Limitations and complications of minimally invasive spinal surgery in adult deformity

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Abstract: Minimally invasive spine (MIS) surgery has rapidly progressed from simple short segment fusions to large adult deformity corrections, with radiographic and clinical outcomes as good as those of open surgery. Anterior longitudinal ligament release (ALLR) and anterior column realignment (ACR) have been key advancements in the ability to correct deformity using MIS techniques. However, patient selection and appropriate preoperative workup is critical to obtain good outcomes and for complication avoidance. Despite favorable outcomes in spinal deformity surgery, MIS techniques are limited in (I) pronounced cervical or thoracic deformity; (II) patients with prior fusion mass; and (III) severe sagittal imbalance necessitating Schwab 5 osteotomy or higher. Guidelines for proper patient selection are needed to guide MIS spine surgeons in choosing the right candidate.

Keywords: Adult spinal deformity; complications; limitations of minimally invasive spine (MIS); minimally invasive surgery; minimally invasive spine (MIS)

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Introduction

Until recently, minimally invasive spine (MIS) techniques have been used mainly for the correction of coronal deformity due to an inability to impact the sagittal plane of patients with severe spinopelvic malalignment. A guideline for the role of MIS techniques in the treatment of adult spinal deformity has been previously published, reserving MIS for patients with either coronal Cobb angles less than 30 degrees or those with >30 degrees of deformity but little to no sagittal imbalance [sagittal vertical axis (SVA) <5 cm] (1). Yet the introduction of MIS anterior column realignment (ACR) with anterior longitudinal ligament release (ALLR) in 2013 has provided an improved ability to restore sagittal balance, and allows for similar radiographic outcomes to open surgery using MIS alone or a combination of hybrid techniques (2-5). While the indications for MIS have been greatly expanded, the limitations of these techniques need to be clearly understood. Certain forms of severe deformity are still best addressed with open techniques. New guidelines are currently being development to guide surgeons in the selection of appropriate surgical candidates.

Patient selection

Selecting the most appropriate approach for the patient can be challenging. Stand-alone lateral constructs should be reserved for patients with comorbidities preclusive of more complicated conventional or circumferential MIS approaches. Patients with any degree of spinal instability, or any degree of coronal or sagittal imbalance should not be treated with stand-alone lateral constructs. Patients with debilitating pain, progressive degenerative scoliosis with advanced age, and obvious medical co-morbidity that preclude prone positioning may be considered. These patients should be screened for osteopenia and osteoporosis however. The vertebral body end plate strength is greatly dependent on the bone density (6). Patient with osteoporosis or advanced osteopenia should not be considered for stand-alone lateral fusion, and may be best treated non-operatively or with limited decompressive surgeries. Perioperative treatment with recombinant human parathyroid hormone (teriparatide/Forteo) has been useful for preoperative augmentation of bone quality, with good outcomes in patients with poor bone mineral density scores. This drug not only has anti-resorptive but also osteoinductive properties that quickly re-establish good bone quality in patients requiring major spinal deformity surgery (7-12).

Indications for MIS lumbar interbody fusion (LIF) have been greatly expanded now to adult degenerative scoliosis, spondylosis and spondylolisthesis, trauma, degenerative disc disease, lumbar stenosis, and adjacent segment failure. MIS LIF has been associated with shorter odds ratio (OR) times, less blood loss, fewer complications, shorter hospital length of stay, and quicker recovery than open surgery (13,14). Long-term outcomes are generally favorable, with maintained improvements in patient-reported pain and function scores as well as radiographic parameters, including high rates of fusion.

Degenerative spine disease and deformity

Minimally invasive surgery was initially developed to address morbidity associated with traditional open spinal approaches. These techniques were first applied to the treatment of degenerative spinal disease. In particular MIS LIF has been effective for indirect foraminal and central decompression and fusion (15,16). More recently, these techniques have been applied to the treatment of degenerative deformity (i.e., adult spinal deformity). MIS LIF has been shown to effectively treat coronal deformity (13,17-19). However, the importance of sagittal imbalance on health related quality of life outcomes has recently been recognized (20). Positive sagittal balance can lead to higher energy requirements to stand and ambulate, leading to early fatigue, intolerance to standing, and walking with compensation through other joints. The impact of MIS LIF on sagittal plane correction has likewise been investigated, however the ability to correct lumbar lordosis and pelvic tilt via MIS LIF are modest at best if the ACR is also not included as part of the surgery (21).

While clinical outcomes data regarding MIS deformity correction is encouraging thus far (22), the main critique of MIS surgery in deformity correction has been its inability to improve sagittal balance to the same extent as traditional open surgery, leaving MIS options solely for mild sagittal or coronal deformity correction. Sagittal imbalance has been traditionally managed with Schwab's posterior column shortening osteotomies, which have been reported to have at least 40% complication rate in adult spinal deformity (ASD) (23,24). ALLR with the use of hyperlordotic cages via the MIS lateral transpsoas approach has been shown to have similar radiographic and clinical outcomes as large posterior column osteotomies (PCOs), while at the same time minimizing complications of open surgery (25). Segmental lordosis after ALLR and ACR is increased by 14° when posterior elements are left intact. A facetectomy increases segmental lordosis restoration range to 21–27°. The spinous process can be resected along with bilateral facetectomy, achieving segmental lordosis restoration of up to 30° with a 30° hyperlordotic cage (26). These results are equivalent to open pedicle subtraction osteotomies (*Figure 1*).

As increasing role of MIS LIF in moderate spinal deformity correction continues to be paved, it is important to keep in mind that the ultimate end goal should be to re-establish spinopelvic harmony, as it has been directly linked to a satisfactory postsurgical outcome as assessed by health related quality of life scores (20,27). Four basic radiographic targets to aim for in order to achieve spinopelvic harmony include: (I) sagittal vertical axis of <50 mm or T1–SI <0°; (II) pelvic tilt of <20°; (III) coronal Cobb angle <10; and (IV) lumbar lordosis pelvic incidence mismatch ±9° (20,28). These targets serve as the foundation for spinopelvic realignment in the sagittal and coronal plane, and even partial improvements of these parameters may translate to better clinical outcomes. Addition of ACR to the MIS armamentarium allows for greater MIS deformity correction previously not capable of with standard MIS techniques. And the severity of deformity dictates a particular MIS or hybrid technique approach (*Table 1*). It is important to note, however, that revision surgeries in patients with large dorsal fusion masses requiring significant pelvic incidence-lumbar lordosis (PI-LL) mismatch correction may not be amenable to MIS techniques alone, simply due to lack of available disc levels for ACR. In such cases, high grade open osteotomies may be necessary to restore spinopelvic harmony. Revision surgery with severe spinal deformity continues to be a limitation for MIS approaches alone.

Adjacent segment failure is a common complication encountered in patients with prior lumbar fusions. Correction of adjacent segment failure may involve additional posterior dissection, revision of existing instrumentation, and negotiation of scar tissue which may lead to increased

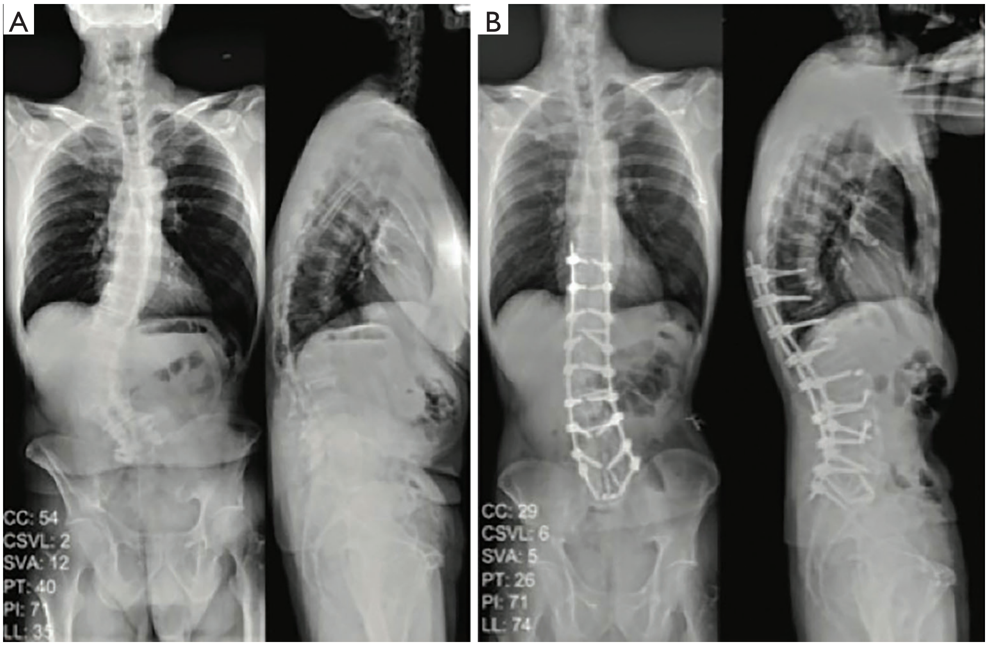

Figure 1 Anteroposterior and lateral 36-inch radiographs of a patient with severe deformity (red group). (A) Preoperative images of a patient with severe deformity; (B) postoperative images obtained after T10–S1 open posterior arthrodesis with osteotomies and with MIS-lateral interbody fusion with multilevel ALL release, showing restoration of disc height and improvement in spinopelvic parameters. MIS, minimally invasive spine; ALL, anterior longitudinal ligament; SVA, sagittal vertical axis; CC, coronal Cobb angle; CSVL, central sacral vertical line; PT, pelvic tilt; PI, pelvic incidence; LL, lumbar lordosis.

Table 1 Radiographic subgroups and related surgical intervention

Parameters	Mild	Moderate	Severe
CC (°)	<30	>30	>30
PI-LL (°)	<20	20–30	>30
SVA (cm)	<5	5–9	>10
PT (°)	<25	25–30	>30
Anterior arthrodesis	Limited MIS LIF; consider stand-alone if PT <20	MIS LIF to neutral vertebrae + ALLR	MIS LIF to neutral vertebrae +/– ALLR
Posterior fixation	Percutaneous fixation	Percutaneous fixation +/– facetectomy	Pedicle screw fixation + osteotomy (Schwab 3–5) depending of mismatch severity and extent of prior fusion mass

Mild represents radiographic parameters of patients with mild symptomatic deformity and spinopelvic compensation; moderate represents radiographic parameters of patients with moderate symptomatic deformity and associated lack of sagittal balance with SVA between 5 and 9 cm; severe represents radiographic parameters of patients with severe symptomatic deformity and associated lack of sagittal balance with SVA greater than 10 cm despite maximal PT. PI-LL, pelvic incidence-lumbar lordosis; SVA, sagittal vertical axis; PT, pelvic tilt; ALLR, anterior longitudinal ligament release; MIS, minimally invasive spine; CC, coronal Cobb angle; LIF, lumbar interbody fusion.

risk of infection and spinal fluid leak. The MIS LIF is an option for treatment of adjacent segment failure. The lateral approach avoids traversing a scarred corridor, and allows placement of an intervertebral cage without the pitfalls of reoperation mentioned above. Additional fixation can be obtained using a lateral plate without the need to revise prior instrumentation. Literature regarding the use of the MIS LIF for adjacent segment failure is lacking, however there is literature regarding the use of this approach for revision lumbar surgery and total disc replacement (29-31).

Complications of MIS

Careful attention to detail throughout the perioperative period is crucial to reduce the risk of complications (32). Complications may arise from the result of inadequate preoperative planning. Meticulous review of preoperative imaging and assessment of neurovascular structures is necessary to avoid unintended injury. Transitional psoas may bring the femoral nerve closer to the posterior blade of the retractor, causing irreversible damage from nerve root ischemia or direct damage. Additionally, incorrect patient positioning may lead to difficulty accessing the L4–5 disk space, leading to increased risk of postoperative motor or sensory deficits.

Numbness, paresthesia, and weakness

Real-time directional electromyography (EMG) monitoring is crucial to minimize the chance of motor nerve injury (33). However, since sensory nerves cannot be monitored, understanding of and attention to regional anatomy is necessary to avoid sensory deficits. While injury can occur at any level of approach, the rate of femoral nerve injury is highest at the L4–5 segment. It is important to distinguish a true motor weakness along the femoral nerve distribution from pain limited weakness due to bruising of the psoas hip flexor from retraction. Reports of true motor weakness range from 3.4–23.7% (32,34,35). The rate of paresthesias following MIS LIF can range from 0.7–30% (32,34,36,37) and numbness has been reported in 8.3–42.4% (13,34,35). Commonly affected sensory nerves are the genitofemoral, lateral femoral cutaneous and anterior femoral cutaneous nerves. Most motor and sensory deficits are transient and recover, with 50% recovery at 90 days, and 90% recovery at 1 year (34).

Abdominal wall paresis and bowel perforation

Abdominal wall paresis, also referred to as a "pseudohernia", may result from iatrogenic nerve injury during the initial dissection of the abdominal wall (38). This results in denervation, paresis, and bulging of the anterior abdominal wall. Associated signs and symptoms include swelling, pain, hyperesthesia, or other sensory abnormalities. It is imperative to rule out a true abdominal hernia in these instances, however in many cases spontaneous recovery can occur.

Lateral incisional hernia

This is a rare complication reported in approximately 1% of patients, and is mainly due to poor fascial closure technique (unpublished results). In our series of 303 patients, 3 were identified with incidental hernias during routine clinical follow-up. One of those patients, however, required hernia repair due to bowel incarceration.

Prevention of hernia formation is the key to complication avoidance. Full thickness closure of the transversalis fascia and muscle layers reduces the risk of incisional hernia, however the traversing nerves can be entrapped with blind sutures, leading to pseudohernia formation. Because of the small incisions used in lateral-MIS approaches, re-approximation of each individual layer may be challenging. In obese patients where visualization is limited, a layer by layer closure is not recommended. When operating near the iliac crest, leaving a small fascial cuff attached to the crest facilitates closure at the end of surgery. Fasciotomies in direct contact with bone are otherwise difficult to close. Lastly, un-breaking the table prior to closure allows a tension free closure and better approximation of tissue. Running or interrupted sutures may be used provided no residual fascial defects are left that would facilitate herniation of the peritoneal contents.

Colonic pseudo-obstruction and bowel perforation

Ogilvie's syndrome (OS), or delayed ileus from colonic pseudo-obstruction can potentially lead to bowel perforation if not recognized in time, with associated mortality rate between 50% and 71% (39-41). It is not, however, a result of direct injury to bowel during surgery as it always presents itself in a delayed fashion. OS is clinically diagnosed as diminished gastric motility that does not resolve on its own in a matter of days. Radiographically it is characterized by dilatation of cecum greater than 9 cm and lack of mechanical obstruction on abdominal CT. Neostigmine, a acetylcholinesterase inhibitor, is rarely used in treating OS if more conservative measures fail (40,42).

Hardware-related complications and proximal junctional kyphosis (PJK)

There have been several reports of complications related to insertion of lateral interbody cages or lateral plates. Dua *et al.* reported a 15% rate of hardware-related complications in a series of 13 patients (43). These cases consisted of two atraumatic coronal plane fractures at L4/5 in the first 6 weeks of the postoperative period. Le *et al.* demonstrated hardware-related complication rate of 5.9% in a series of 101 patients (44,45). Included were three hardware failures and three vertebral body fractures. All cases presented with recurrent back pain except one, which was identified incidentally. The mechanism of hardware failure is unclear, but may involve cage subsidence with a fixed angle screw, resulting in increased force at an area of stress concentration, violation of the endplate during preparation or screw insertion, or incorrect placement of the hardware lock nuts (43-46).

PJK resulting in failure does not improve with the use of MIS techniques, and in fact, may increase when MIS is combined with hybrid PCOs. In a recent unpublished study by Uribe *et al.*, PJK developed in 35.5% of patients, of which 16.1% progressed to proximal junctional failure (PJF). The incidence of PJK increased with addition of PCO (46.2% *vs.* 27.8%). While the mechanism for this is unknown, overcorrection in elderly patients may be a risk factor. Recent literature suggests that the goal SVA may be more liberal in the elderly than +/− 5 cm (47-49). Also, there was a higher PJK rate when the upper-instrumented vertebra was located at T10–L1 *vs.* L2–L4, suggesting location of instrumentation may also be contributory. Further research needs to be performed to pinpoint the exact cause of PJK and PJF in both MIS and open spinal surgery.

Subsidence

As with any technique used for lumbar fusion, subsidence of the cage can occur at either endplate. The subsequent progressive deformity and compression of neural elements can lead to a loss of indirect decompression and reduced chance of successful fusion (50,51).

In a study that included 140 patients and 238 levels fused in the lumbar spine, we recently found subsidence to be present in 14.3% of the cases, and in 8.8% of the total levels fused at a mean follow-up of 9.6 months (44). Only 2.1% of the patients had symptomatic subsidence, however, subsidence appears to correlate with construct length.

Subsidence appears largely correlated with cage size, as there was a 14.1% rate of subsidence with cages smaller than 18 mm, compared to a 1.9% rate of subsidence in cages larger than 22 mm. As such, the largest interbody cage should be used whenever feasible.

Rhabdomyolysis

Rhabdomyolysis is a rare, but known, complication of spinal surgery. Rhabdomyolysis leading to acute renal failure after MIS LIF has also been previously reported (52). Patients who are morbidly obese or procedures with a prolonged operative time are at an increased risk for this complication.

Contralateral psoas hematoma in LIF

Contralateral psoas hematoma is suspected to occur from segmental vessel injury during contralateral annulotomy (53). Preoperative axial and sagittal magnetic resonance imaging (MRI) series should be evaluated to determine whether there are traversing segmental vessels across the contralateral disc space. Contralateral leg weakness can occur as a result of this complication due to femoral nerve compression causing symptomatic neuropraxia. Prompt evacuation is recommended to prevent permanent injury.

Discussion

Due to recent rapid advancement in MIS techniques such as ACR, introduction of hyperlordotic lateral cages, and expandable transforaminal lumbar interbody fusion (TLIF) and LIF titanium cages, surgical indications have greatly expanded to include trauma, degenerative disc disease, spondylosis with instability, lumbar stenosis, spondylolisthesis, adjacent segment failure, and adult degenerative scoliosis with and without sagittal imbalance. MIS techniques have recently been applied to patients with sagittal imbalance or coronal deformity, and studies have confirmed its equivalence to open surgery, with the advantage of reduced blood loss and complications associated with open osteotomies. Yet limitations for the use of these techniques in complex spine surgery still exist, and their application must be evaluated on a case by case scenario. Patients with a prior large fusion mass, significantly increased PI-LL mismatch and large PT are difficult candidates for MIS correction. While MIS can be utilized at adjacent segment levels, such patients may still require a high-grade Schwab osteotomy to accomplish a good sagittal realignment. One of the major disappointments of MIS in spinal deformity surgery is its inability to reduce PJK and PJF rates. Further studies are needed to address this topic.

The benefits of MIS are becoming increasingly obvious in the literature; however, surgeons must remember to exercise judgment when electing to use these techniques over more traditional open procedures.

Conclusions

Recent advancements in spine surgery have reduced the limitations of MIS significantly. MIS does however have unique limitations, some of which are patient specific. Complications, while vastly different from open surgery, exist and must be understood to improve both radiographic and clinical patient outcomes.

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Footnote

Conflicts of Interest: JS Uribe is a consultant for NuVasive, Inc. and receives consultation fees for his input on product design. The other authors have no conflicts of interest to declare.

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