (0%)
Lumbar Stenosis	45.8 \pm 13.3 (28-71)	5/4	27.6 \pm 5.5 (19.8-35.5)	4/9, (44%)	7/9, (78%)
Total	44.5 \pm 10.9 (17-73)	73/96	29.7 \pm 6.8 (18.3-62.0)	94/169, (56%)	45/169, (26%)

Table 3. Surgical Information (Mean \pm SD) (Range)

Diagnosis	Surgery Time (minutes)	Blood Loss (cc)	Hospital Stay (hours)	Radiation Time (seconds)
Recurrent Disc Herniation	173 \pm 59 (110-345)	157 \pm 90 (50-450)	14 \pm 13 (2-48)	195 \pm 82 (81-412)
Massive Disc Herniation	151 \pm 47 (90-270)	145 \pm 120 (50-750)	12 \pm 11 (2-48)	184 \pm 90 (50-445)
Degenerative Spondylolisthesis	174 \pm 53 (102-300)	173 \pm 96 (60-400)	15 \pm 19 (2-72)	172 \pm 55 (87-294)
Axial Intervertebral Disc Collapse	209 \pm 49 (135-300)	213 \pm 77 (75-350)	16 \pm 14 (3-48)	126 \pm 26 (96-178)
DDD/DJD	259 \pm 57 (105-390)	197 \pm 90 (70-450)	17 \pm 14 (3-48)	246 \pm 85 (128-421)
Lumbar Stenosis	225 \pm 71 (110-345)	256 \pm 181 (100-600)	22 \pm 20 (3-72)	204 \pm 35 (148-268)
Total	183 \pm 63 (90-390)	171 \pm 107 (50-750)	15 \pm 14 (2-72)	189 \pm 79 (50-445)

Table 4. Longitudinal Subgroup Scores for ODI and VAS (Mean ± SD)

Diagnosis		Preoperative	2 Yr Postoperative	36-60 Month Follow-up
Recurrent Disc Herniation N=53	ODI	69 ± 16	29 ± 21 ¹	29 ± 19 ¹
	VAS	70 ± 14	28 ± 20 ¹	29 ± 18 ¹
Massive Disc Herniation N=41	ODI	70 ± 15	26 ± 16 ¹	32 ± 21 ¹
	VAS	68 ± 15	21 ± 14 ¹	28 ± 20 ¹
Degenerative Spondylolisthesis N=35	ODI	68 ± 14	28 ± 22 ¹	30 ± 22 ¹
	VAS	65 ± 14	25 ± 21 ¹	28 ± 22 ¹
DDD/DJD N=19	ODI	70 ± 11	27 ± 19 ¹	23 ± 18 ¹
	VAS	76 ± 14	24 ± 12 ¹	22 ± 20 ¹
Axial Intervertebral Disc Collapse N=12	ODI	72 ± 11	25 ± 20 ¹	26 ± 24 ¹
	VAS	73 ± 8	22 ± 20 ¹	23 ± 21 ¹
Lumbar Stenosis N=9	ODI	75 ± 8	27 ± 18 ¹	28 ± 19 ¹
	VAS	70 ± 11	21 ± 15 ¹	22 ± 16 ¹

¹P<0.001 versus preoperative values

Table 5. Single versus Two-Level Fusion Outcomes (Mean \pm SD)

Group		Preoperative	2 Yr Postoperative	36-60 Month Follow-up
1 Level Fusion N= 124	ODI	68 \pm 14	27 \pm 20 ¹	30 \pm 21 ¹
	VAS	66 \pm 15	23 \pm 17 ¹	27 \pm 19 ¹
2 Level Fusion N= 45	ODI	73 \pm 12	29 \pm 19 ¹	27 \pm 19 ^{1,2}
	VAS	77 \pm 13	27 \pm 23 ^{1,2}	26 \pm 21 ^{1,2}

¹P<0.001 versus preoperative values

²P<0.05 1 Level vs. 2 Level 2yr and 30-60 Month Follow-up

Table 6. Young versus Elderly Outcomes (Mean \pm SD)

Group		Preoperative	2 Yr Postoperative	36-60 Month Follow-up
Young N= 157	ODI	70 \pm 13	28 \pm 20 ¹	30 \pm 21 ¹
	VAS	70 \pm 15	25 \pm 19 ¹	27 \pm 20 ¹
Elderly N= 12	ODI	68 \pm 14	22 \pm 14 ¹	25 \pm 15 ¹
	VAS	66 \pm 20	16 \pm 9 ^{1,2}	23 \pm 13 ¹

¹P<0.001 versus preoperative values

²P<0.05 Young versus Elderly at 2yr

Figure 1-2. Surgical Technique

Figure 4. Typical Patient Long Term Imaging Studies – to illustrate durability (preop, 2y, 5yrs)