Minimally invasive techniques for lumbar decompressions and fusions

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Abstract

Purpose of review The purpose of this study is to summarize the recent literature investigating the use of minimally invasive (MIS) techniques in the treatment of lumbar degenerative stenosis, spondylolisthesis, and scoliosis.

Recent findings MIS lumbar decompression and fusion techniques for degenerative pathology are associated with reduced operative morbidity, shortened length of hospital stay, and reduced postoperative pain and narcotics utilization. Recent studies with long-term clinical follow-up have demonstrated equivalence in clinical outcomes between open and MIS surgical procedures. Radiographically, MIS procedures provide adequate postoperative correction of coronal alignment. Correction of sagittal alignment, however, is more variable based on current reports.

Summary MIS techniques are both safe and effective in the treatment of lumbar degenerative pathologies. While some studies have reported on long-term outcomes and costs associated with MIS procedures, more investigation into these topics is still necessary. Additionally, further work is required to analyze the training requirements and learning curves of MIS procedures to better promote adoption amongst surgeons.

Keywords Minimally invasive surgery · Lumbar stenosis · Degenerative spondylolisthesis · Degenerative scoliosis · TLIF · LLIF

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Introduction

The incidence of low-back pathology is high, with estimates that approximately 80 and 2–3% of the population will experience low-back pain and lower extremity radiculopathy in their lifetime, respectively [1]. The most common etiology of low-back pain is degenerative lumbar disease including spinal stenosis, degenerative spondylolisthesis, and degenerative scoliosis [2]. Lumbar degenerative conditions are a leading cause of disability with adverse effects related to both patient quality-of-life and work performance [3]. Additionally, low-back pain from degenerative lumbar disease is associated with a significant cost burden to the healthcare system [4].

Therapeutic options for lumbar degenerative disease include both operative and non-operative modalities. Non-operative management consists of a combination of patient education and counseling, physical therapy, non-steroidal anti-inflammatory medications, and possible oral steroids [1, 5, 6]. Patients with instability, neurologic deficits, or refractory symptomatology are suitable candidates for operative therapy, which typically involves open decompression or fusion procedures. A number of studies, many of them derived from the Spine Patient Outcomes Research Trial (SPORT), have demonstrated greater clinical improvement and reduced costs in patients who receive operative treatment compared to non-operative therapy [7–9]. However, operative therapy utilizing traditional open techniques can be associated with significant perioperative morbidity and prolonged rehabilitation requirements.

Minimally invasive spine (MIS) surgical techniques were developed with the intention of reducing the perioperative morbidity associated with traditional spinal procedures. The smaller incisions and muscle-sparing approaches utilized in MIS techniques have proposed benefits of reduced

intraoperative blood loss, reduced postoperative pain, and shorter duration of postoperative inpatient stay [10•, 11•]. MIS techniques include approaches for posterior spinal decompression, posterior fusion, and lateral fusion with anterior reconstruction. The purpose of this review is to summarize and analyze the literature regarding the utilization of MIS approaches in the treatment of degenerative lumbar spinal stenosis, spondylolisthesis, and scoliosis.

Degenerative spinal stenosis: MIS lumbar decompression

Degenerative spinal stenosis refers to the narrowing of the spinal canal, lateral recess, or neuroforamen [1]. The development of degenerative stenosis is primarily caused by a cascade of events associated with intervertebral disc degeneration [12]. Specifically, loss of disc height leads to increased facet joint stress and cartilaginous degradation. Subsequently, osteophyte formation and ligamentum flavum hypertrophy develop, leading to spinal canal narrowing and neural compression [12]. Depending on the location of stenosis, the clinical presentation often includes back and lower extremity pain, radiculopathy, and bilateral neurogenic claudication [1].

The initial management of lumbar spinal stenosis is typically conservative. Non-operative management includes administration of non-steroidal anti-inflammatory medications (NSAIDs), lumbosacral bracing, physical therapy, and the possibility of epidural/foraminal steroid injections [1]. However, not all patients are suitable candidates for or will be responsive to conservative management. In these cases, lumbar decompression (LD) is oftentimes utilized. Primary indications for surgical treatment include progressive motor weakness and limb pain refractory to a trial of non-operative management [13, 14]. Traditionally, a wide laminectomy via an open approach has been the most utilized operation for LD [13]. This procedure, however, involves extensive muscular disruption and damage to posterior spinal structures [11•, 15]. As a result, spinal instability with development of spondylolisthesis and refractory back pain is significant postoperative concerns [16, 17]. Minimally invasive approaches to lumbar decompression were developed with the goal of preventing postoperative instability by preserving spinal musculature and requiring minimal posterior element disruption [13]. To achieve this, tubular-access approaches have been developed that allow for unilateral or bilateral lumbar decompression via a combination of laminectomy, facetectomy, and foraminotomy.

The literature comparing open and MIS LD procedures has focused on determining potential differences in clinical outcomes, complication rates, and costs between the two techniques. In regards to operative characteristics and other factors in the immediate postoperative period, the literature is

supportive of distinct advantages for the MIS approach [11•, 18]. Mobbs et al. performed a randomized controlled trial of 54 patients with lumbar stenosis undergoing either minimally-invasive or open laminectomy [11•]. Patients undergoing MIS procedures had decreased intraoperative blood loss, shorter time to mobilization, and reduced postoperative length of stay compared to open patients. Furthermore, MIS patients also consumed less narcotics postoperatively and had a higher percentage of patients who did not require any postoperative analgesia. Similar findings were also demonstrated by Nerland et al. in a large multicenter study of 885 patients with central stenosis [18]. However, the authors also demonstrated that single-level MIS decompression procedures were associated with longer operative times than single-level open procedures. However, this result was not significant when cohorts were propensity matched for a number of demographic and comorbidity characteristics.

The efficacy of MIS LD has also been demonstrated in regards to long-term clinical outcomes and costs. Multiple investigations have been performed describing the equivalence or superiority of MIS LD compared to open laminectomy [11•, 18–23]. Ang et al., in a study of 113 patients undergoing single-level lumbar decompression, found statistically equivalent improvements in Oswestry Disability Index (ODI) and Short-Form 36 (SF-36) quality-of-life scores between MIS and open cohorts at 2 years postoperatively [22]. Additionally, in a meta-analysis of 12 clinical studies, Phan et al. determined that MIS cohorts had higher patient satisfaction rates than open cohorts (84.0 vs. 75.4%) [19]. Furthermore, VAS pain scores were significantly lower in MIS cohorts at final follow-up. From a cost perspective, Parker et al. determined that functional gain and costs were equivalent between open and MIS approaches for multilevel hemilaminectomy [20]. Quality-adjusted life years (QALYs) gained was 0.72 for both approaches, while the 2-year total cost was similar for both open (\$25,420) and MIS cohorts (\$23,109). It was also demonstrated that both approaches had equivalent utilization of healthcare resources in terms of care visits, physical therapy, diagnostic imaging, and postoperative medication.

The risk for complications and reoperations following MIS LD has also been extensively scrutinized within the literature. The total complication rates after MIS LD range from 2.4–20.8% in various reports, with the most common complication being intraoperative durotomy [11•, 13, 15, 18, 19, 22–28]. A direct comparison of complication rates in open and MIS decompression procedures was performed in the previously mentioned meta-analysis by Phan et al. [19]. This study not only determined that overall complication rates were similar between procedures, but that the rates of durotomy and postoperative CSF leak were also equivalent. In regards to reoperation risk, reported rates after MIS LD fall between 0.0–7.0% [11•, 19, 21, 22, 25, 26, 28]. Guha et al., in another

meta-analysis comparing cohorts undergoing either open or MIS LD, determined that the reoperation risk was higher in patients undergoing open procedures [21]. The authors claimed that this difference was primarily a result of the increased development of postoperative spondylolisthesis in the open cohort.

Degenerative spondylolisthesis: MIS transforaminal lumbar interbody fusion

Degenerative spondylolisthesis occurs due to progressive facet and intervertebral disk degeneration, most commonly involving the L4–5 levels. The resultant instability can lead both to vertebral body slippage and facet joint hypertrophy. From these, spinal stenosis and compression of nerve roots in the lateral recess can occur. Clinical manifestations include low-back pain and bilateral lower extremity radiculopathy, along with stenotic symptoms such as proximal muscle weakness and neurogenic claudication [1]. The severity of degenerative spondylolisthesis can be described using the Meyerding classification system, which classifies the ratio of the overhanging portion of the superior vertebral body to the anteroposterior length of the inferior vertebral body [29]. Amongst those with degenerative spondylolisthesis, classifications of Meyerding grade I (0–25% slip) and grade II (26–50% slip) predominate.

The predominant operative therapy for degenerative spondylolisthesis has traditionally consisted of open decompression with posterolateral fusion. Due to the operative morbidity associated with the open approach, MIS TLIF procedures have become more extensively utilized for the treatment of grade I/II degenerative spondylolisthesis [30]. MIS TLIF procedures also provide distinct advantages over open or MIS decompression-only approaches in regards to improvements in fusion rates, foraminal height restoration, Meyerding grade, and radiographic slip angle [1, 31].

In judging the effectiveness of MIS TLIF in the treatment of degenerative lumbar spondylolisthesis, direct comparisons to open TLIF cohorts have been made. In regards to the intraoperative and immediate postoperative periods, MIS TLIF has been demonstrated to have notable advantages over the open approach [10, 32, 33]. Parker et al., in a study of 100 patients treated with either MIS or open TLIF, demonstrated that the MIS cohort had significantly lower intraoperative blood loss and overall shorter inpatient length of stay [10•]. Additionally, MIS patients had a shorter duration of postoperative narcotic use, along with a significantly faster average return to work time. However, the MIS cohort had significantly longer operative times compared to the open cohort. Similar findings were described by Kalkari et al., who also utilized quantitative C-reactive protein measurements to conclude that MIS TLIF produced less muscle trauma than open TLIF [33]. However, the authors also quantified total intraoperative

fluoroscopic exposures and concluded that MIS TLIF was associated with higher radiation exposure than open TLIF. While longer operative times and increased radiation exposure may represent limitations to the utilization of MIS TLIF, these findings may also be related to the learning curve for the procedure [34].

Investigations involving long-term clinical and radiographic outcomes have further demonstrated the effectiveness of MIS TLIF in treating degenerative lumbar spondylolisthesis. Direct comparisons between MIS and open TLIF support equivalent improvements in disability, pain, and quality-of-life metrics at time points up to 3 years postoperatively [32, 35, 36]. Longer follow-up periods have also been reported, with Park et al. analyzing a cohort of 83 MIS TLIF patients with 5-year follow-up [37]. Clinically, patients demonstrated a 36-point improvement in Oswestry Disability Index (ODI), along with a 3.2-point improvement in Visual Analogue Scale (VAS) back pain and a 6.7-point improvement in VAS leg pain scores. Radiographically, 81% of patients achieved radiographic fusion, with that figure increasing to 89% when only single-level procedures were analyzed. 6.5% of patients required index-level revisions, while 5.6% had additional procedures at adjacent levels. Perez-Cruet et al. also noted similar clinical findings, demonstrating maintenance of significant improvements in ODI, VAS, and Short-Form 36 (SF-36) scores at an average follow-up of 47 months in 304 patients undergoing MIS TLIF [38•]. Radiographically, overall fusion rate was high at greater than 95%. Total reoperation rate was 3.9%, with only 2% of patients requiring adjacent level reoperations due to symptomatic adjacent segment disease.

In addition to clinical and radiographic investigations, cost analyses have also been performed to compare the efficacy of open versus MIS TLIF. To date, cost analyses within the literature have produced a favorable profile for MIS versus open procedures [10•, 32, 39•]. Singh et al., in a cohort of 66 patients undergoing either open or MIS TLIF, found that total hospital costs were 20.7% lower in MIS patients [39•]. Upon breakdown of cost domains, patients undergoing open TLIF had significantly higher costs in areas related to length of stay such as room/board, pharmacy, blood, and laboratory services. Parker et al., in the previously mentioned cohort of 100 patients undergoing MIS or open TLIF, conducted a similar study with additional investigations of longer-term cost [10•]. The MIS TLIF cohort was associated with significant reductions in mean hospital costs (–\$1758) and 2-year societal cost (–\$9295) compared to open TLIF. As 2-year direct healthcare costs were found to be similar, the observed difference in 2-year societal cost was theorized to be due to indirect cost savings as a result of earlier return to work in MIS TLIF patients. As MIS and open cohorts had similar health state gains as measured by QALYs, the authors concluded that MIS TLIF was both an effective and cost-saving therapeutic modality.

Degenerative spinal deformity: MIS lateral lumbar interbody fusion

Degenerative scoliosis, by definition, occurs when a spinal deformity of more than 10° in the coronal plane exists in a skeletally mature individual [40–42]. The etiology of degenerative spinal deformity is multifactorial and includes intervertebral disk degeneration, facet joint degeneration, and age-associated osteopenia [1, 43]. These processes lead to asymmetric losses in disc height, with resultant curve deformity, spinal instability, and vertebral endplate and facet hypertrophy [43]. Resultant symptomatology includes back pain associated with muscle fatigue and neurological deficits due to a combination of central stenosis, foraminal stenosis, and disc extrusions [1, 43]. A common classification system for degenerative scoliosis includes the Scoliosis Research Society (SRS) Adult Spinal Deformity classification [44]. This system both determines the severity of deformity and guides treatment based on radiographic factors including curve location, angular deformity, pelvic incidence, lumbar lordosis, global alignment, and pelvic tilt.

Indications for the surgical management of degenerative scoliosis include symptomatology refractory to conservative therapy or evidence of deformity with concomitant neurologic deficits. Operative treatment has historically been comprised of open posterior decompression with supplemental fusion to aid in the prevention of curve progression [45]. However, as with other open approaches, these techniques are associated with significant morbidity and high-complication risk [46–49]. As such, MIS LLIF procedures have been adapted for deformity management with many theorized benefits due to its unique approach and facilitation for fusion. In regards to operative characteristics, multiple studies have demonstrated reductions in operative morbidity in terms of intraoperative blood loss and length of stay upon utilization of MIS LLIF [50–55]. MIS LLIF also allows for direct access to the anterior column, removing the necessity for neural element retraction that is a characteristic of both open and MIS posterior techniques [56, 57]. Additionally, MIS LLIF is theorized to improve fusion and resist interbody cage subsidence through the use of larger footprint implants [58, 59]. MIS LLIF also accommodates various supplemental fixation techniques, with percutaneous posterior pedicle screw instrumentation, the most commonly used in the management of degenerative scoliosis.

The efficacy of MIS LLIF in the treatment of degenerative scoliosis is measured in relation to both long-term patient-reported outcomes and radiographic parameters of coronal and sagittal alignment. The majority of published reports are comprised of clinical case series, with a lack of high-quality evidence from prospective investigations with comparative groups. Nonetheless, the literature is heavily supportive of the efficacy of MIS LLIF in regards to patient disability, pain,

and quality of life outcomes [50, 51, 53, 60, 61•, 62–66]. For example, Phillips et al. conducted a study of 107 patients undergoing MIS LLIF for degenerative scoliosis [62]. At 2-year follow-up, patients had statistically significant improvements in ODI, VAS back pain, VAS leg pain, SF-36 physical composite, and SF-36 mental composite scores. Additionally, the authors observed an 85% patient satisfaction rate, with 86% of patients stating that they would have the same procedure again if necessary. Dakwar et al. demonstrated similar improvement of clinical outcomes in a cohort of 25 patients with degenerative scoliosis [53]. Upon quantification of outcome score improvement, patients had a 5.7-point improvement in VAS pain scores and a 23.7-point improvement in ODI scores at a mean follow-up of 11 months.

In addition to improvement in clinical outcomes, another goal of surgery for deformity is correction of coronal and sagittal alignment. Radiographic alignment factors not only provide quantifiable measurements of surgical correction but are also associated with improvements in clinical outcomes [42]. Previous investigations have consistently demonstrated the efficacy of MIS LLIF in the correction of coronal alignment [50–52, 65, 67, 68]. In a study of 30 patients undergoing MIS LLIF with supplemental fixation, Caputo et al. demonstrated a significant 72.3% correction in coronal Cobb angle postoperatively [68]. This change persisted until final follow-up at an average of 14.3 months, with no significant loss of correction. This cohort also exhibited improvements in sagittal alignment parameters, with a 9.8% increase in segmental lordosis and 11.5% increase in global lordosis. Significant increases also occurred in other parameters, including disc height, neuroforaminal height, and neuroforaminal width. While improvement in coronal alignment is well documented, improvement in sagittal alignment is more variable [61•, 66]. Acosta et al. demonstrated this in a study of 23 patients undergoing MIS LLIF [66]. While coronal alignment parameters improved postoperatively, sagittal alignment as measured by regional lumbar lordosis and global segmental alignment did not. The authors argued that MIS LLIF may need to be combined with posterior osteotomies to provide adequate sagittal correction. Future large case series and prospective studies are necessary to elucidate an accurate profile for coronal and sagittal correction after MIS LLIF.

Complication risk is another important aspect to consider in the evaluation of MIS LLIF as a treatment modality for degenerative lumbar scoliosis. Reported complication rates are highly variable between different investigations, with some studies reporting rates up to 36% [50, 53, 55, 60, 62, 64, 68, 69]. However, the most common complications include approach-related anterior thigh numbness, weakness, and pain [52, 53, 60, 62, 65, 70, 71]. As the vast majority of these symptoms are transient and produce no long-term clinical impairment, the true incidence of clinically relevant complications may be lower than reported. Additionally, as the

etiology of these symptoms is related to psoas muscle splitting and retraction near the lumbar plexus, prevention can be mediated through the judicious use of intraoperative EMG and MMG neuromonitoring [72]. Other approach-related complications include vascular and visceral injury as the retroperitoneal space is accessed. However, a recent large case series has demonstrated the incidence of visceral and vascular injuries to be infrequent at 0.08 and 0.10%, respectively [73]. Another concerning operative outcome is symptomatic non-union leading to the necessity for reoperation. However, reported rates of symptomatic pseudarthrosis within the literature are acceptable, with incidences ranging from 2.0 to 8.9% [55, 62, 65, 68]. Comparatively, the rate of reoperation for all etiologies has been reported to be between 3.3 and 19.7% [52, 55, 60, 62, 65, 68, 71].

Limitations to MIS utilization: the learning curve

While the evidence supports the efficacy of MIS techniques in the treatment of degenerative pathology, utilization of MIS approaches is still not widespread. Cited factors for non-adoption of MIS techniques include technical factors, limited training opportunities, and increased radiation exposure [74]. Specifically, the lack of training opportunities can lead to a steep learning curve, where earlier cases in a surgeon's experience may be associated with worse operative and clinical outcomes [75–77]. Studies investigating the learning curve in MIS techniques have identified earlier cases to be associated with increased operative times, radiation exposure, and complication risk [76–78]. Sclafani et al., in a meta-analysis of 15 studies investigating learning curves, determined that 20–30 cases were required to overcome the learning curve for MIS procedures [75]. Many practitioners may be reluctant to utilize MIS approaches because of the aforementioned difficulties of the learning curve. In order to increase the utilization of MIS approaches for degenerative pathology, more effective training implemented earlier in surgeons' careers will likely be necessary.

Conclusions

A variety of MIS procedures can be utilized for the treatment of degenerative spinal stenosis, spondylolisthesis, and scoliosis. MIS procedures provide distinct advantages over open procedures in the perioperative and immediate postoperative periods. These advantages include reduced intraoperative blood loss, reduced postoperative pain and narcotics utilization, and overall shorter length of hospital stay. Long-term clinical outcomes pertaining to disability, pain, and quality-of-life metrics are also equivalent between MIS and open procedures. Radiographically, while MIS procedures produce

adequate correction of coronal alignment, limitations may exist in the correction of sagittal alignment. Additionally, while reports of complication and reoperation rates are promising, more studies with comparative open cohorts are required to make any definitive conclusions. A greater impetus towards training and implementation of MIS techniques earlier in a surgeon's career will be necessary to ease the learning curve and increase the popularity of these techniques amongst spine surgeons.

Compliance with ethical standards

Conflict of interest Kern Singh reports personal fees from DePuy, Zimmer, Stryker, Globus, Pioneer, Lippincott, Thieme, Jaypee Publishing, and Slack Publishing, outside the submitted work. All other authors declare that they have no conflict of interest.

Human and animal rights and informed consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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