Minimally-Invasive Spine Surgery

Jason K Hsieh¹, Nehaw Sarmey¹, Daniel Lubelski¹, Thomas E Mroz², Michael Steinmetz³

¹Cleveland Clinic Lerner College of Medicine, 9500 Euclid Ave. NA21, Cleveland, Ohio, USA
²Center for Spine Health, Cleveland Clinic Foundation, 9500 Euclid Ave, Cleveland, Ohio, USA
³Department of Neurosurgery, Case Western Reserve University School of Medicine, MetroHealth Medical Center, Cleveland, Ohio, USA

ABSTRACT

Minimally-invasive spine surgery encompasses a variety of techniques designed to improve perioperative measures and long-term functional outcomes by limiting approach-related morbidity to the paraspinal musculature. The rapid development of minimally-invasive techniques has resulted in a relative shortage of high-quality studies comparing the efficacy of minimally-invasive spine surgery to standard approaches. In this review, we discuss the literature concerning the most commonly used minimally-invasive approaches to the lumbar and cervical spine.

KEY WORDS: Cervical decompression and fusion, lateral transpsoas fusion, lumbar disc disease, lumbar stenosis, lumbar fusion and instrumentation, minimally-invasive spine surgery

INTRODUCTION

In recent decades, an increasing number of spinal surgical approaches and techniques have been developed that limit approach-related morbidity to the paraspinal musculature (44,60). Minimally invasive spine (MIS) surgery encompasses a variety of techniques designed to improve perioperative measures (e.g. blood loss, postoperative pain narcotic usage, recovery time) and long-term functional outcomes. Large, randomized, controlled trials (RCTs) regarding the comparative outcomes of MIS surgery vs. traditional or open spinal surgeries are sparse. Many retrospective studies, case series, smaller prospective studies, and some large non-randomized series suggest that for certain indications, MIS surgery is equally safe and efficacious compared to open approaches, and furthermore, may have superior perioperative measures such as blood loss, length of stay, and postoperative pain (21,22,38,41,42,47,55,58,80,81).

On the other hand, there is a learning curve for MIS surgery, and early patients experienced worse outcomes in some trials (23,50,57). Several studies raise the question of whether minimally invasive techniques may sometimes result in incomplete treatment of pathology compared to open approaches (4–6,26). In this review, we discuss the literature concerning perioperative and long-term outcomes for the most commonly used lumbar and cervical MIS surgeries.

Traditional vs. Minimally-Invasive Spine Surgery

Relative to MIS, open spinal approaches often require wider surgical exposures and increased bony and muscular disruption. MIS approaches often achieve decompression through more limited amounts of osseous resection and muscle destruction. The growth of MIS surgery has outpaced the supporting high-quality evidence and for this reason, the existing lower level evidence must be interpreted carefully with consideration for potential confounders and bias. Much of the literature suggests that MIS techniques compare favorably to open approaches in perioperative outcomes such as decreased blood loss and decreased narcotic usage, (22,42) as well as faster recovery time, less postoperative pain, and a faster return to work for patients undergoing some cervical and lumbar MIS surgeries (22,38).
Compared to open approaches, some studies suggest that MIS approaches lead to lower infection rates (59) and better preservation of muscle bulk and strength (34,45,56).

**Lumbar Disc Disease**

Tubular microdiscectomy uses sequential dilation of the paraspinal muscles with a series of concentric tubular dilators, rather than dissection, to access the pathological disc.

In 2006, Wu et al. published one of the largest retrospective reviews on this approach, which included 873 patients treated with MIS lumbar discectomy compared to 358 patients treated with traditional lumbar discectomy over the same time period (80). The authors found that patients treated with MIS had less blood loss (44 mL vs. 135 mL), shorter length of stay (4.8 d vs. 7.3 d) and return to work (15 d vs. 21 d), and less use of postoperative analgesics (18% vs. 37%). Furthermore, this study found a lower rate of complications (4.0 vs. 5.3%) and a similar rate of successful outcomes between MIS and open surgery as measured by modified MacNab criteria. In the MIS group, outcomes were measured as excellent for 74% and good for 19%, while in the open group outcomes were excellent for 70% and good for 20% (80). Another, smaller retrospective review of MIS lumbar discectomy by Cole and Jackson (18) in obese patients supported its safety and efficacy; 31/32 patients had improved back and leg pain, 25 did not require chronic analgesics 3 months postoperatively, there were no infections, and only two needed reoperation for late or recurrent herniation. Other small, retrospective studies supported benefits of MIS in terms of length-of-hospitalization, decreased narcotic use, and decreased operative blood loss (26,29).

Some randomized controlled trials have failed to demonstrate as clear a benefit for MIS lumbar discectomy. In the first report of the Sciatica Micro-Endoscopic Diskectomy trial, (6) a double-blinded RCT of 167 patients treated with tubular discectomy compared to 161 patients treated with conventional microdiscectomy, Arts et al. found no clinically or statistically significant benefit to tubular discectomy in terms of their primary outcome, the Roland-Morris Disability Questionnaire Score (RDQ) during the entire 52 week follow-up period. However, at 52 weeks postoperatively, the difference in RDQ was statistically significant and favored the conventional group (MIS: 4.7 vs. Conventional: 3.4). Interestingly, the patients treated with tubular discectomy reported greater leg and back pain as measured by visual analog scale (VAS) throughout the 52-week follow-up period and lower rates of perceived recovery at one year (measured by a Likert scale). At 2-year follow-up, there continued to be no significant difference in RDQ while leg and back pain VAS scores continued to favor conventional discectomy (5). The authors of this study also found no difference in muscle injury between the two treatment arms as measured by postoperative creatine phosphokinase levels or multifidus atrophy (4).

On the other hand, one smaller RCT by Ryang et al. in 2008 of 60 patients (70) demonstrated similar operative time, blood loss, and complication rates for MIS lumbar discectomy compared to open discectomy, while in another RCT in 2007 of 40 patients, (67) Righesso et al. found that MIS lumbar discectomy resulted in shorter hospital stay and size of incision, but no difference in blood loss or return to work. Both of these smaller studies supported MIS as having similar clinical results as open discectomy.

Although smaller randomized studies and a preponderance of non-randomized and retrospective evidence support the safety and efficacy of MIS lumbar discectomy, the failure of the Sciatica Micro-Endoscopic Diskectomy trial to substantiate the benefits of MIS surgery on short-term functional outcomes raises questions as to whether this surgery truly offers patients an improved operative and postoperative course with equivalent long-term results. The development of detailed guidelines is needed, which requires further investigation in the form of large, high-quality studies. In addition, other questions to be addressed include how the degree of disc removal (i.e. limited vs. aggressive disc resection) affects outcomes and in which patients should a surgeon favor minimally invasive surgery or limited extent of disc resection.

**Lumbar Spinal Stenosis**

The benefits of conventional open surgery for lumbar spinal stenosis refractory to conservative measures are well-supported in the literature (7–9,48,78). In 2002, two groups independently reported the adaptation of MIS techniques to the treatment of lumbar stenosis (28,42,62). In this approach, a unilateral portal is introduced using sequential dilation and hemilaminectomy is performed. By angling the retractor medially, the contralateral canal and lateral recess may also be decompressed. Above the L3 level, it can be difficult to decompress the ipsilateral recess, so often a
bilateral cross-over technique is used where each recess is decompressed from an approach from the contralateral side.

In one early series published in 2007 of 114 patients that underwent MIS decompression for lumbar spinal stenosis, (35) Ikuta et al. reported that their patients experienced an improvement in Japanese Orthopedic Association (JOA) lumbar score (14.5 to 23.9) and a decrease in pain by VAS score (71 to 33) (35). This is consistent with a prior report from the same group where 38 of 44 total patients experienced a “good” outcome (36). Another study by Khoo and Fessler in 2002 showed that MIS lumbar decompression had similar clinical outcomes as open decompression as well as reduced operative blood loss, postoperative stay, and use of narcotics (42). One 4-year longitudinal prospective study published in 2009 by Castro-Menéndez et al. of 50 patients with lumbar stenosis treated with MIS decompression found “good or excellent” results in 72% of patients with a mean decrease in Oswestry Disability Index (ODI) score of 30.23 and decrease in lumbar and leg pain VAS scores of 0.84 and 6.02, respectively (14). In a retrospective study of 374 patients with unilateral microdecompression, (19) Costa et al. reported in 2007 that 329 patients (87.9%) experienced a clinical benefit (defined as improvement in VAS and Prolo Scale scores). Only 3 patients (0.8%) reported segmental instability at a treated level, but none required surgery for stabilization. This is consistent with biomechanical studies (30) and other reports (75) which have found that MIS lumbar decompression is associated with a very low rate of postoperative instability.

There is limited class I or II evidence comparing MIS and traditional laminectomy for lumbar stenosis. In a recent randomized trial published in 2014 by Mobbs et al., (55) 54 patients with degenerative lumbar spinal stenosis were randomized to either MIS laminectomy with bilateral decompression or open (traditional) laminectomy. Patients in the MIS group had significantly greater improvement in VAS scores (5.6 vs. 3.9, p = .013) and a trend towards greater improvement in ODI (28.6 vs. 17.5, p = 0.055) at postoperative assessment. There was no significant difference in quality of life between groups by SF-12 scores or in patient satisfaction. Blood loss, time to mobilization, length of stay, ad narcotic use were all significantly better in the MIS group. Complication and reoperation rates were not different between groups.

In another study published in 2009 by Yagi et al., (81) 41 patients with single-level lumbar stenosis with no or mild/moderate spondylolisthesis were randomized to a modified unilateral-approach microendoscopic midline decompression (20 patients) or conventional laminectomy (21 patients). Patients in the MIS group experienced less blood loss, had lower postoperative VAS scores, required less postoperative NSAID use, and had lower postoperative creatine phosphokinase levels than patients receiving conventional (traditional) laminectomy. They also had higher improvement rates for low-back pain and movement enabling activities of daily living as compared to open surgery. Furthermore, at one year after surgery, patients in the MIS group had significantly lower rates of paravertebral muscle atrophy (as measured by axial MRI cross-sectional multifidus and erector spinae area) and low-back pain.

Just as with MIS lumbar discectomy, the relative paucity of evidence available requires that conclusions regarding the comparative outcomes of MIS decompression for lumbar stenosis be made cautiously. However, most evidence supports the efficacy of MIS lumbar decompression with regards to achieving similar clinical outcomes as traditional laminectomy while providing patients better postoperative recovery.

**Lumbar Fusion and Instrumentation**

**Anterior Lumbar Interbody Fusion**

In 1995, Mathews51 and Zucherman (84) separately reported the application of laparoscopic minimally-invasive technique to the anterior lumbar interbody fusion (ALIF) procedure originally developed by Burns in 1933 (12). Although this technique is no longer in favor, early studies in 1995 and 1996 on the laparoscopic ALIF (LALIF) reported encouraging results which were tempered somewhat by high complication rates; one study required 3 open conversions in its first 4 patients, (49) and another study excluded 1 out of 6 attempted LALIFs from its results because an iliac vein tear prevented successful completion of the laparoscopic procedure (51). Both studies reported successful fusion in all patients at six months.

A large, non-randomized multicenter trial published in 1999 by Regan et al. (66) investigated 240 patients undergoing LALIF compared with 591 patients undergoing open ALIF. The authors found that the laparoscopic group had shorter length-of-stay and reduced intraoperative blood loss, but had increased operative time. The overall complication rate was comparable (Laparoscopic: 4.9% vs. Open: 4.2%), but device-related reoperation (reoperation within 6 months
for implant or fusion-related complications) was higher in the laparoscopic group (4.7% vs. 2.3%). There was a 10% conversion rate to open surgery.

An alternative to the traditional open approach known as the mini-open ALIF evolved during the same time period. In the mini-open ALIF, a smaller incision is made in the anterior paramedian abdominal surface and the surgeon approaches the spine through the retroperitoneum with preservation and mobilization of the peritoneum and its contents (52). The mini-open ALIF was found to be quick, safe, and effective; in one series of 686 mini-open approaches to the lumbar spine, (11) Brau reported in 2002 that exposure time took between 18.7 and 38.4 minutes (depending on the level) and the procedure resulted in a low rate of complications - most commonly deep vein thrombosis (1%), venous injury (0.8%), and arterial thrombosis (0.8%).

Many different studies compared the laparoscopic ALIF with the mini-open ALIF. One non-randomized comparison published by Zdeblick and David in 2000 (83) of 50 patients undergoing either mini-open or laparoscopic L4-L5 ALIF found that for single-level surgeries, there was no difference in operative time, blood loss, or LOS, while for 2-level surgeries the laparoscopic surgery took 25 minutes longer than the mini-open approach. The complication rate was substantially and significantly higher in the laparoscopic group (20% vs. 4%) and 16% of the laparoscopic surgeries had inadequate exposure, resulting in the placement of only one cage or dowel per level. In comparison, all patients in the mini-open group had two cages or dowels placed per level. In another prospective series of 47 patients, (15) Chung et al. in 2003 found that blood loss and length of stay were not different between laparoscopic and mini-open groups, while operative time was significantly longer for the laparoscopic surgery. Both surgeries achieved a high fusion rate (91%) and similar clinical and radiologic outcomes; there was no difference in pain by VAS, ODI, or patient satisfaction index after two years. Retrospective studies confirmed that laparoscopic ALIF resulted in longer operative times and greater complication rate, including particularly retrograde ejaculation (37,40).

While there are not many high-level studies investigating the comparative effectiveness of LALIF, the current evidence suggests that while LALIF and other endoscopic approaches to the ALIF may be able to achieve similar clinical outcomes compared with open or mini-open ALIF, (11,15,66) their high cost, increased complexity, and relatively higher complication rate have caused most surgeons to abandon endoscopic ALIF techniques in favor of mini-open or open ALIF due to their safety, relative simplicity, and efficacy (37).

**Posterior Lumbar Interbody Fusion**

In 2002, Khoo (43) reported the use of MIS for Posterior Lumbar Interbody Fusion (PLIF), a procedure originally pioneered by Cloward in 1952 (16,17). In this report, (43) Khoo et al. used tubular spinal access systems to perform a minimally-invasive “PLIF-style decompression” including hemilaminotomy, facetectomy, and foraminotomy. After this, full aggressive discectomy was performed and bone spacers were placed in the vertebral body interspace. Afterwards, a percutaneous pedicle screw system was used to instrument the fused level.

Non-randomized prospective and retrospective studies of patients undergoing single-level MIS vs. open PLIF have demonstrated similar clinical and radiographic outcomes, (21,58) however, one study revealed that patients treated with MIS reported lower (more favorable) VAS and ODI scores, (21) in addition to lower postoperative serum CK and less multifidus muscle atrophy on MRI. Patients in these studies treated with MIS had less blood loss, postoperative pain, shorter recovery time, and shorter postoperative length of stay (21,58) MIS PLIF resulted in slightly longer operative time (275 min vs. 152 min) and more fluoroscopy exposure (297 sec vs. 123 sec). In addition, a study by Kim et al. in 2011 et al of patients undergoing two- and three-level MIS PLIF found that the procedure was safe and effective (46).

A prospective, non-randomized trial published in 2009 by Kasis et al. (41) comparing traditional PLIF with a modified limited exposure PLIF with total facetectomy (LI-PLIF) found significantly greater improvement in all patient-reported outcome scores after the limited-exposure approach compared to open total facetectomy. These included ODI (LI-PLIF: 22.5 vs. PLIF:28.8), VAS for back pain (LI-PLIF: 3.8 vs. PLIF:5.4), VAS for leg pain (LI-PLIF: 4.0 vs. PLIF: 5.1) and SF-36 for bodily pain (LI-PLIF: 18.5 vs. PLIF: 14.7). In addition, patients in the MIS cohort had a shorter length of stay (2.24 vs. 4.04 days) and a substantially lower rate of operative complications (6.7% vs. 19.3%) as compared with the open group. Trials of PLIF using an expandable spacer with and without minimally-invasive technique resulted in similar clinical outcomes with good relief of pain and disability (by VAS and ODI) (24,25).
A 2014 systematic review (27) of MIS fusion compared to open TLIF and PLIF for degenerative lumbar disorders identified 26 studies which were all of low-level evidence. Though the quality of evidence precludes any substantive conclusions about comparative efficacy, the sum of these trials revealed equivalent operative times for both techniques but less blood loss, shorter length of stay, and more fluoroscopy for patients treated with MIS fusion. Patient-reported outcomes across these trials were equivalent. There was a trend towards lower rates of surgical and medical adverse events in patients treated with MIS, but this may be the result of underlying selection bias in the non-randomized literature on MIS PLIF.

Transforaminal Lumbar Interbody Fusion

 Introduced by Holly and Schwender in 2006, (32,72) the minimally-invasive modification of the transforaminal lumbar interbody fusion (TLIF) incorporates the use of tubular dilation through the intervertebral foramen. A 2009 study (64) by Peng et al. of 29 patients undergoing MIS-TLIF paired with 29 matched patients undergoing open TLIF found that the MIS approach achieved similar clinical outcomes as measured by the rate of grade I fusion, ODI,VAS back and leg pain scores, and SF-36 scores at 6 months and 2 years. The MIS group had longer operative time (216.4 min vs. 170.5 min) and fluoroscopic time (105.5 sec vs. 35.2 sec) but less blood loss (150 vs. 681 mL), postoperative narcotic use (17.4 mg vs. 35.7 mg), and shorter postoperative hospitalization (4 d vs. 6.7 d). Another matched pair study published in 2013 (73) by Seng et al. found that MIS TLIF and open TLIF achieved improvement in ODI, neurogenic symptom score, back and leg pain, and SF-36 scores at 6 month, 2 year, and 5-year follow-up postoperatively without any significant differences. Again, MIS was associated with longer fluoroscopic time (55.2 sec vs. 16.4 sec) though no significant difference in operative time was found in this study (MIS: 185 sec vs. Open: 166 sec, p = 0.085). MIS patients also used less postoperative morphine (8.5 mg vs. 24.2 mg), ambulated earlier (1.5 d vs. 3 d) and had a shorter LOS (3 d vs. 5.9 d). Importantly, Grade 1 fusion was achieved in 97.5% of both groups and the overall complication rate of 15% for MIS was lower than that of open surgery (20%). A 2014 study by Wong et al. (79) with 4-year follow up of 144 consecutive 1- and 2-level minimally invasive TLIFs with an institutional control of 54 open TLIFs also supports that MIS TLIF is safe and has excellent long-term clinical outcomes. Compared to open TLIF, MIS had a shorter operative time (2.05 hr vs. 3.75 hr), decreased blood loss (115 mL vs. 485 ml) and fewer postoperative transfusions (2.1% vs. 11.1%), and shorter LOS (2.75 d vs. 4.40 d). Both groups had similar fusion rates (MIS: 92.5% vs. Open: 93.5%). Both groups achieved similar reductions in ODI score and VAS leg and back pain scores.

Several smaller and retrospective studies also support these findings. A 2009 study (71) by Schizas et al. of 36 total patients undergoing MIS vs. open TLIF found no difference in length of surgery, postoperative pain, or analgesia consumption, while clinical outcomes (VAS and ODI) were similar between groups. The MIS group had less blood loss and a shorter hospital stay. A 2011 retrospective study (1) by Adogwa et al. of 30 patients with grade I degenerative spondylolisthesis treated with either MIS TLIF (15 patients) or open TLIF (15 patients) reinforced the ability of MIS TLIF to achieve similar clinical outcomes as open TLIF; both groups achieved equally good improvement inVAS back and leg pain scores, ODI, and EuroQoL-5D scores. The MIS group in this study had a shorter postoperative length of stay (3 d vs. 5.5 d), shorter length of narcotic use (2 weeks vs. 4 weeks) and faster return-to-work (8.5 weeks vs. 17.1 weeks).

Overall, the level of evidence available for comparisons between MIS and open TLIF and PLIF procedures is poor (27). Nonetheless, findings generally support MIS as a safe and effective alternative to open TLIF with perioperative benefits such as decreased length of stay and postoperative pain. Importantly, a recent study of postoperative complications after TLIF found that the rate of surgical intervention for symptomatic adjacent segment disease (ASD) was less in patients treated with MIS TLIF than those treated with open TLIF (9.3% vs. 22.7%) (63).

Lateral Transpsoas Fusion

The direct lateral approach to the anterior lumbar spine is an effective means of accessing the anterior lumbar spine. The two direct lateral transpsoas approaches (XLIF, Nuvasive; DLIF, Medtronic, Inc.) were developed from techniques reported by Mayer and McAfee separately in 1997 and 1998 (52,53). This approach relies on entering the retroperitoneal space from the lateral abdomen and dividing the psoas muscle. This allows the anterolateral lumbar spine to be approached through a small incision, in minimally-invasive fashion, with preservation of the paraspinal musculature.
In a retrospective cohort of 97 patients, a study by Berjano and colleagues\textsuperscript{10} found that the far lateral interbody fusion resulted in clinical success in 92% of patients. There were no cases of permanent neurological impairment, vascular, or visceral injuries. 7% of patients experienced transient neurological symptoms (all independently resolved within one month), and 9% experienced transient thigh discomfort. In another retrospective study by Alimi et al. of 145 treated levels in 90 patients, (2) 84.8% had an excellent, good, or fair outcome by Macnab criteria. Patient ODI improved by 21.1%, and VAS scores for back, buttock, and leg pain improved by 3.7, 3.6, and 3.7 respectively. 4.4% and 2.2% of patients experienced thigh numbness and weakness, respectively, and all cases except one resolved in 3 months. A comparative study by Smith et al. (74) of 87 patients undergoing open ALIF and 115 undergoing XLIF found that clinical improvement in both groups was not significantly different at two years. However, there was a complication rate of 16.7% in the open ALIF group and 8.2% in the XLIF group. Furthermore, XLIF had a 10-13.6% cost savings compared to open ALIF.

Several smaller studies support the safety and efficacy of lateral interbody fusion and its low rate of permanent neurologic complications (3,61,76). One retrospective series published in 2013 by Meredith et al.\textsuperscript{35} described the authors’ initial experience adapting XLIF to access the anterior thoracic and thoracolumbar spine. This study included 18 patients treated with XLIF for various pathologies including disc herniation, fracture, tumor, pseudoarthrosis, and proximal junctional kyphosis. At a mean follow-up of 14 months, all patients except one (who died of metastatic disease) achieved radiographic fusion. Complications included pleural effusion in 2 patients, durotomy in 2 patients (one requiring reoperation) and sacral fracture 6 weeks post-operatively requiring extension of posterior spinal fusion in one patient.

Furthermore, patients undergoing lateral interbody fusion for degenerative scoliosis and deformity experience good restoration of lumbar lordosis and reduction of scoliosis (2,76). In one prospective 3-year series published in 2013 by Caputo et al., (13) 30 patients treated by a single surgeon underwent XLIF with supplemental posterior instrumentation for the treatment of adult degenerative scoliosis. Patients in this study experienced significant improvement in the coronal Cobb angle (20.2 deg to 5.6 deg), apical vertebral translation (23.6 mm to 9.5 mm), disc height (4.8 mm to 10.4 mm), and neuroforaminal height and width (11.1 mm to 20.00 mm and 12.1 mm to 13.0 mm, respectively) from preoperative to postoperative scans. These changes persisted at an average follow-up time of 14.3 months. At one year, of 127 levels treated with XLIF, 112 (88.2%) demonstrated bony fusion on CT. 8 patients (26.6%) experienced complications, the most common of which were rupture of the anterior longitudinal ligament and wound breakdown with 2 patients experiencing each.

In another prospective, multicenter single-arm series published in 2013 by Phillips et al., (65) 107 patients with degenerative scoliosis underwent XLIF with or without supplemental posterior fixation. An average of 4.4 levels were treated per patient. At 24 month follow-up, 82 patients (77%) of patients were assessed and of these, 85% were satisfied and 86% reported they would repeat the surgery again if given the choice. Patient ODI improved by 21.5 and VAS back and leg scores improved by 3.4 and 3.5, respectively. SF=36 scores improved by 17.9 for the physical component summary and 13.5 for the mental component summary. 26 patients (24.3%) experienced complications, and the greatest predictor was the number of levels treated. 13 patients (12%) required at least 1 additional spinal surgical procedure within 24 months; only 2 (2%) required surgery for pseudoarthrosis of an XLIF-treated level, while 4 (4%) underwent additional surgery at adjacent segments, and 7 (7%) underwent additional posterior-only surgery for reasons unrelated to nonunion.

Although the technique is relatively new, evidence suggests that the XLIF is able to achieve high rates of fusion while minimizing morbidity. Patients most commonly experience transient leg weakness that self-resolves. Further investigation into the relative efficacy of this approach is warranted.

Cervical Decompression and Fusion

Minimally invasive techniques originally developed for lumbar spinal surgery have been adopted to a number of cervical procedures. Among the first reports was a study by Horgan in 1999\textsuperscript{33} in which two cadavers had simulated reduced, anteriorly displaced type II odontoid fractures. Using a guide wire, plastic sheath, and endoscopic guidance, bone screws were successfully placed for fixation. In 2006, a case report details the use of MIS for atlantoaxial fixation (39).

The feasibility of percutaneous or minimally-invasive placement of lateral mass screws was demonstrated by Wang
and Levi in 2006 in a series of 18 patients, during which two patients required conversion to open surgery (77). No other intraoperative complications occurred and follow-up CT demonstrated no gross bony violations; all patients in this study achieved bony fusion. However, some surgeons have advocated against the use of MIS techniques in posterior cervical procedures (20). Nonetheless, others argue that the use of guidewires and adequate soft tissue dilation may lessen the risks involved (60). One group demonstrated in cadavers the ability to place 41 of 42 total screws accurately using 3D fluoroscopy (31).

Microendoscopic laminoforaminotomy is among the better-studied cervical applications of MIS surgery. Fessler and Khoo first introduced the technique in 2002 in a series of 25 patients with cervical root compression from either stenosis or disc herniation who underwent microendoscopic foraminotomy (22). Compared to 26 control patients undergoing open cervical laminoforaminotomy, the MIS approach achieved equivalent clinical results; 92% of the patients had resolution or improvement of their radiculopathy, and 87% had resolution or improvement of their neck pain. The microendoscopic approach had less blood loss (138 mL vs. 246 mL per level), shorter postoperative stay (20 hrs vs. 68 hrs), and needed fewer narcotics (11 vs. 40 equivalents).

These findings were supported by randomized clinical trials; in 2008 an RCT of 175 patients undergoing either full endoscopic posterior foraminotomy or microsurgical anterior cervical discectomy for lateral disc herniations, clinical results were the same in both groups and there was no significant difference in revision or complication rates (69). In another RCT in 2009 of tubular retractor-assisted foraminotomy/discectomy (TAFD) vs. open foraminotomy/discectomy (OFD), (47) with 22 and 19 patients, respectively. Clinical outcomes were similar, but skin incision size, length of stay, analgesic using time, and postoperative neck pain were more favorable in the MIS (TAFD) group.

Outcomes of MIS anterior cervical discectomy and fusion (ACDF) were reported in 2009 by Ruetten et al., in a study in which they compared fully-endoscopic anterior cervical discectomy (FACD) with conventional ACDF for cervical disc herniations (68). Of 103 total patients, 49 were treated with ACDF and 54 were treated with endoscopic anterior cervical discectomy. Postoperatively, there were no significant differences in clinical outcomes between groups; 85.9% of patients had complete relief of pain postoperatively. The revision rate was found not to be different between groups (6.1% ACDF, 7.4% FACD). In a series of 67 cases of endoscopic anterior cervical discectomy and fusion with 5-year follow-up, (82) Yao et al. in 2011 reported that 86.6% had good or excellent clinical results, with demonstrated restoration of original intervertebral height and lordosis angle. There was a 100% fusion rate, and only one patient required revision with open ACDF at 6 years postoperatively due to an adjacent segment disc herniation. During this series, there were no intraoperative complications, dysphagia, or esophageal injury. Evaluation of the outcomes of cervical MIS is limited by the lack of published evidence – even more so than that for lumbar MIS. Further investigation in the form of high-level trials directly comparing MIS to conventional approaches to the cervical spine is warranted.

CONCLUSION

The rapid development of minimally-invasive spine surgery has outpaced the conduction of high-level scientific studies regarding its effectiveness compared to current leading standard-of-care therapies. While many promising MIS procedures are supported by some randomized trials and a preponderance of lower-level evidence, other less-favored MIS procedures, such as the laparoscopic anterior lumbar interbody fusion, demonstrated promise in initial studies as well. The continued development and incorporation of MIS techniques into the surgical lexicon has the potential to greatly benefit patients both in terms of perioperative course and overall clinical outcome; however, the excitement about this possibility must be tempered by the commitment to developing a useful and unbiased body of literature guiding the use of these new techniques.

REFERENCES


58. Ntoukas V, Müller A. Minimally invasive approach versus traditional open approach for one level posterior lumbar interbody fusion. Minim Invasive Neurosurg MIN 53:21–24, 2010


64. Peng CWB, Yue WM, Poh SY, Yeo W, Tan SB. Clinical and radiological outcomes of minimally invasive versus open transforaminal lumbar interbody fusion. Spine 34:1385–1389, 2009


