Original Article

Robotically Assisted Minimally Invasive Transforaminal Lumbar Interbody Fusion (MIS-TLIF) Outcomes in the Aging Hispanic Population: A Retrospective Cohort Study

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Abstract: Minimally invasive techniques for lumbar spinal fusions have evolved significantly to treat lumbar spinal stenosis, degenerative spondylolisthesis, and many other complex conditions. This study evaluates the clinical outcomes of patients aged 65 and older who underwent minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) with robotic assistance. In this single-surgeon single-institution retrospective cohort study, 72 patients aged 65 and older who underwent MIS-TLIF from 2018 to 2021 were analyzed. Patients had diagnoses of lumbar spinal stenosis, with or without degenerative spondylolisthesis. Clinical outcomes were assessed using the Oswestry Disability Index (ODI) and Visual Analogue Scale (VAS) for back and lower extremities at baseline, and 6, 9, or 12 months postoperatively. The data was analyzed, and outcomes were compared using paired t-tests. Significant improvements in disability were observed postoperatively, with mean ODI scores decreasing from 46.4% to 9.3% (95% CI: -41.2, -33.1). In terms of pain intensity, mean VAS scores for back pain decreased from 8.0 to 3.5 (95% CI: -5.1, -3.9) and leg pain scores also decreased from 8.2 to 2.9 (95% CI: -5.9, -4.6). These changes indicate substantial clinical improvements ($p < 0.001$). This study substantiates the efficacy of MIS-TLIF in significantly improving pain relief and functional mobility among seniors with lumbar conditions. The substantial reductions in ODI and VAS scores highlight its clinical benefits potential to set a new standard of care. By offering a robotically assisted, minimally invasive alternative, this approach aligns with contemporary healthcare objectives of enhancing patient recovery while minimizing procedural risks and costs.

Keywords: MIS-TLIF; Robotic Spine Surgery; Lumbar Stenosis; Degenerative Spondylolisthesis; Elderly Patient Care; Spinal Fusion; Postoperative Outcomes; Quality of Life; Orthopedics

1. Introduction

Lumbar spinal fusion techniques have evolved throughout the past thirty-plus years to better stabilize and decompress unstable and stenotic vertebral segments. What started with open laminectomies and posterolateral fusions with freehand pedicle screw placement gradually progressed to minimally invasive approaches and interbody fusions with pre-planned, robotically navigated and assisted pedicle screw trajectories. From the first successful posterior lumbar interbody fusion (PLIF) in 1940, which used a spinous process autograft, to Blume in 1981, who described a unilateral approach to the already established

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PLIF procedure. Subsequently, Harms popularized the open TLIF (oTLIF) technique in the late 1990s, a posteriorly based open lumbar fusion with or without interbody support. The oTLIF has been the workhorse for spine surgeons throughout the past three to four decades [1-3]. By the 2000s, the minimally invasive transforaminal lumbar interbody fusion (MIS TLIF) came to fruition. It drew significantly from the paraspinal sacrospinalis splitting approach between the multifidus and longissimus muscles, first described by Wiltse in 1988. The MIS TLIF revolutionized and reinvented the practices of many spine surgeons around the country. The term "minimally invasive surgery" was popularized in part due to the significant improvement in the acute postoperative period regarding decreased tissue dissection and morbidity. It also reduced blood loss, infection rate, length of stay, and overall complication rate. The benefits of minimally invasive approaches go further as they also result in cost savings for the healthcare system's secondary to decreased length of stay (LOS), need for transfusion, lower inpatient resource utilization such as inpatient rehabilitation, and narcotic medication overuse [4].

The elderly population in the United States increases every year. In 2010, there were 11.2 million Americans aged 80 years and over [5]. This is a 22% increment in this subgroup compared to the year 2000. According to the American Community Survey (ACS), in 2016, the estimated number of people in the United States aged 65 and over was 49.2 million. Of these, 58% were aged 65 to 74; 29% were between the ages of 75 to 84, and 13% were 85 and older [6]. This population subgroup commonly presents with lumbar spinal stenosis (with or without neurogenic claudication), mechanical lower back pain (with or without radicular symptoms), multilevel degenerative disc disease, and degenerative spondylolisthesis. These findings are found both clinically and with lumbar MRI use. To better illustrate this, a 2009 study evaluating cases that underwent computed tomography (CT scan) showed that 47% of patients who were 60 years of age and older had lumbar spinal stenosis [3,7].

The number of spinal procedures performed on the elderly, particularly fusion procedures, increases every year [8]. The four-year outcome data in the Spine Patients Outcomes Research Trial (SPORT) shows that the operative treatment of lumbar spinal stenosis and degenerative spondylolisthesis provides better long-term benefits than non-operative management. Further, it is common knowledge that healthcare funds are scarce, and payers are demanding better quality of care for compensation provided. Therefore, there is a need for a consensus on the most effective approach and surgical technique for lumbar spinal stenosis in this age group. Most spine surgeons in Puerto Rico opt for open laminectomy and posterolateral fusion with or without interbody fusion as their technique of choice in this aging population. Alternatively, they also rely on indirect decompressions via an oblique lumbar interbody fusion (OLIF) or a lateral lumbar interbody fusion (LLIF), particularly when instrumented fusions are needed. The present study aims to assess clinical outcomes for patients aged 65 years and over who underwent a minimally invasive robotically assisted transforaminal lumbar interbody fusion (MIS TLIF) at one or two lumbar levels.

2. Methodology

After receiving approval from the Institutional Review Board at Ponce Health Sciences University, we conducted a retrospective analysis at Centro Médico Menonita in Cayey, Puerto Rico. We included patients aged 65 and over requiring lumbar fusion at one or two lumbar levels between August 2018 and December 2021. A total of 72 patients matched the inclusion criteria. Patients aged 64 and under, trauma patients, grade 3 spondylolisthesis or greater, 100 % axial back pain patients, patients with prior instrumented fusions, and patients undergoing lumbar decompression without implants (i.e., laminoforaminotomy) were excluded.

None of the patients in this study were active smokers, and nearly all had BMIs of 35 or less, with a few exceptions due to severity of pathology and symptoms. All patients presented with axial low back pain, unilateral or bilateral radicular leg symptoms, and neurogenic claudication. All patients underwent conservative non-operative management, including but not limited to physical

therapy, oral medications, and pain management blocks by a pain management specialist for at least six months prior to opting for a procedure. The data collected from the hospital medical records for this study included: age, sex, comorbidity variables (hypertension, obesity, active smoking status, diabetes mellitus, etc.), and information pertaining to the procedure (length of surgery, estimated blood loss, complications, location, and number of vertebral segments operated).

As part of an established preoperative planning protocol in this practice, all patients provided standing lumbar spine X-rays AP/LAT and flexion/extension views, CT lumbar with axial/sagittal/coronal reconstructions, and a DEXA scan showing bone density greater than -2.5 score in the lumbar spine to confirm candidacy for an instrumented fusion. Additionally, all patients needed a complete laboratory workup, including a CBC with differential, CMP, coagulation profile, HbA1c less than 7%, Vitamin D levels of 30-50 ng/mL, urine analysis, urine culture, serum albumin levels between 3.5 to 5.4 g/dL, transferrin levels between 200 to 360 mg/dL. The preoperative protocol also required an EMG-nerve conduction study, outpatient cardiology clearance, and hospital pre-admission evaluation and clearance.

For the evaluation of surgical success, the clinical outcomes were evaluated based on the improvement of back and leg pain individually, the degree of preoperative versus postoperative functional disability, and whether there were any perioperative complications. Patients' back and leg pain levels were evaluated using a ten-point Visual Analogue Scale (VAS). VAS scores range from 0 to 10, with lower scores indicating less severe pain symptoms. The Oswestry Disability Index (ODI) was used to quantify preoperative and postoperative disability. ODI scores range from 0 to 50, with lower scores indicating less disability. These ODI scores are then calculated into ODI percentages, the unit used in most studies and will be referenced in this study as well. Patients were interviewed in person or by phone to assess long-term VAS and ODI scores. Clinical outcomes were evaluated at baseline preoperatively and postoperatively at 6, 9, and 12-month marks.

All of the lumbar fusions are performed via two paraspinal Wiltse incisions to perform an MIS TLIF technique regardless of age or severity of pathology. All cases were instrumented with robotic assistance using Medtronics cannulated Solera/Voyager MIS corticocancellous pedicle screws via guided K-wires and FUSE titanium interbody cage instrumentation. Patient autograft was utilized from a medial facetectomy, BMP-2 (Infuse, Medtronic Sofamor Danek, Memphis, Tennessee; 1.4mL per level), demineralized bone graft, and 20-30cc of cancellous bone chips per level. The aforementioned were placed through a quadrant retractor system attached to a fixed table arm. Medtronics O-arm and Mazor X robotic technology (without stealth navigation edition) were used to plan screw trajectories and customize pedicle screw sizes for improved accuracy. All screws were probed with neuromonitoring, and all yielded satisfactory results. Lateral fluoroscopy was used to confirm correct screw placement and to ensure all inserted instruments, including disc pre-instrumentation, were in a safe area. All patients underwent post-instrumentation O-arm spin to corroborate preplanned robotic software screw projections to the real-time screw trajectories seen on CT image quality. For those patients with a personal history of cancer, we used Nuvasive Osteocel (5cc) instead of BMP-2. All patients were pre-medicated with tranexamic acid (20mg/kg loading dose and 4mg/kg infusion until wound closure; dose adjusted for cardiac and renal disease patients). Also, all patients were given 2g cefazolin IV every three hours and 1g vancomycin if allergic to penicillin. Prior to closure, all wounds were irrigated with diluted iodine (35mL in 1000mL saline preparation) and three additional liters of normal saline and cefazolin or bacitracin prior to interbody insertion. Vancomycin powder was placed subfascial and suprafascial inside all wounds prior to closure as long as the patient did not have a vancomycin allergy. If there was a dural tear during the procedure, vancomycin was only placed suprafascial. All wounds were closed in layers with Vicryl 1 and 2-0 undyed, and finally, subcuticular closure with Quil 2-0. Dermabond was then placed on all surgical wounds, followed by adequately sized dressings.

Statistical analysis was conducted using MedCalc software. Initially, descriptive statistics were applied to summarize demographic and clinical variables such as age, sex, comorbidities, and surgical details, providing an overview of the patient cohort. To assess changes in clinical outcomes, two-sided paired t-tests were used to compare preoperative and postoperative scores of the ODI and VAS scales. The ODI scores were analyzed in percentage terms to reflect the extent of disability reduction, while VAS scores were evaluated to measure changes in pain intensity. We accepted p-values below 0.05 as indicative of statistical significance. Results were reported with 95% confidence intervals to quantify the precision of the observed effects.

3. Results

Patient Demographics and Surgical Details: A total of 72 (35 male and 37 female) patients with a mean age of 71 years [65-85 range] fulfilled the inclusion criteria and were included in the study. Most patients had a preoperative diagnosis of lumbar spinal stenosis with radiculopathy. The most stenotic level was L4-L5 in 41 patients (56.9%), followed by L5-S1 in 24 patients (33.3%), L3- L4 in five patients (6.9%), and two patients (2.9%) were surgically intervened at the L2-L3 level. Sixty-eight patients (94.4%) underwent single-level MIS TLIF, and four (5.6%) underwent 2-level MIS TLIF. Diabetes mellitus, hypertension, chronic kidney disease, asthma, obesity, and thyroid disease were the comorbidities that showed the most prevalence (Table 1).

Table 1. Prevalence of Comorbidities Among Study Participants

Prevalence of Comorbidities	***n* (%)**
Asthma	8 (11.1%)
Chronic Kidney Disease	2 (2.8%)
Diabetes Mellitus	36 (50%)
Hypertension	54 (75%)
Obesity	3 (4.2%)
Thyroid Disease	17 (23.6%)
Ex-Smoker (History of tobacco use)	26 (36.1%)

This table summarizes the frequency and percentage of common comorbidities found in the study cohort of 72 patients undergoing minimally invasive transforaminal lumbar interbody fusion. The data highlight the prevalence of each condition to contextualize the health profile of the patient population.

Surgical Outcomes and Complications: The mean surgical time for a single level, robotically assisted MIS TLIF was 292.4 minutes. The mean surgical time for a two-level, robotically assisted MIS TLIF was 466.4 minutes. The average estimated blood loss (EBL) was minimal at 78.8 ccs (SD=15.51). The average length of stay was 1.1 days [range 1-5 days], with only two patients discharged home after 24 hours. These two prolonged hospitalizations were due to (1) a blood transfusion which delayed discharge and (2) the need for an additional day in the hospital for pain control. Three events were categorized as surgical complications (3 of 72 cases; 4.2% complication rate). These included a blood transfusion to resolve a hemoglobin value of 8.0, a seroma formation with pedicle screw misplacement, and a small dural tear that was repaired primarily. The misplaced pedicle screw was inserted 4mm too medial out of 296 total screws placed robotically. This indicates a 0.34% hardware revision rate. None of the three complications resulted in any long-term consequences for the patients, and none of the patients in this study necessitated inpatient rehabilitation. All patients were able to return home from the hospital with the only directives being (1) to ambulate one mile per day and (2) progress as tolerated with stretching at six weeks. None of the patients in this study had an infection or rule-out thereof.

Oswestry Disability Index: The study demonstrated significant improvements in ODI scores from preoperative to postoperative assessments. Initially, the mean preoperative ODI score (Table 2) was 46.4% (SD = 17.3), indicating a moderate to severe disability level among participants. This score significantly decreased to 9.3% (SD = 7.6) postoperatively, reflecting a substantial reduction in patient-reported disability. The mean difference observed was -37.1 percentage points (95% CI: -41.2, -33.1, $p < 0.0001$).

Visual Analogue Scale: Similarly, significant improvements were noted in pain severity as measured by the VAS for both back and leg pain. The mean back pain score (Table 2) decreased from 8.0 (SD = 2.8) preoperatively to 3.5 (SD = 2.3) postoperatively, with a mean difference of -4.5 points (95% CI: -5.1, -3.9, $p < 0.0001$). Leg pain scores (Table 2) also showed considerable improvement, decreasing from 8.2 (SD = 2.5) to 3.5 (SD = 2.6), resulting in a mean difference of -5.2 points (95% CI: -5.9, -4.6, $p < 0.0001$).

Table 2. Pre-operative and Post-operative ODI and VAS Score Results.

		Mean (95% CI)	**SD**
ODI%	Pre	46.4 (42.6, 50.2)	17.3
	Post	9.3 (7.5, 11.0)	7.6
Back VAS	Pre	8.0 (7.3, 8.7)	2.8
	Post	3.5 (3.0, 4.1)	2.3
Leg VAS	Pre	8.2 (7.6, 8.8)	2.5
	Post	2.9 (2.3, 3.6)	2.6

This table presents the mean scores and standard deviations for the Oswestry Disability Index (ODI) and Visual Analogue Scale (VAS) both before and after the surgical intervention. Scores are meant to illustrate the effectiveness of the procedure in improving patient-reported outcomes

Table 3. Statistical Analysis of ODI and VAS Score Improvements.

	Mean difference (95% CI)	**SD**	**Paired t (p)**
ODI%	-37.1 (-41.2, - 33.1)	17.3	-18.26 (<0.001)
Back	-4.5 (-5.1, -3.9)	2.4	-15.88 (<0.001)
Leg	-5.3 (-5.9, -4.6)	2.9	-15.49 (<0.001)

This table details the statistical analysis performed using paired samples t-tests to compare pre-operative and post-operative changes in ODI and VAS scores. The mean differences, 95% confidence intervals (CI), and p-values are provided to quantify and validate the significance of the observed improvements.

4. Discussion

Spinal disorders in the ever-growing elderly population are quite common and can present with debilitating symptoms. Although patients may respond to conservative management, we know from the SPORT trial data that surgical management of lumbar spinal stenosis and degenerative spondylolisthesis has better long-term results. Therefore, it is increasingly important to identify safe and effective interventions that improve the quality of life of elderly patients with such disorders while simultaneously lowering costs for healthcare. Spine surgery is usually indicated only after nonsurgical treatments (pain medications, pain management blocks, and physical therapy) have failed to relieve severe symptoms. Most spine surgery complications are related to excessive blood loss necessitating a blood transfusion, wound healing issues, infections, cerebrospinal fluid leakage, hardware misplacement, pulmonary embolism, and thrombophlebitis [9-11].

Minimally invasive transforaminal lumbar interbody fusion (MIS TLIF) has become a widely adopted surgical approach in treating degenerative lumbar diseases. Minimally invasive spine surgery (MIS), as an approach to the spine, is associated with less intra-operative blood loss, less muscle tissue dissection, and a shorter length of stay when compared to open lumbar fusions. MIS also translates to cost savings for hospitals and the healthcare system due to shorter length of stay and decreased inpatient resource utilization (such as inpatient rehabilitation programs and narcotic medication overuse). Literature reviews on perioperative outcomes between MIS TLIF and open TLIF have reported significantly better perioperative outcomes, at least in the short-term, in MIS TLIF compared to open TLIF [11,12]. It is important to note that MIS surgery may be cumbersome for pedicle screw placement accuracy. To increase the reproducibility of acquiring good to excellent screw placement trajectories, and to improve patient safety, we introduced robotic spine surgery with the Medtronics Mazor X robot (Medtronics Sofamor Danek, Memphis, TN) back in 2018, and it has just recently been updated to the navigated stealth edition.

The present study examined the clinical outcomes for patients 65 and over who underwent MIS-TLIF for lumbar spinal stenosis with or without degenerative lumbar spondylolisthesis in one or two lumbar levels. Previous studies that have examined retrospective data comparing MIS and open TLIF approaches have found lower blood loss and shorter hospital length of stay in MIS TLIF compared to open TLIF [5,8]. In our study, the mean estimated blood loss (78.8 mL) and length of hospitalization (1.1 days) were significantly lower when compared to open TLIF reported outcomes in other studies. For instance, Villavicencio et al. reported a greater mean EBL (366.8 mL) and length of hospitalization (4.2 days) in their open TLIF group [8]. Additionally, Dhall et al. also reported a greater mean EBL (505 mL) and length of hospitalization (5.5 days) in their open TLIF group [5].

Most patients visit surgeons' clinics with the desire to reduce pain and regain some of their functionality. Consequently, MIS TLIF has been found to provide patients with a significant reduction in back and leg pain [12, 13]. Moreover, another retrospective study of 40 patients who underwent MIS TLIF for spondylolisthesis also found a significant reduction in back and radicular leg pain from VAS 52 and 65 to 15 and 8 [7]. Still, Lee et al. reported a statistically significant reduction in back pain VAS scores for the MIS group compared to the open group at postoperative six months and one-year marks ($P < 0.05$) [12]. In our study, we observed a significant reduction in back and radicular leg pain from the preoperative baseline to the one-year mark. The mean preoperative back and radicular pain VAS scores were 8.0 and 8.2 respectively. Postoperative year one, the mean VAS pain scores reduced to 3.5 for back pain (mean difference -4.5; 95% CI -5.1 to -3.9; p-value <0.0001), and 2.9 for radicular leg pain (mean difference -5.2; 95% CI -5.9 to -4.6; p-value <0.0001). These results were considered a clinically and statistically significant improvement in VAS pain scores for our patients.

Most of these patients seeking a spine surgery consultation have lost some degree of function secondary to pain, limited range of motion, and nerve compression. In our study, functional outcome was measured using the ODI questionnaire. Previous prospective studies have shown a significant reduction in mean ODI scores in patients who underwent MIS TLIF [12]. Deutsch and Musacchio found that 85% of their cases had a greater than 20-point reduction postoperatively in ODI scores after an MIS TLIF [14]. One open surgery technique study showed mean ODI scores for the MIS group dropped 25.5 points, from 51 pre-operatively to 25.5 at the one-year post-op mark, while the open group went from a pre-op ODI score of 55.2 to 36.4 at the one-year post-op mark (18-point drop). Statistical analysis would show significance in these ODI differences with a p-value of < 0.05 [12]. In this study, we demonstrated similar results since our mean preoperative and postoperative ODI percentage scores were 46.4% and 9.3%, respectively. This means that our patients also had a greater than 20-point reduction in their ODI scores after an MIS TLIF. Statistical analysis yielded an ODI percentage score mean difference of -37.1, with 95% CI -41.2 to -33.1, and a p-value of <0.0001.

Limitations to this study include its retrospective nature and short one- to two-year follow-up data in most cases. In addition, all cases are from a single surgeon that only performs MIS robotic TLIFs and has no other comparable open cases. Therefore, our comparison data comes from published literature on open lumbar fusion cases. Future papers should attempt prospective randomized, double-blinded studies to weigh in on the unanswered questions more heavily and explore outcomes on populations with diverse ethnic backgrounds. Specifically, whether patients 65 and over undergoing a one or two-level fusion should be operated via a long-held traditional open approach or benefit more from an MIS approach to the spine, which preserves what little muscle capacity they have left.

5. Conclusions

Our retrospective cohort analysis suggests a potential association between robotically assisted MIS TLIFs and statistically significant reductions in both VAS and ODI scores when comparing preoperative baselines to one-year postoperative outcomes. These findings could indicate improvements in axial low back and radicular leg pain, as well as enhanced functionality and daily living activities—two key factors patients often consider when evaluating surgical options. While these results align with previous studies on minimally invasive techniques in younger populations, we now observe similar outcomes in a Hispanic population aged 65 and older. Given the growing aging population and the potential advantages MIS may offer over open surgery in the short term, it would seem appropriate to consider MIS techniques more routinely for older adults, particularly when one or two levels are involved. Older, physically vulnerable patients may benefit from the muscle-sparing nature of MIS procedures. Additionally, the literature suggests that MIS may lead to reduced blood loss, lower tissue dissection, and limited subperiosteal stripping, potentially resulting in faster ambulation, reduced inpatient resource use (such as physical therapy and narcotics), lower infection rates, and shorter hospital stays.

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