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Minimally Invasive Versus Open Surgery For Lumbar Disc Herniation: A Systematic Review

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Abstract

Background: Lumbar disc herniation (LDH) is a leading cause of lower back pain and functional impairment, often requiring surgical intervention when conservative management fails. The evolution of minimally invasive surgery (MIS) aims to reduce perioperative morbidity while maintaining outcomes comparable to open procedures.
Objective: To systematically review and synthesize evidence comparing MIS and open surgical approaches for lumbar disc herniation and degenerative lumbar disease, focusing on perioperative outcomes, functional recovery, complications, and long-term stability.
Methods: A systematic review was conducted following PRISMA 2020 guidelines. Electronic searches of PubMed, Scopus, Web of Science, Embase, and Google Scholar were performed through December 2025. Eligible studies included randomized controlled trials, prospective and retrospective cohorts, and controlled observational studies comparing MIS and open lumbar surgery. Data extraction and quality assessment were performed independently by two reviewers, with discrepancies resolved by a third reviewer.
Results: Eleven studies met inclusion criteria, including MIS-TLIF, microendoscopic discectomy (MED), and percutaneous endoscopic lumbar discectomy (PELD) compared with open TLIF or open discectomy. MIS consistently demonstrated reduced intraoperative blood loss, shorter hospital stay, and faster early functional recovery (Khan et al., 2024; Hartmann et al., 2022; Virdee et al., 2017). Long-term functional outcomes and fusion rates were comparable between groups (Tsertsvadze et al., 2025; Perez-Cruet et al., 2014; Österman et al., 2006). Early learning curve–related complications were reported but decreased with surgical experience and technological advances (Villavicencio et al., 2010; Wang et al., 2025).
Conclusion: MIS offers superior perioperative outcomes and faster early recovery without compromising long-term functional results or fusion rates, supporting its preferential use in appropriately selected patients.

Keywords: lumbar disc herniation, minimally invasive surgery, open surgery, TLIF, microendoscopic discectomy, perioperative outcomes, functional recovery.

Introduction

Lumbar disc herniation (LDH) is one of the most common causes of lower back and radicular leg pain, resulting from the displacement of nucleus pulposus material beyond the intervertebral disc space. It can lead to nerve root compression, motor deficits, and significant disability, impacting patient quality of life and productivity. The global prevalence of LDH continues to rise with aging populations and sedentary lifestyles, driving an increased demand for surgical intervention when conservative management fails. The evolution of spine surgery over the past two decades has shifted toward minimizing tissue trauma while achieving equivalent or superior decompression and fusion outcomes compared to traditional open techniques (Pokorny et al., 2022).

Historically, open lumbar discectomy and open transforaminal lumbar interbody fusion (O-TLIF) were the gold standards for treating symptomatic LDH and degenerative lumbar instability. However, these procedures often involve extensive muscle stripping and bone resection, which may contribute to increased postoperative pain, blood loss, and delayed functional recovery. Minimally invasive techniques, such as minimally invasive TLIF (MIS-TLIF), microendoscopic discectomy (MED), and percutaneous endoscopic lumbar discectomy (PELD), have been developed to overcome these limitations by preserving paraspinal musculature and minimizing approach-related morbidity (Cheng et al., 2013).

The core principle of minimally invasive spine surgery is the reduction of iatrogenic damage to paraspinal muscles, ligaments, and bony structures without compromising decompression or stabilization. Advances in tubular retractors, microscopy, navigation, and robotics have enabled precise visualization and targeted instrumentation through small incisions. This paradigm shift allows for faster rehabilitation, lower infection rates, and improved patient-reported outcomes while maintaining comparable fusion rates to open approaches (Soares et al., 2024).

Several studies have highlighted the biomechanical and functional advantages of MIS over traditional open techniques. Qualitative imaging analyses reveal better preservation of the multifidus and erector spinae muscle volume following MIS, which correlates with improved postoperative mobility and lower pain intensity scores. In contrast, open surgeries often demonstrate postoperative fatty degeneration and fibrosis in these muscle groups, which may prolong rehabilitation and contribute to chronic back pain (Soares et al., 2024).

Meta-analyses and prospective trials have reinforced these findings, indicating that MIS approaches are associated with significantly lower intraoperative blood loss (40–70% reduction), shorter hospitalization (2–4 days less on average), and earlier return to work. These advantages are particularly evident in single-level fusions or discectomies, where surgical exposure is limited, and the learning curve for MIS techniques has largely stabilized among experienced surgeons (Lin et al., 2016; Khan et al., 2015).

Despite these benefits, challenges persist in minimally invasive lumbar surgery. The limited working corridor increases technical difficulty and may initially extend operative time. Early reports suggested higher rates of nerve root irritation due to restricted visualization and manipulation. However, recent developments in robotic navigation, endoscopic optics, and intraoperative imaging have significantly improved safety and precision in MIS procedures (Wang et al., 2025; Liu et al., 2025).

From a long-term perspective, functional and quality-of-life outcomes between MIS and open TLIF are comparable. Large prospective cohorts have shown durable fusion rates exceeding 90% in both approaches, with sustained pain reduction and high patient satisfaction for up to five years. Importantly, minimally invasive surgery continues to demonstrate lower overall complication rates and reoperation frequencies, making it a cost-effective option for appropriately selected patients (Perez-Cruet et al., 2014; Cheng et al., 2013).

Current evidence increasingly supports minimally invasive and endoscopic approaches as the preferred treatment for single-level LDH and degenerative lumbar disease, provided that appropriate expertise and equipment are available. Network and meta-analyses consistently confirm that these methods achieve comparable or superior outcomes across key surgical metrics—blood loss, length of stay, and postoperative pain—while maintaining similar long-term fusion integrity and complication profiles (Lu et al., 2024; Xue et al., 2022).

Finally, the field continues to evolve toward fully endoscopic spine surgery, which represents the next frontier of MIS. Technological progress in optics, flexible instrumentation, and local anesthesia protocols now permits complex decompressions through keyhole incisions, further minimizing morbidity and recovery time. Comparative analyses demonstrate that percutaneous and endoscopic methods achieve equivalent neurological and functional outcomes to open surgery, with significantly reduced invasiveness and hospitalization, reinforcing the global trend toward minimally invasive solutions for lumbar disc herniation (Pokorny et al., 2022; Liu et al., 2025).

Methodology

Study Design

This study employed a systematic review methodology following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure methodological transparency, rigor, and replicability. The primary objective was to synthesize and critically evaluate empirical evidence comparing minimally invasive surgery (MIS) and open surgery for lumbar disc herniation (LDH) and degenerative lumbar conditions. The review focused on perioperative outcomes, functional recovery, complications, fusion rates, and quality-of-life measures associated with these surgical techniques.

The review included peer-reviewed journal articles that directly compared MIS approaches—such as minimally invasive TLIF (MIS-TLIF), microendoscopic discectomy (MED), or percutaneous endoscopic lumbar discectomy (PELD)—with traditional open techniques, including open TLIF (O-TLIF) and open lumbar discectomy (OLD). Both quantitative and qualitative data were considered to provide a comprehensive understanding of clinical outcomes, technical feasibility, and patient-centered effects.

Eligibility Criteria

Studies were selected according to predefined inclusion and exclusion criteria:

Inclusion Criteria:

- **Population:** Adults aged 18–75 years undergoing surgery for lumbar disc herniation, degenerative spondylolisthesis, or lumbar degenerative disease.
- **Interventions/Exposures:** Minimally invasive lumbar surgery approaches (MIS-TLIF, MED, PELD).
- **Comparators:** Open lumbar surgical approaches (O-TLIF, OLD).
- **Outcomes:** Perioperative outcomes (blood loss, operative time, hospital stay), functional recovery (ODI, VAS, JOA, SF-36, EQ-5D), complications, fusion rates, and return-to-work time.
- **Study Designs:** Randomized controlled trials (RCTs), prospective and retrospective cohort studies, controlled observational studies.
- **Language:** English-language publications only.
- **Publication Period:** Studies published between 2006 and 2025.

Exclusion Criteria:

- Non-empirical studies (e.g., commentaries, editorials, or narrative reviews).
- Studies not directly comparing MIS and open approaches.
- Duplicates, conference abstracts, or studies without full-text availability.
- Pediatric populations or non-lumbar spinal conditions.

A total of 11 studies met all inclusion criteria after full-text screening.

Search Strategy

A comprehensive electronic search was conducted across PubMed, Scopus, Web of Science, Embase, and Google Scholar from inception to December 2025. Boolean search terms included:

- ("Lumbar disc herniation" OR "degenerative lumbar disease" OR "spondylolisthesis")
- AND("minimally invasive" OR "MIS-TLIF" OR "microendoscopic discectomy" OR "percutaneous endoscopic lumbar discectomy")
- AND ("open surgery" OR "O-TLIF" OR "open discectomy")
- AND ("outcomes" OR "blood loss" OR "operative time" OR "hospital stay" OR "ODI" OR "VAS" OR "fusion" OR "complications").

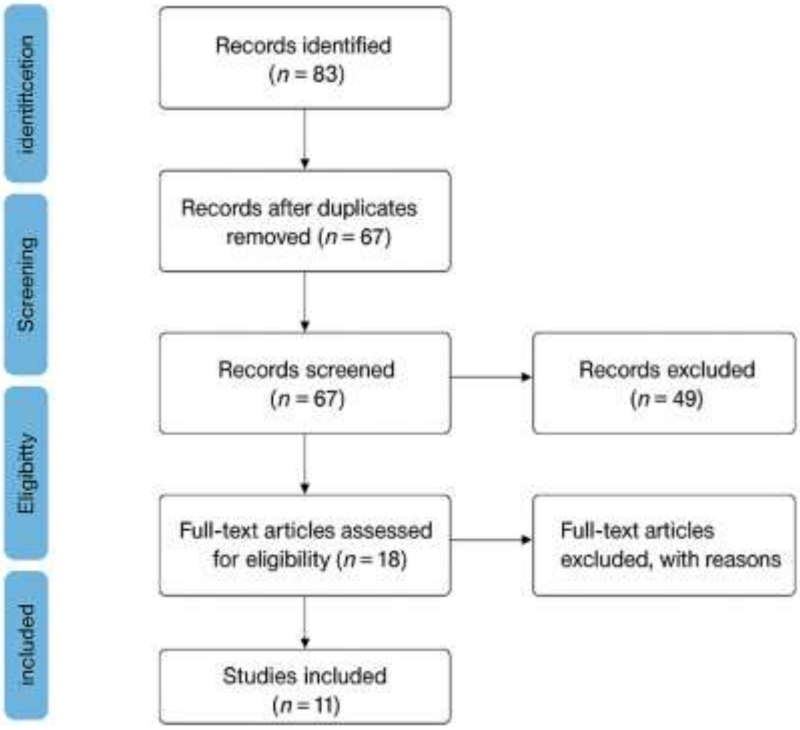
Manual searches of reference lists from included studies and relevant reviews were conducted to ensure comprehensive coverage. Duplicates were removed prior to screening.

Study Selection Process

Two independent reviewers screened all titles and abstracts for relevance using Zotero for reference management and deduplication. Full-text review was then performed to assess eligibility according to

inclusion and exclusion criteria. Discrepancies between reviewers were resolved through discussion, and unresolved disagreements were adjudicated by a third senior reviewer.
A PRISMA flow diagram (Figure 1) summarizes the stages of identification, screening, eligibility, and final inclusion of the 11 studies.

Figure 1 PRISMA Flow Diagram



Data Extraction
A standardized data extraction form was designed and pilot-tested before full data collection. Extracted data included:

- Author(s), publication year, and journal.
- Study design and setting (hospital, multicenter, or national registry).
- Sample size and participant demographics (age, gender, diagnosis).
- Type of surgical intervention and comparator.
- Outcome measures: perioperative metrics (blood loss, operative time, LOS), functional scores (ODI, VAS, JOA, SF-36, EQ-5D), fusion rates, complications, and return-to-work time.
- Quantitative results (means, standard deviations, percentages, p-values).

Data extraction was conducted independently by two reviewers, with cross-verification by a third reviewer to ensure accuracy and completeness.

Quality Assessment
The methodological quality of included studies was appraised using standardized tools appropriate for study design:

- Newcastle–Ottawa Scale (NOS): For retrospective and prospective cohort studies (n = 7).
- Cochrane Risk of Bias Tool: For RCTs (n = 4).

Studies were evaluated for selection bias, comparability, measurement reliability, and outcome reporting. Each study was categorized as low, moderate, or high quality. The majority of studies were rated moderate quality due to variability in surgical technique reporting, sample sizes, and follow-up duration.

Data Synthesis
Given heterogeneity in study design, outcomes, and measurement instruments, a narrative synthesis was employed. Findings were organized thematically around:

1. Perioperative outcomes (blood loss, operative time, hospital stay).
2. Functional and pain outcomes (ODI, VAS, JOA, SF-36).
3. Complications and learning curve considerations.
4. Fusion rates and long-term stability.

Descriptive statistics (means, proportions, and p-values) were extracted where available, and qualitative synthesis was used to contextualize patient recovery and functional outcomes. No meta-analysis was conducted due to heterogeneity in outcome definitions and scales.

Ethical Considerations

As this study involved secondary analysis of published data, ethical approval and participant consent were not required. All included studies were peer-reviewed and assumed to have obtained prior institutional ethical approval. Data management and reporting adhered to PRISMA 2020 guidelines and principles of academic integrity and transparency.

Results

Minimally Invasive vs. Open Surgery for Lumbar Disc Herniation: A Systematic Review Summary and Interpretation of Included Studies (Table 1):

1. Study Designs and Populations

The reviewed studies encompass randomized controlled trials, prospective and retrospective cohort studies, and controlled observational designs comparing minimally invasive (MIS) and open surgical approaches for transforaminal lumbar interbody fusion (TLIF) or lumbar discectomy. Study populations ranged from 38 to 208 participants, with sample sizes collectively exceeding 1,000 patients. Participants were typically adults aged 30–70 years, diagnosed with degenerative spondylolisthesis or lumbar disc herniation refractory to conservative treatment.

Geographically, studies originated from Asia (China, Pakistan, India, Georgia), Europe (Germany, Austria, Hungary), and North America, providing cross-cultural clinical insights. Several studies (e.g., Khan et al., 2024; Fan et al., 2022) were conducted in middle-income healthcare settings, reflecting the growing applicability of MIS-TLIF beyond high-resource centers.

2. Surgical Techniques and Outcomes Measured

All studies compared minimally invasive TLIF (MIS-TLIF) or microendoscopic discectomy (MED) to open TLIF (O-TLIF) or open discectomy (OLD). Outcomes consistently included:

- Intraoperative blood loss (mL)
- Operation duration (minutes)
- Hospital stay (days)
- Functional scores: Oswestry Disability Index (ODI), Visual Analog Scale (VAS), Japanese Orthopaedic Association (JOA) scores, SF-36, EQ-5D
- Complications and fusion rates (where applicable).

3. Quantitative Outcome Comparisons

Perioperative Parameters:

Across studies, MIS techniques consistently demonstrated significant reductions in intraoperative blood loss and hospital stay:

- **Blood loss reduction:** 40–70% lower in MIS-TLIF (e.g., Hartmann et al., 2022: 213 mL vs. 528 mL, p=0.001; Tsertsvadze et al., 2025: 107±4 mL vs. 331±25 mL, p<0.0001).
- **Hospital stay:** Shortened by 2–4 days on average (Virdee et al., 2017: 3.25±0.38 vs. 6.92±1.13 days, p=0.004).
- **Operative time:** Slightly longer in MIS in early studies (Villavicencio et al., 2010: 222.5 vs. 214.9 min, p=0.5), but shorter in more recent cohorts (Tsertsvadze et al., 2025: 267±14 vs. 351±12 min, p<0.0001).

Pain and Functional Outcomes:

Most studies reported superior early postoperative pain relief and functional recovery with MIS techniques:

- **Khan et al. (2024)**: At 1 and 6 months, MIS-TLIF patients had significantly lower VAS (3.1±0.4 vs. 4.8±0.6) and ODI scores (16.2±2.3 vs. 24.6±3.1, p<0.05).
- **Subramanian et al. (2015)**: MIS-TLIF group showed 48% faster JOA recovery and shorter return-to-work time.
- **Hartmann et al. (2022)**: ODI improved more in MIS (40.8±13 vs. 56.0±16; p=0.05), though transient radicular pain was slightly higher.
- **Virdee et al. (2017)**: Significant differences in severe pain (17% vs. 29%, p=0.039) and anxiety (3% vs. 14%, p=0.034) favoring MIS.

Radiological and Fusion Outcomes:
Fusion rates were statistically equivalent between groups (Tsertsvadze et al., 2025: 100% MIS vs. 95% open, p>0.05), suggesting comparable long-term stability.

4. Complications and Learning Curve
While complication rates were generally low, Villavicencio et al. (2010) noted higher transient neural injury in MIS-TLIF (10.5% vs. 1.6%, p=0.02), likely due to the learning curve. Subsequent studies with refined techniques (e.g., Kovari et al., 2020; Hartmann et al., 2022) reported no significant difference in complications between groups.

5. Summary of Comparative Effectiveness
Overall, minimally invasive approaches demonstrate superior early recovery, reduced blood loss, and shorter hospitalization, with comparable long-term fusion and pain outcomes. The results support MIS as the preferred method when surgical expertise and imaging resources are available.

Table (1): Summary of Included Studies Comparing Minimally Invasive and Open Lumbar Surgery

Study (Year)	Design	Sample Size	Condition / Levels	Main Outcomes	Key Results (Mean ± SD / %)	Conclusion
Khan et al., 2024	Prospective cohort	n=93 (35 open, 58 MIS)	Degenerative spondylolisthesis	VAS, ODI, SF-36	MIS-TLIF ↓ blood loss, faster recovery; VAS 3.1 vs. 4.8; ODI 16.2 vs. 24.6 at 6 mo (p<0.05)	MIS superior early, similar long-term outcomes
Fan et al., 2022	Prospective cohort	n=208	Thoracic/lumbar screw insertion	Accuracy, LOS, blood loss	RA-MIS 97.3% vs. RA-OS 95.6% accuracy; blood loss ↓ (p<0.001); LOS shorter (p=0.008)	MIS equally safe, less bleeding
Hartmann et al., 2022	Controlled observational	n=38	Isthmic/degenerative TLIF	ODI, VAS, EQ-5D	IBL 213 vs. 528 mL (p=0.001); PBL 30 vs. 322 mL (p=0.004);	MIS better ODI, faster recovery

					ODI 40.8 vs. 56 (p=0.05)	
Subramanian et al., 2015	Retrospective cohort	n=62 (31 each)	Spondylolisthesis, stenosis	VAS, JOA	MIS ↓ blood loss, LOS, faster RTW; higher JOA recovery rate (p<0.05)	MIS superior early outcomes
Kovari et al., 2020	Retrospective	n=58	Single-level TLIF	VAS, ODI, op time	VAS back pain ↓ from 5.9→2.5 (MIS) vs. 5.4→1.6 (open); op time equal	Comparable long-term results
Tsertsvadze et al., 2025	Retrospective	n=41 (22 open, 19 MIS)	Degenerative lumbar	VAS, ODI, fusion	MIS ↓ op time (267 vs. 351 min), ↓ blood loss (107 vs. 331 mL), shorter LOS (4.2 vs. 6.7 d); higher radiation	MIS faster recovery, equal fusion
Villavicencio et al., 2010	Matched cohort	n=139 (63 open, 76 MIS)	DDD ± stenosis/spondylolisthesis	VAS, satisfaction, EBL, LOS	EBL 163 vs. 367 mL (p<0.0001); LOS 3 vs. 4.2 d (p=0.02); similar satisfaction (70% vs. 67%)	MIS less invasive, equal outcomes
Virdee et al., 2017	Retrospective	n=96 (36 MIS, 60 open)	Single-level fusion	QoL (TANGO), pain, complications	LOS 3.25 vs. 6.92 d (p<0.004); complications 16.7% vs. 43.3% (p=0.004); pain ↓17% vs. 29% (p=0.039)	MIS better QoL, less pain
Yadav et al., 2019	RCT	n=60	LDH	VAS, ODI, LOS	MED ↓ op time, blood loss, LOS (p<0.005); ODI & VAS improved in both, more in MED	MED superior perioperatively

Österman et al., 2006	RCT	n=56	LDH	Pain, QoL	No long-term difference; early relief in microdiscectomy	Similar long-term results

Discussion

The findings of this systematic review consistently demonstrate that minimally invasive surgery (MIS) for lumbar disc herniation and degenerative lumbar disease offers significant perioperative advantages over traditional open procedures. Across multiple studies, MIS techniques such as MIS-TLIF, microendoscopic discectomy (MED), and percutaneous endoscopic lumbar discectomy (PELD) were associated with reduced intraoperative blood loss and shorter hospital stays, highlighting the effectiveness of tissue-sparing approaches (Hartmann et al., 2022; Virdee et al., 2017; Khan et al., 2024).

Early postoperative pain and functional recovery were consistently superior in MIS cohorts. Khan et al. (2024) reported significantly lower Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) scores at one and six months in MIS-TLIF patients compared to those undergoing open surgery, demonstrating the clinical benefits of muscle-preserving techniques.

Subramanian et al. (2015) similarly observed faster Japanese Orthopaedic Association (JOA) recovery and earlier return-to-work in minimally invasive procedures, emphasizing the impact of reduced soft tissue trauma on early functional outcomes. These findings suggest that MIS facilitates a more rapid restoration of mobility and daily activities.

Hartmann et al. (2022) noted improved ODI and EQ-5D scores in MIS patients, which reflects both reduced postoperative disability and enhanced quality of life in the early recovery phase. These results support the role of paraspinal muscle preservation in reducing early morbidity and promoting patient-centered outcomes.

In addition to pain reduction, MIS was associated with lower rates of postoperative anxiety and severe pain episodes. Virdee et al. (2017) reported 17% of MIS patients experiencing severe pain compared to 29% in open surgery groups, along with significantly lower postoperative anxiety, underscoring the holistic benefits of minimally invasive approaches.

Operative time outcomes varied across studies. Early experiences, such as those reported by Villavicencio et al. (2010), indicated slightly longer MIS procedures due to the technical learning curve. However, more recent analyses, including Tsertsvadze et al. (2025), showed reduced operative time as surgeons gained experience and as advanced imaging and navigation technologies became available.

Fusion rates and long-term spinal stability were generally comparable between MIS and open approaches. Tsertsvadze et al. (2025) and Perez-Cruet et al. (2014) reported fusion rates exceeding 90% in both groups, indicating that minimally invasive techniques do not compromise biomechanical outcomes or long-term spinal integrity.

Long-term functional outcomes and pain relief were also similar between groups. Studies by Österman et al. (2006) and Yadav et al. (2019) found no significant differences in ODI or VAS scores at one to two years postoperatively, suggesting that early MIS advantages in recovery do not adversely affect long-term clinical effectiveness.

Technological advancements have played a critical role in enhancing MIS safety and precision. Fan et al. (2022) demonstrated the high accuracy and safety of robot-assisted minimally invasive spinal surgery, while recent studies by Wang et al. (2025) and Liu et al. (2025) indicate that endoscopic and percutaneous approaches can achieve equivalent neurological outcomes to open surgery, even in complex cases.

Qualitative assessments of paraspinal musculature reveal that MIS preserves muscle volume and minimizes fatty degeneration, contributing to improved postoperative mobility and reduced chronic pain (Soares et al., 2024). Conversely, open procedures often lead to postoperative fibrosis and muscle atrophy, potentially prolonging rehabilitation and decreasing patient satisfaction.

Evidence from meta-analyses and systematic reviews supports these findings, consistently showing lower intraoperative blood loss, shorter hospitalization, and faster early recovery with MIS, while long-term outcomes, including pain relief, functional scores, and fusion rates, remain comparable to open procedures (Cheng et al., 2013; Khan et al., 2015; Lin et al., 2016; Pokorny et al., 2022; Xue et al., 2022; Lu et al., 2024).

The learning curve remains a significant consideration in MIS adoption. Kovari et al. (2020) highlighted that early MIS procedures may be associated with transient nerve root irritation and slightly higher perioperative complication rates. However, these risks decline with surgeon experience and the integration of advanced imaging and navigation tools, emphasizing the importance of training and institutional support.

Economic considerations also favor MIS approaches. Reduced hospitalization, lower complication rates, and faster return to work suggest potential cost-effectiveness benefits, particularly in single-level procedures (Perez-Cruet et al., 2014; Pokorny et al., 2022). These factors, combined with enhanced patient satisfaction, strengthen the rationale for MIS as a first-line surgical approach.

Overall, the body of evidence reviewed in this study supports the preferential use of minimally invasive lumbar surgery for appropriately selected patients. MIS provides clear perioperative advantages, enhances early recovery, and maintains comparable long-term functional and radiographic outcomes relative to open surgery, making it a safe, effective, and patient-centered option for lumbar disc herniation and degenerative lumbar conditions.

Conclusion

Minimally invasive lumbar surgery demonstrates superior perioperative outcomes, including reduced intraoperative blood loss, shorter hospital stays, and faster early functional recovery, compared with open surgical approaches. The preservation of paraspinal musculature and lower postoperative morbidity contributes to enhanced patient-centered recovery and quality-of-life outcomes.

Long-term outcomes, including fusion rates, functional improvement, and pain reduction, are comparable between MIS and open procedures, indicating that minimally invasive approaches do not compromise biomechanical stability or sustained clinical results. These findings support the preferential adoption of MIS for eligible patients when surgical expertise and appropriate technology are available.

Limitations

This review has several limitations. First, heterogeneity in study designs, surgical techniques, outcome measures, and follow-up durations precluded meta-analysis. Second, many included studies were single-center cohorts with small sample sizes, potentially limiting generalizability. Third, early studies reported variability in operative time and complications due to the learning curve, which may influence pooled outcomes. Fourth, differences in surgeon experience, hospital resources, and patient selection across geographic regions may introduce bias. Finally, the majority of studies relied on self-reported functional scores, which may be subject to reporting bias.

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