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Review Article

Minimally Invasive Transforaminal Lumbar Interbody Fusion for Degenerative Spondylolisthesis

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Abstract

Background: Degenerative spondylolisthesis with symptomatic stenosis is a common indication for lumbar fusion, and minimally invasive (MIS) transforaminal lumbar interbody fusion (TLIF) has become a widely used alternative to open surgery.

Objective: To synthesise published evidence comparing MIS-TLIF with open TLIF for degenerative spondylolisthesis.

Methods: Narrative review of indication studies, technique descriptions, comparative cohorts, randomized and registry data, and meta-analyses.

Findings: MIS-TLIF reduces blood loss and length of stay relative to open TLIF, with comparable fusion rates (90-95%) and similar long-term pain-score improvement in five-year registry data. Complication and reoperation rates are broadly similar between techniques, though MIS-TLIF carries a front-loaded learning curve and greater fluoroscopic exposure.

Conclusions: MIS-TLIF offers meaningful perioperative advantages over open TLIF for degenerative spondylolisthesis without compromising fusion or long-term function, supporting its selective use in appropriately chosen patients by adequately trained surgeons.

Keywords: Minimally invasive surgery; Transforaminal lumbar interbody fusion; Degenerative spondylolisthesis; Spinal fusion; Patient-reported outcomes

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Keywords: minimally invasive surgery; transforaminal lumbar interbody fusion; degenerative spondylolisthesis; spinal fusion; patient-reported outcomes

Introduction

Degenerative spondylolisthesis is an acquired anterior slip of one vertebral body on another in the setting of facet and disc degeneration, most often at L4-L5, and is a leading cause of surgically treated lumbar stenosis in older adults. Herkowitz and Kurz's prospective comparison established that decompression combined with arthrodesis produced superior outcomes to decompression alone in single-level disease, cementing fusion as a standard adjunct to decompression [1]. Transforaminal lumbar interbody fusion, first described by Harms and Rolinger as a unilateral posterolateral corridor for circumferential fusion, avoids the bilateral thecal sac retraction of posterior lumbar interbody fusion while restoring anterior column support [2]. Building on early minimally invasive lumbar fusion concepts [3] and initial technical-feasibility reports [4], Holly and colleagues formalised minimally invasive TLIF (MIS-TLIF) using tubular retractors and percutaneous instrumentation to reduce approach-related morbidity while preserving the biomechanical goals of open TLIF [5]. Use of fusion, including MIS techniques, for degenerative spondylolisthesis has risen substantially over the past two decades [6]. Proponents argue that the smaller surgical corridor reduces approach-related muscle injury, blood loss and postoperative pain without sacrificing the biomechanical rationale of interbody fusion, while critics point to a steep learning curve, increased radiation exposure, and a comparatively immature long-term evidence base relative to open TLIF, which has decades of follow-up data. This narrative review synthesises the published evidence on MIS-TLIF for degenerative spondylolisthesis, focusing on indications, surgical technique, perioperative and long-term outcomes relative to open TLIF, and complications, to help clarify where the current evidence stands.

Degenerative Spondylolisthesis and Surgical Indications

The natural history of degenerative spondylolisthesis is generally favourable: in a cohort of 145 non-surgically managed patients followed a minimum of ten years, radiographic slip progressed in 34%, but progression did not correlate with worsening clinical symptoms [7]. Nonetheless, patients with persistent neurogenic claudication or radicular pain refractory to conservative care are candidates for surgery. The Spine Patient Outcomes Research Trial (SPORT) randomised and observational cohorts demonstrated that surgical treatment produced significantly greater improvement in

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pain, function and disability than non-operative care through four years, providing level-1 support for operative management in appropriately selected patients [8]. Administrative data confirm that fusion, rather than decompression alone, has become the dominant surgical strategy for degenerative spondylolisthesis nationally, with growing adoption of minimally invasive approaches [6]. Low-grade (Meyerding I-II) single-level disease with mechanical back pain and radicular symptoms is the most consistent indication for TLIF, whether open or minimally invasive [9]. Because SPORT and most subsequent comparative literature enrolled patients with confirmed radiographic instability and stenosis rather than incidental slips, the indications discussed throughout this review pertain specifically to symptomatic, imaging-confirmed degenerative spondylolisthesis rather than asymptomatic radiographic findings.

MIS-TLIF Technique

MIS-TLIF accesses the disc space through Kambin's triangle via a unilateral, muscle-splitting corridor established with serial tubular dilators, avoiding the extensive subperiosteal paraspinal muscle stripping of open TLIF [5]. After partial or complete unilateral facetectomy and neural decompression, discectomy and endplate preparation are performed through the tube, an interbody cage is placed, and percutaneous pedicle screws are typically inserted bilaterally under fluoroscopic or navigated guidance [9,4]. A specific technical refinement allows percutaneous reduction of the slipped segment through the same tubular corridor, with one series of 40 consecutive patients achieving a mean 76% reduction in forward translation [10]. The evolution from Foley and colleagues' early minimally invasive lumbar fusion platform [3] through technical-feasibility studies [4] to contemporary tubular and expandable-retractor systems reflects an iterative refinement aimed at preserving the circumferential fusion achieved by open TLIF while minimising collateral soft-tissue injury [9]. Intraoperative fluoroscopy or, increasingly, image-guided navigation is used to confirm trajectory during percutaneous screw placement, a step that accounts for much of the increased radiation exposure documented in comparative series relative to open, freehand instrumentation [11].

Perioperative Outcomes versus Open TLIF

Comparative literature is consistent in showing perioperative advantages for MIS-TLIF. A meta-analysis by Hammad and colleagues found significantly reduced intraoperative blood loss with MIS-TLIF and a lower pooled complication rate (11.3% versus higher in open TLIF) [12]. Phan and colleagues' systematic review and meta-analysis similarly reported reduced blood loss and shorter hospital stay favouring MIS-TLIF across degenerative lumbar disease indications [13], and an updated meta-analysis by Khan and colleagues confirmed reduced blood loss, shorter length of stay and fewer complications with MIS-TLIF, at the cost of increased intraoperative radiation exposure [11]. Restricting analysis to randomized controlled trials, Miller and colleagues quantified an approximately 200 mL reduction in blood loss with MIS-TLIF for single-level degenerative disease [14], and a synthesis by Kim and colleagues likewise found MIS-TLIF associated with less blood loss, shorter hospitalisation and, in some series, lower postoperative back pain, at the expense of longer fluoroscopy time [15]. These perioperative benefits extend to higher-risk subgroups: a systematic review and meta-analysis restricted to obese patients found MIS-TLIF retained its blood-loss and complication advantages without compromising functional improvement [16]. Cost-utility analyses specific to degenerative spondylolisthesis have found MIS-TLIF more cost-effective than open TLIF over a two-year horizon, driven by shorter hospital stay and faster return to work [17,18]. Operative time findings are less uniform: while several series show similar or shorter

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operative times with MIS-TLIF once the learning curve is passed, the five-year QOD registry data found MIS-TLIF associated with longer, not shorter, mean operative time despite its blood-loss advantage, illustrating that perioperative benefits do not accrue uniformly across every metric [19].

Table 1: Comparative perioperative outcomes of MIS-TLIF versus open TLIF reported in major systematic reviews and meta-analyses [12,13,11,14,15].

Study	Design	Blood loss	Length of stay	Complication rate	Radiation exposure
Hammad 2019	Meta-analysis	Significantly less with MIS (P<0.001)	Shorter with MIS	11.3% MIS vs higher open	Not pooled
Phan 2015	Systematic review/ meta-analysis	Reduced with MIS	Shorter with MIS	Comparable	Not pooled
Khan 2015	Updated meta-analysis	Reduced with MIS	Shorter with MIS	Fewer with MIS	Increased with MIS
Miller 2020	Meta-analysis, RCTs only	~200 mL less with MIS	Shorter with MIS	Not primary endpoint	Not pooled
Kim 2020	Narrative review	Less with MIS	Shorter with MIS	Comparable	Higher with MIS

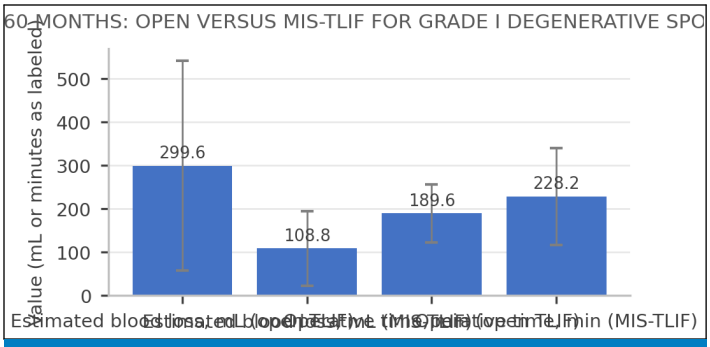

Figure 1: Perioperative blood loss and operative time, open versus MIS-TLIF, from the 5-year Quality Outcomes Database registry comparison for grade I degenerative lumbar spondylolisthesis (n=297): MIS-TLIF had less blood loss (108.8 ± 85.6 vs 299.6 ± 242.2 mL, P<0.001) but longer operative time (228.2 ± 111.5 vs 189.6 ± 66.5 minutes) [19].

Fusion Rates and Long-Term Functional Outcomes

Despite its narrower surgical corridor, MIS-TLIF achieves fusion rates comparable to open TLIF, generally in the 90-95% range in comparative series [20,9]. A prospective randomized study found near-identical solid fusion rates (90% in both arms at one year) and statistically indistinguishable Oswestry Disability Index (ODI) improvement between standard and MIS-TLIF [20]. Long-term comparative data corroborate this equivalence: a matched-pair analysis with five-year follow-up found comparable clinical outcomes and adjacent-segment disease rates (approximately 10% in each group) between MIS and open TLIF [21], and a meta-analysis restricted to studies with a minimum two-year follow-up found MIS-TLIF and open TLIF produced comparable long-term improvement in patient-reported outcome measures, with no clear superiority of either technique in the durable term [22]. The largest prospective comparative dataset, the multicentre Quality Outcomes Database (QOD) registry, has tracked grade I degenerative spondylolisthesis patients from one to five years: early QOD analyses found both open and MIS fusion produced significant, similar functional improvement [23], a subsequent two-year analysis of 265 patients found MIS-TLIF associated with less disability, higher quality of life and higher satisfaction [24], and the five-year, 297-patient follow-up found no significant differences between MIS and open TLIF in ODI, back and leg pain, EQ-5D, or NASS satisfaction, with similar cumulative reoperation rates, despite MIS-TLIF retaining a blood-loss advantage at long-term follow-up [19]. Elderly-specific data extend this durability: a five-year follow-up study in patients over 65 found MIS-TLIF produced sustained improvement in pain, disability and quality of life, with 93% of elderly patients satisfied with treatment at five years, comparable to younger controls and to previously published shorter-term satisfaction rates [25]. Taken together, this body of registry, matched-cohort and meta-analytic evidence indicates that the durability of fusion and functional gain achieved with MIS-TLIF is not materially

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different from that of open TLIF once patients are followed beyond the immediate perioperative window.

Table 2: Long-term comparative studies of MIS-TLIF versus open TLIF for degenerative lumbar disease/spondylolisthesis [21,22,23,24,19,25].

Study	Follow-up	Sample	Key long-term finding
Seng 2013	5 years	Matched-pair cohort	Comparable outcomes; ~10% ASD in both groups
Heemskerk 2021	≥2 years (meta-analysis)	Multiple pooled cohorts	Comparable long-term PROMs
Mummaneni 2017	1 year (QOD)	Registry cohort	Significant improvement, both techniques similar
Chan 2020	2 years (QOD)	265 patients	MIS: less disability, higher QOL/satisfaction
Chan 2023	5 years (QOD)	297 patients (72 MIS, 225 open)	No significant PRO differences; similar reoperation
Goh 2025	5 years	Elderly (>65y) cohort	Sustained improvement; 93% satisfaction at 5 years

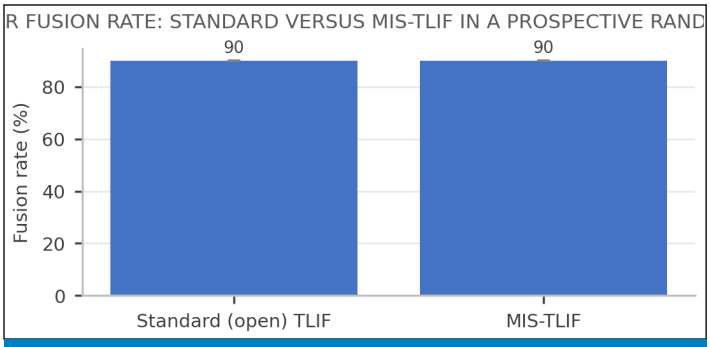

Figure 2: Solid fusion rate at one year in a prospective randomized study comparing standard (open) and minimally invasive TLIF: 90% in both arms [20].

Complications and Reoperation

Aggregate complication rates for MIS-TLIF and open TLIF are broadly similar across meta-analyses, though the distribution of complications differs by technique [12,11]. A systematic review of complications specific to the initial learning curve of minimally invasive spine surgery found an overall postoperative complication rate of 11% across fusion and non-fusion MIS procedures, with implant malposition, neural injury and nonunion the most common events for fusion specifically, alongside a 3% reoperation rate [26]. A single-surgeon MIS-TLIF learning-curve series reported an overall complication rate of 12.67%, with dural tear the most frequent single complication at 5.32% [27]. These findings underscore that MIS-TLIF, more than open TLIF, is sensitive to case volume and surgeon experience, with complication rates falling substantially after the initial 20-50 cases as familiarity with tubular retraction, fluoroscopic anatomy and percutaneous instrumentation increases [26,27]. This learning-curve effect has practical implications for training and credentialing, since early-career complication rates reported in the literature may not generalise to surgeons who have completed a structured MIS fellowship or mentored case series. Reassuringly, long-term registry and matched-cohort data do not show excess reoperation with MIS-TLIF: cumulative five-year reoperation rates in the QOD cohort were statistically similar between MIS and open groups [19], and adjacent-segment disease rates were comparable at five years in a matched-pair series [21].

Patient Selection Considerations

Appropriate patient selection remains central to realising the benefits of MIS-TLIF. Low-grade, single-level degenerative spondylolisthesis with predominant radicular symptoms is the most favourable indication, whereas multilevel disease, high-grade slips, and markedly distorted anatomy are more often better suited to an open approach or reserved for surgeons with greater MIS experience [9]. Obesity, once considered a relative contraindication to open spine surgery because of wound-related morbidity, appears particularly well suited to the MIS approach given its retained blood-loss and complication advantages in this subgroup [16]. Comparative QOD analyses of decompression alone

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versus MIS-TLIF suggest that a meaningful subset of degenerative spondylolisthesis patients, particularly those with less segmental instability, may achieve comparable outcomes without an interbody fusion, highlighting that the fusion-versus-decompression decision remains as important as the open-versus-MIS decision [28]. Cost-utility analyses further support MIS-TLIF as the more resource-efficient strategy for degenerative spondylolisthesis when surgeon expertise permits [17,18].

Conclusion

The published literature on MIS-TLIF for degenerative spondylolisthesis, spanning foundational indication studies, technique descriptions, randomized comparisons, large multicentre registries and multiple meta-analyses, converges on a consistent picture: MIS-TLIF reduces blood loss, hospital stay and, in several analyses, complication rates relative to open TLIF, while achieving equivalent fusion rates and long-term patient-reported outcomes out to five years. Reoperation and adjacent-segment disease rates are comparable between techniques. The principal trade-offs are a demonstrable, front-loaded learning curve and greater intraoperative radiation exposure. For appropriately selected patients with low-grade, single- or two-level degenerative spondylolisthesis, MIS-TLIF represents a well-supported, and in several cost-utility analyses more efficient, alternative to open TLIF, provided it is performed by surgeons who have progressed beyond the early learning curve.

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