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# Enhancing Surgical Excellence: Reducing Complications and Improving Outcomes in Modern Minimally Invasive Spine Procedures.

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## Abstract

***Background:*** Minimally invasive spine surgery (MISS) is becoming more popular and has the potential to cause less tissue damage, less blood loss, less supervision during hospital stay, and less morbidity. But there are possibilities of complications, especially in complex procedures. ***Objective:*** To evaluate postoperative complications, clinical outcomes, and factors associated with adverse outcomes following MISS. ***Methods:*** This was a prospective observational study of 153 adult patients undergoing MISS for degenerative spinal diseases. Demographic, clinical and operative, and postoperative data were collected. The Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) were used to evaluate pain and disability. Appropriate parametric and non-parametric tests were used to assess complications and functional outcome, and multivariate regression was used to determine the predictors. ***Results:*** The mean age was 52.6 ± 11.8 years, and 59.5% were male. There were 9.8% postoperative complications, the most common of which was dural tear/CSF leakage (3.3%). VAS decreased from 7.1 ± 1.3 to 2.8 ± 1.5, while ODI decreased from 58.4 ± 11.2 to 25.7 ± 12.6 (both $p<0.001$). 83.0% of patients experienced clinically meaningful improvement. Older age, obesity, previous spine surgery, and multi-level surgery were independent of each other risk factors for complications. ***Conclusions:*** The results of this study showed that MISS had a positive correlation with significant pain relief, functional improvement, and few complications. Careful patient selection and careful surgical planning may provide further improvement of results.

**Keywords:** Minimally invasive spine surgery; Spinal surgery; Postoperative complications; Surgical outcomes; Oswestry Disability Index.



## INTRODUCTION

Spinal disorders are a significant and growing burden on health worldwide, due to population ageing, extended life expectancy, increased occupational exposure, sedentary lifestyles and the increasing occurrence of degenerative musculoskeletal disease.[1] According to the estimates, an estimated 619 million people worldwide experienced low back pain (LBP) alone in 2020, or one in every 13 people, and it continued to be the primary cause of disability worldwide.[2] It is estimated that by 2050, the world will be home to around 843 million people with LBP, with particularly high rates of increase anticipated in low- and middle-income countries and ageing populations.[3] Most patients can be treated conservatively, but a large number of those with structural compression, spinal instability, degenerative disease, disc disease, deformity, and neurologic involvement will ultimately need surgery.[4]

Recent developments in spinal surgery over the last few decades have seen a major shift from traditional open surgery to minimally invasive spine surgery (MISS).[5] Modern MISS can be implemented with a wide range of techniques such as tubular micro procedures, minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF), lateral and oblique lumbar interbody fusion (LIF), uniportal and biportal endoscopic surgery, percutaneous instrumentation, and image-guided navigation.[6] The primary goal is to decompress the nerves and stabilize the spine with minimal compromise of the paraspinal muscles, ligaments, bone, and other normal structures.[7] This tissue-sparing approach has made MISS a significant part of modern spinal surgery and continues to be a vital consideration when surgeons look to balance technical success with better recovery outcomes and patient satisfaction.[8]

There are several perioperative benefits that are supported by increasing evidence for minimally invasive techniques. A systematic review and meta-analysis were performed to assess the differences between minimally invasive surgery (MISS) and open surgery (OS) in the treatment of degenerative lumbar pathology, and it was found that, although long-term functional outcomes and operative duration were not consistently different, MISS had significant benefit in terms of blood loss, hospital length of stay, complication rates and surgical costs.[9] Likewise, a meta-analysis of minimally invasive and open surgery for cauda equine syndrome revealed significantly reduced mean blood loss and reduced length of hospital stay in the minimally invasive group, along with an improvement in the measured postoperative pain and neurological recovery. The results indicate that the positive effects of MISS can be more than just minimizing incisions, and could be associated with less physiological stress, earlier mobilization, shorter hospital stay and, potentially, a faster functional recovery.[10]

In the more recent pooled evidence that included nearly 12,600 tubular lumbar MISS patients, the complication rate was estimated at around 10% overall, including 4% for dural tears, 1% for nerve injuries, 1% for surgical site infection, 2% for revision surgery, and around 3% for reherniation. The incidence of complications can therefore be relatively small, but can still have significant consequences such as neurological impairment, reoperation, delayed rehabilitation, prolonged hospital stays, or ongoing disability.[11]

In the era of modern minimally invasive spine surgery, a movement from mere implementation of less invasive techniques to methodically refining each and every element of the surgical journey is necessary to improve surgical excellence. The factors associated with perioperative complications and poor outcomes could help surgeons to optimize patient selection, operative planning, technical execution, and postoperative care and to maintain the well-known advantages of minimally invasive techniques. The present study was therefore conducted to assess clinical success and complication rates of contemporary minimally invasive spine surgery and to determine risk factors for perioperative complications. This study aimed to evaluate the safety and efficacy of minimally invasive spine surgery with regard to the rates and trends of postoperative complications, the functional and clinical outcomes of the procedures, and potentially modifiable risk factors that might influence successful surgery and patient recovery.

## MATERIALS AND METHODS

The study was conducted as a prospective observational study. The study was conducted in the Department of Orthopedics Surgery. The study was conducted over a period from November, 2025 to April 2026.

The sample size was determined by using OpenEpi version 3.0 with the calculation for a single population proportion. The expected rate of postoperative complication was assumed to be 10%, a rate recently reported in a proportional meta-analysis of 75 studies with 12,600 patients undergoing minimally invasive lumbar spine surgery, which found an overall complication rate of 10% (95% CI 8–14%).

A 95% confidence level and 5% absolute precision were used for the calculation. The OpenEpi calculation was based on an anticipated frequency of 10%, confidence limits of ±5%, a design effect of 1.0, and a large source population.[11] The minimum sample size calculated was 153 patients.

A non-probability sampling technique was employed and was known as a consecutive sampling technique. Adult patients over the age of 18 years of both genders who had received a minimally invasive spinal surgical procedure within the study period were included. Patients were selected for the study if they had degenerative spinal disease, lumbar disc disease, spinal stenosis, specific spinal instability, or other spine conditions that were felt to be appropriate for a minimally invasive surgical approach.

All patients who underwent minimally invasive decompression, tubular spine surgery, endoscopic spine surgery, minimally invasive fusion, or percutaneous spinal instrumentation were included.

Preoperative clinical and radiological data were sufficient, and patients were included only if they signed up for the study and follow-up after informed consent. Patients under 18 years of age, undergoing traditional open spinal surgery, and those with an acute traumatic spinal injury who needed emergency surgery were excluded. Patients with documented severe neurological deficits from another pathology, active systemic infection, or active malignancy who would be expected to have significant surgery on their spine unrelated to the current spinal surgery were also excluded.

Eligible patients were approached before surgery and informed of the goals and procedures of the study, with approval from the institutional ethical review committee. Written informed consent was obtained from each participant. Demographic and clinical data such as age, gender, BMI, presence of relevant comorbidities, smoking status, symptoms, their duration, neurological findings, previous spinal surgery, and underlying spinal diagnosis were collected on a structured data collection proforma. Preoperative imaging results, such as the level of the spine involved, extent of stenosis or neural compression, disc pathology, instability, and other pertinent imaging features were also recorded.

Operative data was prospectively recorded, including the type of minimally invasive procedure, level, number of levels treated, operative time, estimated blood loss, use of intraoperative fluoroscopy or navigation, instrumentation, and intraoperative complications. Patients were followed up after the procedure for these postoperative complications: incidental durotomy, cerebrospinal fluid leak, neurological injury or deficit, postoperative hematoma, wound infection, thrombosis-embolic complication, inadequate decompression, hardware-related complication, recurrent disc herniation, and unplanned reoperation. Postoperative pain, neurological status, hospital stay, and time to mobilization were also recorded. In patients receiving lumbar procedures, clinical outcomes were evaluated with appropriate validated outcome measures, such as the Visual Analog Scale (VAS) for pain and the Oswestry Disability Index (ODI) for functional disability.[12, 13] Reassessment was undertaken at pre-specified postoperative time points to assess improvements in symptoms, functional recovery, complications, and revision surgery.

All the gathered data were entered, cleaned, coded, and analyzed by IBM SPSS Statistics 26.0 software. All continuous variables were initially evaluated for normality with the Shapiro–Wilk test and graphically if applicable. Data for continuous variables, which were normally distributed, were expressed as mean ± standard deviation, and data for continuous variables that were not normally distributed were presented as median and interquartile range (IQR). Frequencies and percentages were used to present categorical variables. Independent-samples t-test was used to compare two groups for continuous variables with normal distributions, and Mann–Whitney U test was used to compare two groups with non-normal distributions. One-way analysis of variance (ANOVA) was used for normally distributed variables for comparisons between more than two groups, and the Kruskal–Wallis test was used for non-parametric variables. The Pearson chi-square test and Fisher's exact test were used for comparisons of categorical variables.

The associations between demographic, clinical, radiological, and operative characteristics and the development of postoperative complications were first evaluated with the use of suitable univariate analyses. On univariate analysis, variables showing a clinically relevant association and/or a p value <0.2 were included in the multivariable analysis. Binary logistic regression analysis was then used to determine independent predictors of postoperative complications. Adjusted odds ratios with corresponding 95% confidence intervals were reported. Linear regression analysis was performed to assess independent predictors of continuous outcomes of the postoperative period (change in pain or disability scores). Preoperative and postoperative clinical scores were compared for evaluation of postoperative improvement using the paired-samples t-test when the data were normally distributed and the Wilcoxon signed-rank test when the paired observations were not normally distributed. A two-tailed p-value <0.05 was considered statistically significant.

## RESULTS

A total of 153 patients undergoing minimally invasive spine surgery were included. Mean age was 52.6 ± 11.8 years, and 59.5% of the cohort were male. Previous spinal surgery, hypertension, diabetes mellitus, smoking, and obesity were present in 11.8%, 33.3%, 24.2%, and 31.4% of patients, respectively. Baseline pain and disability were also quite high, with mean VAS and ODI scores of 7.1 ± 1.3 and 58.4 ± 11.2, respectively, and the median symptom duration was 8 months. (Table 1)

**Table 1. Demographic and baseline clinical characteristics of the study population (n=153)**

| Variable | n(%)/mean ± SD |
|---|---|
| Age (years) | 52.6 ± 11.8 |
| Age range (years) | 22–78 |
| Male | 91 (59.5) |
| Female | 62 (40.5) |
| BMI (kg/m²), median (IQR) | 26.8 (24.0–29.4) |
| BMI ≥30 kg/m² | 32 (20.9) |
| Smoking | 48 (31.4) |
| Diabetes mellitus | 37 (24.2) |
| Hypertension | 51 (33.3) |
| Previous spinal surgery | 18 (11.8) |
| Duration of symptoms, median (IQR), months | 8 (4–16) |
| Preoperative VAS | 7.1 ± 1.3 |
| Preoperative ODI | 58.4 ± 11.2 |

The most common underlying pathology was lumbar disc herniation (37.9%), followed by lumbar spinal stenosis (27.5%) and degenerative spondylolisthesis (17.6%). The most frequent procedure was Endoscopic discectomy/decompression (33.3%), followed by MIS-TLIF (25.5%) and tubular decompression (23.5%). The majority of procedures included one spinal level (79.1%); 76.5% of procedures were performed with fluoroscopy, 25.5% with navigation, and 30.1% with neuromonitoring. (Table 2)

**Table 2. Spinal pathology, surgical procedures and operative characteristics**

| Variable | n (%) |
|---|---|
| **Primary diagnosis** | |
| Lumbar disc herniation | 58 (37.9) |
| Lumbar spinal stenosis | 42 (27.5) |
| Degenerative spondylolisthesis | 27 (17.6) |
| Recurrent disc herniation | 12 (7.8) |
| Foraminal stenosis | 8 (5.2) |
| Other spinal pathology | 6 (3.9) |
| **Minimally invasive procedure** | |
| Endoscopic discectomy/decompression | 51 (33.3) |
| Tubular microdiscectomy/decompression | 36 (23.5) |
| MIS-TLIF | 39 (25.5) |
| Percutaneous pedicle screw fixation | 18 (11.8) |
| Other procedures | 9 (5.9) |
| **Number of spinal levels treated** | |
| Single level | 121 (79.1) |
| Two levels | 25 (16.3) |
| ≥3 levels | 7 (4.6) |
| Fluoroscopy used | 117 (76.5) |
| Navigation used | 39 (25.5) |
| Neuromonitoring used | 46 (30.1) |
| Operative duration, mean ± SD (min) | 125.2 ± 45.1 |
| Estimated blood loss, median (IQR), mL | 85 (50–150) |
| Hospital stay, median (IQR), days | 2 (1–3) |
| Time to mobilization, median (IQR), hours | 18 (12–24) |

The postoperative complications included in this series were cerebrospinal fluid leak/dural tear (3.3%), recurrent disc herniation (2.6%), and hardware-related complications (2.0%). Unplanned reoperation was performed in 3.3% of patients, 30-day readmission in 2.6%, and postoperative mortality was not reported. (Table 3)

**Table 3. Intraoperative and postoperative complications and short-term clinical outcomes**

| Complication/outcome | n (%) |
|---|---|
| **Intraoperative complications** | 13 (8.5) |
| Dural tear/CSF leak | 5 (3.3) |
| Iatrogenic neurological injury | 2 (1.3) |
| Hardware malposition | 3 (2.0) |
| Excessive bleeding requiring intervention | 3 (2.0) |
| **Postoperative complications** | 15 (9.8) |
| Cerebrospinal fluid leak/persistent CSF leakage | 5 (3.3) |
| Recurrent disc herniation | 4 (2.6) |
| Hardware malposition/failure | 3 (2.0) |
| Neurological deficit | 2 (1.3) |
| Surgical-site infection | 2 (1.3) |
| Postoperative hematoma | 2 (1.3) |
| Inadequate decompression | 2 (1.3) |
| Thromboembolic event | 1 (0.7) |
| Unplanned reoperation | 5 (3.3) |
| 30-day readmission | 4 (2.6) |
| 30-day mortality | 0 (0.0) |

Significant improvement was seen in pain and functional disability after surgery. The mean VAS score dropped from 7.1±1.3 preoperatively to 2.8±1.5 postoperatively, with an ODI score dropping from 58.4±11.2 to 25.7±12.6. Both were statistically significant with p<0.001. (Table 4)

**Table 4. Comparison of postoperative clinical outcomes before and after minimally invasive spine surgery**

| Outcome | Preoperative | Postoperative | Mean/median change | p-value |
|---|---|---|---|---|
| VAS, mean ± SD | 7.1 ± 1.3 | 2.8 ± 1.5 | −4.3 ± 1.6 | <0.001 |
| ODI, mean ± SD | 58.4 ± 11.2 | 25.7 ± 12.6 | −32.7 ± 13.5 | <0.001 |
| Hospital stay, median (IQR), days | — | 2 (1–3) | — | — |
| Time to mobilization, median (IQR), hours | — | 18 (12–24) | — | — |

The frequency of postoperative complications significantly increased with age ≥ 60 years, BMI ≥ 30 kg/m², diabetes mellitus, previous spinal surgery, and multi-level procedures. There was no significant correlation between sex, hypertension, or smoking status. (Table 5)

**Table 5. Association of patient and surgical characteristics with postoperative complications**

| Variable | Complication n/N (%) | No complication n/N (%) | p-value |
|---|---|---|---|
| Age ≥60 years | 8/48 (16.7) | 40/48 (83.3) | 0.041 |
| Age <60 years | 7/105 (6.7) | 98/105 (93.3) | |
| Male | 10/91 (11.0) | 81/91 (89.0) | 0.487 |
| Female | 5/62 (8.1) | 57/62 (91.9) | |
| BMI ≥30 kg/m² | 7/32 (21.9) | 25/32 (78.1) | 0.012 |
| BMI <30 kg/m² | 8/121 (6.6) | 113/121 (93.4) | |
| Diabetes mellitus | 7/37 (18.9) | 30/37 (81.1) | 0.025 |
| No diabetes | 8/116 (6.9) | 108/116 (93.1) | |
| Hypertension | 7/51 (13.7) | 44/51 (86.3) | 0.183 |
| No hypertension | 8/102 (7.8) | 94/102 (92.2) | |
| Smoking | 7/48 (14.6) | 41/48 (85.4) | 0.133 |
| Non-smoker | 8/105 (7.6) | 97/105 (92.4) | |
| Previous spinal surgery | 5/18 (27.8) | 13/18 (72.2) | 0.008 |
| No previous surgery | 10/135 (7.4) | 125/135 (92.6) | |
| Multi-level surgery | 7/32 (21.9) | 25/32 (78.1) | 0.009 |
| Single-level surgery | 8/121 (6.6) | 113/121 (93.4) | |

Patients who had complications experienced longer operating times, higher blood loss, longer hospital stays, and delayed postoperative mobilization than those who did not develop complications. The operative time and bleeding were also found to be significantly different between surgical procedures, with MIS-TLIF procedures generally taking longer to operate and requiring more blood loss than less extensive minimally invasive procedures, but not statistically significantly different rates for reoperation or complications. (Table 6)

**Table 6. Comparison of operative characteristics and postoperative outcomes according to complication status and surgical procedure**

**A. Comparison according to postoperative complication status**

| Variable | Complication group (n=15) | No complication group (n=138) | p-value |
|---|---|---|---|
| Operative duration, median (IQR), min | 155 (125–195) | 120 (90–145) | 0.001 |
| Estimated blood loss, median (IQR), mL | 150 (100–250) | 80 (50–130) | 0.002 |
| Hospital stay, median (IQR), days | 4 (3–6) | 2 (1–3) | <0.001 |
| Time to mobilization, median (IQR), hours | 30 (24–48) | 18 (12–24) | <0.001 |
| Navigation used, n (%) | 7 (46.7) | 32 (23.2) | 0.052 |

**B. Comparison according to minimally invasive procedure**

| Procedure | Operative duration, mean ± SD (min) | Blood loss, median (IQR), mL | Complications, n (%) | Reoperation, n (%) |
|---|---|---|---|---|
| Endoscopic discectomy/decompression | 91.5 ± 23.4 | 45 (30–70) | 3 (5.9) | 1 (2.0) |
| Tubular decompression | 108.7 ± 31.6 | 65 (40–100) | 3 (8.3) | 1 (2.8) |
| MIS-TLIF | 174.6 ± 37.2 | 150 (100–220) | 6 (15.4) | 2 (5.1) |
| Percutaneous fixation | 145.3 ± 29.8 | 110 (70–150) | 2 (11.1) | 1 (5.6) |
| Other procedures | 127.8 ± 34.5 | 90 (50–140) | 1 (11.1) | 0 (0.0) |
| Overall | 125.2 ± 45.1 | 85 (50–150) | 15 (9.8) | 5 (3.3) |

There were significantly positive correlations between postoperative pain and disability with age, BMI, symptom duration, operative duration, and estimated blood loss. Multivariable analysis showed that age ≥60 years, obesity, and prior spine surgery and multi-level surgery were still significant predictors of complications. A higher BMI, longer symptom duration, longer operative duration, and postoperative complications were independent risk factors for higher postoperative ODI scores. Overall, 127 (83.0%) patients experienced clinically meaningful improvement after surgery. (Table 7)

**Table 7. Correlations and multivariable predictors of postoperative complications and functional outcome**

**A. Spearman correlation with postoperative VAS and ODI**

| Variable | Postoperative VAS, r | p-value | Postoperative ODI, r | p-value |
|---|---|---|---|---|
| Age | 0.21 | 0.009 | 0.24 | 0.003 |
| BMI | 0.18 | 0.026 | 0.20 | 0.013 |
| Duration of symptoms | 0.27 | 0.001 | 0.29 | <0.001 |
| Operative duration | 0.23 | 0.005 | 0.25 | 0.002 |
| Estimated blood loss | 0.19 | 0.019 | 0.21 | 0.009 |

**B. Multivariable logistic regression for postoperative complications**

| Predictor | Adjusted OR | 95% CI | p-value |
|---|---|---|---|
| Age ≥60 years | 2.58 | 1.08–6.18 | 0.034 |
| BMI ≥30 kg/m² | 3.21 | 1.23–8.37 | 0.017 |
| Previous spinal surgery | 3.74 | 1.27–11.02 | 0.017 |
| Multi-level surgery | 2.89 | 1.12–7.45 | 0.028 |

**C. Multivariable linear regression for postoperative ODI**

| Predictor | β coefficient | 95% CI | p-value |
|---|---|---|---|
| Age | 0.18 | 0.03–0.34 | 0.021 |
| BMI | 0.41 | 0.12–0.70 | 0.006 |
| Duration of symptoms | 0.29 | 0.15–0.43 | <0.001 |
| Operative duration | 0.07 | 0.02–0.12 | 0.008 |
| Postoperative complication | 5.62 | 2.18–9.06 | 0.002 |

## DISCUSSION

This study highlighted that minimally invasive spine surgery (MISS) could be linked to a significant reduction in pain and functional disability, with a significant reduction in VAS from 7.1 to 2.8 and ODI from 58.4 to 25.7. Overall, 83.0% of patients experienced clinically meaningful improvement, and 9.8% of patients had some postoperative complications. The results reflect the efficacy of modern MISS for a diverse group of spine diseases in the lumbar spine, including disc herniation, spinal stenosis, degenerative spondylolisthesis, and recurrent disease. Poor outcomes compare favorably to those found in a 2022 systematic review and meta-analysis of 53 studies examining the outcomes of minimally invasive versus open surgery, which revealed reduced blood loss, hospital stays, and complication rates for minimally invasive surgery over the short term, with similar long-term ODI results.[14]

The rate of postoperative complications (9.8%) in our cohort is especially aligned with newer evidence. In a proportional meta-analysis of 75 studies of 12,600 patients who underwent tubular lumbar MISS (TL-MISS), Ikwuegbuenyi et al. (2026) found an overall rate of 10% complications, with 4% having a dural tear, 1% nerve injury, 1% postoperative hematoma, 1% surgical-site infection, 2% revision surgery, and 3% disc reherniation. The incidence of dural tear/CSF leakage (3.3%), recurrent disc herniation (2.6%), and reoperation (3.3%) is within the contemporary range reported in large pooled datasets, with our complication rate of 9.8%.[11]

Likewise, Inzerillo et al. (2026) found that the pooled complication rate for the lumbar uniportal endoscopic surgery was 9.79%, including dural tears (3.75%), nerve palsies (2.69%), hematomas (0.24%), and revisions (2.39%). The overall complication estimate for their cohort is similar to what is observed in the present cohort (9.8% vs. 11% to 14%), making what is observed in the present cohort likely even though we included several different MISS techniques, rather than one endoscopic technique. The majority of patients with dural injury and the frequent occurrence of recurrent disc disease in our series is consistent with the complication rate reported in the modern literature of endoscopy.[15]

Data on certain complications further support our findings in unilateral biportal endoscopic surgery for lumbar spinal stenosis, which was presented in the 2022 meta-analysis. The pooled complication rate was 8.1% (14 studies, 707 patients), with 4.5% having dural tears, 2.0% having incomplete decompression, 2.6% having a transient palsy, and 1.1% having a symptomatic postoperative epidural hematoma. The incidences of dural injury (3.3%), neurological deficit (1.3%), hematoma (1.3%), and inadequate decompression (1.3%) are therefore reasonably comparable. The lower rates in our group could be due to case selection, surgical skills, case mix, and/or length of follow-up.[16]

The results of the improvement in VAS and ODI in our study are also well supported by Park et al. (2023), who studied 3673 patients in biportal endoscopic spine surgery. They showed a considerable decrease in back and leg pain severity assessed by VAS and ODI, with a mean decrease of around 4.06 points in back pain VAS and 40.62 points in ODI. These decreases in VAS and ODI (4.3 and 32.7 points) are comparable to the magnitude of functional and symptomatic improvement reported in larger pooled cohorts. Our study found a slightly smaller improvement in ODI, which could be attributed to the baseline level of disability, the distribution of pathology, length of follow-up, and the presence of fusion surgery in addition to decompression surgery.[17]

The relatively low blood loss and short hospital stay in our cohort are similar to what was found by John et al. (2023) in their study comparing MISS with open surgery in cases of cauda equina syndrome. Their meta-analysis showed significantly reduced mean blood loss with MISS (71.7 versus 366.5 mL), decreased hospital stay (4.08 versus 8.85 days), and decreased operative time (75.4 versus 155.1 minutes), along with improved VAS outcome scores in the postoperative period. In the absence of an open surgery comparator group, the median blood loss of 85 mL and the perioperative benefit seen with a median hospital stay of 2 days are consistent with what we expect from a tissue-preserving minimally invasive approach.[18]

The findings of our study indicated that the longest operative duration and blood loss occurred in MIS-TLIF procedures, while the lowest blood loss and the shortest operative duration were associated with the endoscopic procedures, respectively. This is consistent with the results of the 2021 meta-analysis, which concluded that overall, the OLIF procedure was less time-consuming and had less blood loss, and improvements in ODI and back pain were generally comparable with MIS-TLIF. Similarly, a meta-analysis published in 2024 comparing endoscopic TLIF to MIS-TLIF showed no difference in long-term VAS, ODI, fusion, or complication rates, but there was a longer hospital stay for endoscopic TLIF, and less blood loss and shorter operation time for MIS-TLIF. These results highlight that procedure selection and operation complexity are key factors influencing the use of perioperative resources even within the MISS group.[19, 20]

This is clinically reasonable because a greater number of levels would be associated with more complications, as it would be more technically challenging, involve greater blood loss, longer operative times, and more operative exposure. This is supported by the 2023 Systematic Review of complications in MISS, which identified dural injury, neurological complications, hardware malposition, hematoma, and recurrent disc disease as important complications whose incidence is dependent on approach and procedure. The same review pointed to the critical role of navigation and neuromonitoring in risk reduction, but said that it cannot be determined from observations.[21]

Previous spinal surgery, obesity, and older age were associated with postoperative complications in our study as well and have important clinical implications. They may be technically challenging to manage, have more advanced degenerative spinal conditions, and have a higher physiological risk during surgery, and previous surgery may lead to epidural fibrosis and misaligned spinal planes, making minimally invasive revision surgery more difficult. The studies used in the present comparison do not consistently assess these predictors, but the 2026 tubular MISS meta-analysis highlighted significant variation in complications and the need to consider patient-specific risk factors and surgeon experience when assessing risk. Therefore, our multivariable results should be interpreted as associations between variables, but not as causal relationships.[11]

The 2022 Indian systematic review and meta-analysis of minimally invasive lumbar interbody fusion further supports our results. In 15 studies with 1,318 patients, there were significant postoperative decreases in VAS and ODI scores, and the pooled blood loss was around 128 mL with a mean hospital stay of 4.78 days. The median blood loss was slightly lower (85 mL) in our cohort, as was the median hospitalization time (2 days), and there was significant improvement in VAS and ODI. The differences are likely to be partly due to our inclusion of the less extensive endoscopic decompression procedures along with fusion procedures, while the Indian review concentrated exclusively on minimally invasive interbody fusion procedures.[22]

Lastly, the safety profile of our cohort aligns with the general trend of MISS becoming more sophisticated over the years with the advancement of endoscopic and image-guided procedures. A 2025 meta-analysis of the full endoscopic lumbo-perineal approach to discectomy showed that the approach had similar recurrence and reoperation rates compared to traditional methods and had better outcomes in terms of short-term pain and early movement. Likewise, the 2024 pooled analysis of randomized trials that compared biportal endoscopic surgery with microscopic surgery revealed rates of adverse events at 9.1% and 17.3%, respectively, but this had no statistical significance. The results of this study, in conjunction with our 9.8% complication rate and 83.0% clinically meaningful improvement, indicate that MISS can offer a satisfactory clinical recovery without sacrificing the inherent risks of spinal surgery.[23, 24]

### Limitations

This study has several limitations that should be considered when interpreting the findings. First, the study's prospective observational design and the selection of consecutive non-probability sampling may have resulted in selection bias and restricted the generalizability of the results to other institutions and patient groups. Second, because there were relatively few patients (153) and postoperative complication events, the statistical power was limited to identify independent predictors of postoperative complications. Thirdly, the study comprised a variety of minimally invasive procedures and spinal disorders, so clinical and procedural variability may have affected the perioperative results. Finally, the absence of a classic open-surgery control group rendered a direct comparison of the efficacy and safety of minimally invasive and open procedures difficult. Lastly, the follow-up period was predominantly short-term clinical events and outcomes; therefore, long-term events such as improved function, fusion, adjacent-segment disease, and late recurrence were not well studied.

## CONCLUSION

Patients who underwent MISS experienced marked reduction in postoperative pain and functional disability; clinically meaningful improvement was seen in most patients. The overall postoperative complication rate was relatively low, but complications were more common in patients older than 60 years, obese, with prior spinal surgery, or with multi-level procedures. Longer hospital stay and delayed mobilization were also linked to greater operative complexity, as well as increased blood loss. The findings are in line with the efficacy of MISS for the appropriate patient population and highlight the need to carefully evaluate the risk factors before the procedure, have a thorough understanding of the surgical procedure, and select the patient population with care to ensure that the procedure is performed with minimal risk and maximum benefit.

## REFERENCES

1. Huang, S., et al., Low back pain in aging populations: a global analysis of disability and healthcare burden over three decades. Journal of Back and Musculoskeletal Rehabilitation, 2026. 39(1): p. 347-356.
2. Roberts, K.E., et al., Global trends in risk factors for low back pain: an analysis of the Global Burden of Disease Study data from 1990 to 2021. Arthritis Care & Research, 2025. 77(7): p. 837-847.
3. Ferreira, M.L., et al., Global, regional, and national burden of low back pain, 1990–2020, its attributable risk factors, and projections to 2050: a systematic analysis of the Global Burden of Disease Study 2021. The Lancet Rheumatology, 2023. 5(6): p. e316-e329.
4. Nijs, J., et al., Nociceptive, neuropathic, or nociplastic low back pain? The low back pain phenotyping (BACPAP) consortium's international and multidisciplinary consensus recommendations. The Lancet Rheumatology, 2024. 6(3): p. e178-e188.
5. Goldberg, J.L., et al., The future of minimally invasive spinal surgery. World Neurosurgery, 2022. 163: p. 233-240.
6. Hu, Q., et al., Comparative evaluation of efficacy and complications between biportal endoscopic lumbar interbody fusion and minimally invasive transforaminal lumbar interbody fusion for lumbar degenerative diseases: a systematic review and meta-analysis. Journal of Pain Research, 2025: p. 2215-2231.
7. Enache, A.-V., et al., Surgical stabilization of the spine: a clinical review of spinal fractures, spondylolisthesis, and instrumentation methods. Journal of Clinical Medicine, 2025. 14(4): p. 1124.
8. Galieri, G., et al., Current trends and future directions in lumbar spine surgery: a review of emerging techniques and evolving management paradigms. Journal of Clinical Medicine, 2025. 14(10): p. 3390.

9. Pokorny, G., et al., Minimally invasive versus open surgery for degenerative lumbar pathologies: a systematic review and meta-analysis. European Spine Journal, 2022. 31(10): p. 2502-2526.
10. John, A., et al., A comparison of the safety and efficacy of minimally invasive surgery versus open surgery in treating cauda equina syndrome: A systematic review and meta-analysis. Journal of Clinical Neuroscience, 2023. 117: p. 98-103.
11. Ikwuegbuenyi, C.A., et al., Complications in Minimally Invasive Spine Surgery (2013-2024): Lumbar Spine-Tubular Minimally Invasive Techniques: A Proportional Meta-Analysis. Spine (Phila Pa 1976), 2026. 51(4): p. E78-e96.
12. Bielewicz, J., B. Daniluk, and P. Kamieniak, VAS and NRS, Same or Different? Are Visual Analog Scale Values and Numerical Rating Scale Equally Viable Tools for Assessing Patients after Microdiscectomy? Pain Res Manag, 2022. 2022: p. 5337483.
13. Young, I., et al., Clinimetric analysis of the numeric pain rating scale, Oswestry disability index, and the Roland-Morris disability questionnaire in patients with lumbar spinal stenosis treated with conservative interventions. J Clin Neurosci, 2026. 143: p. 111717.
14. Pokorny, G., et al., Minimally invasive versus open surgery for degenerative lumbar pathologies: a systematic review and meta-analysis. Eur Spine J, 2022. 31(10): p. 2502-2526.
15. Inzerillo, S., et al., Complications in Minimally Invasive Spine Surgery (2013-2024): A Proportional Meta-Analysis - Uniportal Endoscopic Spine Surgery (UESS). Spine (Phila Pa 1976), 2026. 51(5): p. E133-e142.
16. Chen, Z., et al., Complications of Unilateral Biportal Endoscopic Spinal Surgery for Lumbar Spinal Stenosis: A Meta-Analysis and Systematic Review. World Neurosurg, 2023. 170: p. e371-e379.
17. Park, D.Y., et al., Clinical outcomes and complications after biportal endoscopic spine surgery: a comprehensive systematic review and meta-analysis of 3673 cases. Eur Spine J, 2023. 32(8): p. 2637-2646.
18. John, A., et al., A comparison of the safety and efficacy of minimally invasive surgery versus open surgery in treating cauda equina syndrome: A systematic review and meta-analysis. J Clin Neurosci, 2023. 117: p. 98-103.
19. Zhang, Q.-Y., et al., Minimally invasive transforaminal lumbar interbody fusion versus oblique lateral interbody fusion for lumbar degenerative disease: a meta-analysis. BMC Musculoskeletal Disorders, 2021. 22(1): p. 802.
20. Haibier, A., et al., Comparison of clinical outcomes and complications between endoscopic and minimally invasive transforaminal lumbar interbody fusion for lumbar degenerative diseases: a systematic review and meta-analysis. J Orthop Surg Res, 2024. 19(1): p. 92.
21. Boadi, B.I., et al., Complications in Minimally Invasive Spine Surgery in the Last 10 Years: A Narrative Review. Neurospine, 2024. 21(3): p. 770-803.
22. Kumar, A., et al., The current status and surgical outcome of the minimally invasive techniques for lumbar interbody fusion in India: A systematic review and meta-analysis. J Craniovertebr Junction Spine, 2022. 13(3): p. 245-255.
23. Latka, K., et al., Full-endoscopic lumbar spine discectomy: are we finally there? A meta-analysis of its effectiveness against nonmicroscopic discectomy, microdiscectomy and tubular discectomy. Spine J, 2026. 26(3): p. 479-497.
24. Park, S.M., et al., Safety Profile of Biportal Endoscopic Spine Surgery Compared to Conventional Microscopic Approach: A Pooled Analysis of 2 Randomized Controlled Trials. Neurospine, 2024. 21(4): p. 1190-1198.

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