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REVIEW

Minimally invasive procedures on the lumbar spine

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Abstract

Degenerative disease of the lumbar spine is a common and increasingly prevalent condition that is often implicated as the primary reason for chronic low back pain and the leading cause of disability in the western world. Surgical management of lumbar degenerative disease has historically been approached by way of open surgical procedures aimed at decompressing and/or stabilizing the lumbar spine. Advances in technology and surgical instrumentation have led to minimally invasive surgical techniques being developed and increasingly used in the treatment of lumbar degenerative disease. Compared to the traditional open spine surgery, minimally invasive techniques require smaller incisions and decrease approach-related morbidity by avoiding muscle crush injury by self-retaining retractors, preventing the disruption of tendon attachment sites of important muscles at the spinous processes, using known anatomic neurovascular and muscle planes, and minimizing collateral soft-tissue injury by limiting the width of the surgical corridor. The theoretical benefits of minimally invasive surgery over traditional open surgery include reduced blood loss, decreased postoperative pain and narcotics use, shorter hospital length of stay, faster recover and quicker return to work and normal activity. This paper describes the different minimally invasive techniques that are currently available for the treatment of degenerative disease of the lumbar spine.

Key words: Minimally invasive surgery; Spine surgery; Lumbar spine; Degenerative disease; Interbody fusion; Posterolateral fusion; Decompression; Indirect decompression techniques

Core tip: Degenerative disease of the lumbar spine is a common and increasingly prevalent condition that is often implicated as the primary reason for chronic low back pain and the leading cause of disability in the western world. Compared to the traditional open spine surgery, minimally invasive techniques require smaller incisions and decrease approach-related morbidity. The benefits of minimally invasive surgery over traditional open surgery include reduced blood loss, decreased postoperative pain and narcotics use, shorter hospital length of stay, faster recovery and quicker return to work and normal activity.

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INTRODUCTION

Modern minimally invasive spine surgery (MIS) was introduced in the 1990s with the description of tubular retractors for access to the lumbar spine and the report of the first lumbar microendoscopic discectomy[1,2]. Since that time, advances in technology and surgical instrumentation have led to MIS developing into an important and rapidly growing filed of spine surgery. Today, MIS techniques and approaches are used in the treatment of a wide variety of spinal pathologies including degenerative disc disease, disc herniation, instability, deformity, fracture, infection and tumors[3]. Compared to the traditional open spine surgery, MIS was pursued as a means to reduce iatrogenic tissue trauma during surgery. The theoretical benefits of MIS over traditional open surgery include smaller incisions, less soft tissue damage, reduced estimated blood loss (EBL), decreased postoperative pain and narcotics use, shorter hospital length of stay (LOS), faster recover and quicker return to work and normal activity[4,5]. Traditional open spine surgery approaches often require extensive muscular and ligamentous disruption during the surgical approach to the spine resulting in decreased spinal stability and subsequent associated morbidities[6]. MIS minimizes approach-related morbidity by avoiding muscle crush injury by self-retaining retractors, preventing the disruption of tendon attachment sites of important muscles at the spinous processes, using known anatomic neurovascular and muscle planes, and minimizing collateral soft-tissue injury by limiting the width of the surgical corridor[7]. The decrease in the approach-related morbidity and indirect iatrogenic destabilization of the spine are important advantages of MIS over open spine surgery.

MIS approaches have been increasingly used in the treatment of degenerative diseases of the lumbar spine. As microsurgery, endoscopy and various percutaneous techniques advance and our rapidly aging population drives greater demand for spinal care, MIS will likely play an increasingly important role in the treatment of lumbar degenerative disease. This paper describes the different MIS techniques that are currently available for the treatment of degenerative disease of the lumbar spine.

MINIMALLY INVASIVE NON-FUSION PROCEDURES

MIS microdiscectomy

Lumbosacral nerve root compression or irritation secondary to an intervertebral disc herniation is a major cause of sciatica and low back pain. Patients with disc-related sciatica may be managed conservatively or *via* surgery when conservative treatment fails or symptoms worsen over time. It is estimated that over 250000 elective lumbar spine surgeries are performed in the United States each year for persistent symptoms of sciatica[8]. Of those, lumbar discectomy remains one of the most commonly performed procedures[9]. The goal of surgery is most commonly to remove intervertebral disc material and decompress the nerve root. Traditionally, the standard surgical treatment of lumbosacral disc herniation has been open microdiscectomy, however, with the rapid advances in surgical techniques and technology, there has been a growing trend towards MIS microdiscectomy.

An MIS microdiscectomy involves the use of serial tubular retractors to dilate the paraspinous musculature without stripping it off the spinous processes, and an endoscope or surgical microscope to visual the surgical field[10]. While the benefits of minimal soft tissue disruption appear to favor MIS microdiscectomy over open microdiscectomy, there is a significant learning curve associated with performing the procedure safely. Although many innovative techniques in the treatment of lumbar disc herniation have been developed, open microdiscectomy remains the standard of care at the current time[11].

A recent meta-analysis of controlled trials that compared outcomes of MIS and open microdiscectomy in patients with sciatica evaluated 29 studies (16 randomized controlled trials and 13 non-randomized studies) with a total of 4472 patients[11] (Table 1). Regarding clinical outcomes, the study found a moderate to low quality evidence of no differences between MIS and open microdiscectomy. Regarding perioperative outcomes, there was low to moderate evidence of no difference between MIS and open microdiscectomy; this was particularly notable for complications and reoperation rates. The study also found no significant difference in quality-adjusted life years (QALYs) or total costs from a societal perspective during the first year following treatment. The authors found low quality evidence that MIS took 10-15 min longer, resulted in a 52 cc reduction in EBL and reduced mean LOS by 1.5 d. The increased surgical time with MIS may be explained by the learning curve associated with MIS, variability in the techniques used and differences in how operative times were defined[11].

Currently, there is evidence from several comparative studies of MIS and open microdiscectomy suggesting that clinical outcomes between the two groups are similar. As surgeons become more proficient with MIS techniques and investigators conduct well-powered, randomized controlled trials, the indications favoring MIS microdiscectomy will be better defined.

MIS direct decompression

Lumbar spinal stenosis is the most common indication for spine surgery in patients older than 65, and its prevalence in the United States is expected to rise 59% by the year 2025[12]. Age-related degenerative changes

Table 1 Differences between outcomes of minimally invasive *vs* open surgical techniques

MIS techniques	Ref.	Differences in outcome compared to open techniques
Non-fusion techniques		
MIS microdiscectomy	Kamper *et al*[11]	Moderate to low evidence of no differences between MIS and open microdiscectomy
		No significant differences in QUALYs or total costs
		MIS took 10-15 min longer, resulted in 52 cc reduction in EBL and reduced mean LOS by 1.5 d
MIS direct decompression (Laminectomy/laminotomy)	Rahman *et al*[16]	Decreased EBL compared to open technique
		MIS procedures were 37-47 min shorter
		Decreased LOS by 2.52 d in patients undergoing decompression at ≤ 2 levels
		MIS had fewer complications (7.9% *vs* 16.1%)
	Anderson *et al*[17]	No significant differences in terms of ODI, Short-Form-12, and VAS
	Khoo *et al*[18]	Longer operative times in MIS group (109 min *vs* 88 min)
		Decreased EBL and postoperative stay in MIS group
	O'Toole *et al*[21]	0.10% surgical site infection rate
		Authors concluded that MIS technique may reduce SSI rate by 10-fold
MIS indirect decompression (Interspinous process devices)	Kuchta *et al*[26]	Statistically significant improvement in symptom severity and physical functioning throughout 2-yr follow-up period
	Bowers *et al*[27]	85% failure rate and 38% complication rate
	Brussee *et al*[28]	Poor outcome in 68.9% of patients
	Kim *et al*[29]	Cost analysis study found devices to be extremely costly and questioned cost-effectiveness
Fusion techniques		
Intertransverse onlay fusion	-	No literature available comparing MIS versus open posterolateral onlay fusion
Percutaneous pedicle screw fixation	Lehmann *et al*[34]1	EBL and muscle damage markers significantly lower in MIS group
		Compartment pressure, blood flow and EMG readings similar between both groups
		Radiation exposure greater in MIS group
MIS transforaminal lumbar interbody fusion	Seng *et al*[51]	Statistically increased fluoroscopic times (55.2 s *vs* 16.4 s) and operative times (185 min *vs* 166 min) in MIS group
		MIS had less EBL than open (127 cc *vs* 405 cc)
		Postoperative morphine use less in MIS group (8.5 mg *vs* 24.2 mg)
		Shorter LOS in MIS group (3.5 d *vs* 5.9 d)
	Parker *et al*[55]	MIS associated with reduction in mean hospital cost of $1758, indirect cost of $8474, total 2-yr social cost of $9295
		Similar 2-yr direct health care cost and QALYs gained
MIS direct lateral interbody fusion	Villavicencio *et al*[73]	Lower complication rate in MIS versus open (8.2% *vs* 16.7%)
	Rodgers *et al*[74]	Significantly lower complication rate in MIS cohort (7.5% *vs* 60%)
		Decreased EBL, lower transfusion rate and shorter LOS
	Deluzio *et al*[75]	Average LOS in MIS group 49% shorter
		Average cost savings for MIS group at 45 d of $2536/patient

[1]Animal study. MIS: Minimally invasive surgery; LOS: Length of stay; EBL: Estimated blood loss; ODI: Oswestry Disability Index; VAS: Visual analog scale; SSI: Surgical site infection; EMG: Electromyography; cc: Centimeter cubed; QALY: Quality adjusted life year.

in the lumbar spine such as hypertrophy of the facet joints with or without synovial cyst formation, foraminal stenosis due to decrease in the intervertebral disc height or osteophyte formation, ligamentum flavum thickening causing central and lateral recess compression and bulging or herniation of the intervertebral disc are all potential contributors to lumbar spinal stenosis. Surgery has been shown to decrease pain and improve functional status in patients with lumbar spinal stenosis[13]. Traditionally, an open midline approach involving a wide, bilateral laminectomy with medial facetectomy with or without foraminotomy has been the standard technique for surgical treatment of lumbar spinal stenosis. However, lumbar decompression surgery is increasingly being performed using tubular decompression, a MIS technique. This procedure utilizes a small paramedian incision and through the use of serial tubular dilators to reduce multifidus muscle injury while providing sufficient exposure of the surgical decompression site and allowing for bilateral decompression through a single incision[14]. Decompressing the contralateral side through a single unilateral paramedian incision allows the surgeon to spare the spinous process, rostral and caudal supraspinous and interspinous ligaments as well as the contralateral lamina and facet joint, thereby minimizing iatrogenic destabilization of the spine while achieving sufficient decompression for symptomatic relief. Furthermore, the use of an intraoperative endoscope or microscope for magnification and lighting allows for adequate visualization of the spinal anatomy[15].

Multiple studies have described shorter operating room times, decreased EBL, shorter LOS, lower surgical site infection rates, fewer complications and faster recovery times in MIS compared to the open lumbar decompression for spinal stenosis[16-20].

Rahman *et al*[16] retrospectively reviewed the medical records and relevant imaging of 126 patients (38 MIS *vs* 88 standard open technique) who underwent bilateral surgical decompression for lumbar stenosis to determine intraoperative EBL, length of operation, LOS, and number and nature of complications. On average, patients undergoing open procedures had 194 cc more EBL than patients undergoing MIS procedures, with the greatest difference in patients undergoing procedures involving ≥ 3 levels. MIS procedures were 37-47 min shorter than open procedures. Looking at the hospital LOS, the authors found that patients undergoing decompression at ≤ 2 levels had a LOS that was 2.52 d shorter in the MIS group. In terms of overall complications, the MIS group had fewer complications than the open group (7.9% *vs* 16.1%). However, one limitation of this study was that it did not evaluate long-term outcomes of the two procedures.

Anderson *et al*[17] performed a retrospective analysis of 110 patients in two matched cohorts to compare the tubular retractor approach and traditional midline approach to decompressive surgery for unilateral lumbar radiculopathy. The two approaches were evaluated based on patient reported outcomes using the Oswestry Disability Index (ODI), Short Form-12, and visual analog scale. The authors found no significant differences between the surgical approaches with respect to patient reported outcomes.

Khoo *et al*[18] compared 25 patients undergoing microendoscopic decompressive laminotomy to 25 patients undergoing open decompression for lumbar spinal stenosis. The authors found that effective circumferential decompression was achieved in the majority of patients in both groups. Surgery was longer for the MIS procedure group compared to the open group (109 min per single level *vs* 88 min per single level). EBL was reduced by 125 cc in the MIS group and postoperative stay was decreased 48 h, from 94 h in the open group to 42 h in the MIS group.

O'Toole *et al*[21] performed a retrospective review of prospectively collected data in 1274 patients undergoing MIS decompression and found a 0.10% rate of surgical site infection. The authors concluded that MIS techniques may reduce postoperative wound infections as much as 10-fold compared to open techniques.

At the current time, favorable complication profiles and patient outcome studies with MIS tubular decompression makes this technique an acceptable treatment option in the surgical management of lumbar spinal stenosis (Table 1). Studies assessing long-term outcomes and cost-utility of MIS *vs* open lumbar decompression are needed to further establish the value of MIS decompression.

MIS indirect decompression

Lumbar interspinous process devices (IPDs) are a MIS technology intended to unload the facet joints, restore foraminal height, lower intradiscal pressure, restricts overextension and provide motion-preserving stabilization[22]. IPDs are used in the treatment of degenerative lumbar spinal stenosis and intermittent neurogenic claudication where they provide indirect decompression to the neural structures[23]. They have also been used in the treatment of discogenic low back pain, facet syndrome, disc herniation and lumbar spinal instability[24]. In 2005, the United States Food and Drug Administration (FDA) approved the first ever IPD (X-STOP, Medtronic, Memphis, TN, United States) for the treatment of patients aged 50 or older suffering from neurogenic intermittent claudication secondary to a confirmed diagnosis of lumbar spinal stenosis. The device was indicated for those patients with moderately impaired physical function who experience relief in flexion from their symptoms of leg/buttock/groin pain, with or without back pain, and have undergone a regimen of at least 6 mo of non-operative treatment. The device may be implanted at one or two lumbar levels in patients in whom operative treatment is indicated at no more than two levels[25]. Since the FDA approval of the first IPD, a growing number of devices have been introduced to the spine implant market and used for a wide range of lumbar spinal pathologies, many of them outside of the intended indications.

Outcomes with the use of IPDs have thus far been inconsistent. Kuchta *et al*[26] reported on a single-center clinical outcomes of 175 patients with symptomatic lumbar spinal stenosis treated with X-STOP implantation and reported statistically significant ($P < 0.001$) improvements in symptom severity and physical functioning throughout the 2-year follow-up period. Bowers *et al*[27] reviewed complications associated with the use of X-STOP in 13 patients and found a 85% ultimate failure rate with patients requiring additional surgery for symptomatic relief. The authors also reported a 38% complications rate, including 3 spinous process fractures and 2 instances of new onset radiculopathy. Brussee *et al*[28] review 65 patients with neurogenic claudication who underwent placement of X-STOP device and found poor outcomes in 68.9% of patients.

Multiple studies have also reported high complication and reoperation rates following implantation of IPDs. Complication rates published in the literature range from 11.6% to 38% while reported reoperation rates range from 4.6% to 85%[26-31]. Epstein *et al*[23] reported on the cost of the treatment of 16 patients with a total of 31 X-STOP devices and found a total cost of $576407 charge for the devices alone plus an added $80944 charge for the operating/recovery room. The authors concluded that IPDs appear to be extremely costly and questioned the cost-effectiveness of these devices.

At the current time, there is evidence of poor long-term outcomes as well as high complication and reoperation rates following the use of IPDs for the treatment of degenerative lumbar conditions (Table 1). Studies on the cost-effectiveness and value of IPDs are currently lacking and are needed to determine the future faith of these devices.

MIS LUMBAR FUSION PROCEDURES

MIS posterolateral intertransverse onlay fusion without instrumentation

In the traditional posterior midline approach to the lumbar spine, access to the intertransverse region requires extensive stripping of the paraspinal musculature to the tips of the transverse processes. This process results in significant destruction, postoperative atrophy and scarring of the multifidus muscles which has been associated with significant postoperative morbidity[32]. For this reason, a MIS paraspinal muscle-splitting technique (modified Wiltse approach) using an expandable tubular dilator has become an increasingly popular technique used for exposure of the transverse processes and intertransverse space. The use of an expandable tubular retractor allows for both of the transverse processes and the fusion bed to be simultaneously exposed.

The theoretical advantages of this MIS technique are decreased paraspinal muscle destruction, decreased surgical incision size, decreased EBL, decreased postoperative narcotic use and shorter LOS. However, there are no studies in the literature comparing outcomes or cost-effectiveness of lumbar intertransverse onlay fusion utilizing the MIS muscle-splitting approach compared to the traditional open approach (Table 1).

MIS percutaneous pedicle screw fixation

Pedicle screw fixation allows for the creation of a solid and biomechanically rigid construct that allows for fusion to occur at the intended levels. Traditionally, open midline incisions were utilized for exposure of the spine in preparation for pedicle screw placement. Open procedures require extensive tissue dissection to expose the entry points and provide adequate lateral-to-medial orientation for optimal screw trajectory. This dissection in turn may result in muscular denervation, facet capsule disruption, damage to the proximal facet joints and weakening of other ligamentous structures, resulting in prolonged post-operative pain and morbidity[33]. Open lumbar fusion procedures are associated with increased operative times, increased EBL and risk of postoperative surgical site infection[34]. LOS and cost of treatment are also adversely affected by open pedicle screw fixation and spinal fusion techniques[35]. Recently, MIS percutaneous pedicle screw fixation has become an increasingly popular MIS technique for lumbar spine fixation[36-38]. Percutaneous pedicle screw placement offers several distinct advantages over the traditional open approach. It eliminates the need for a midline incision and extensive paraspinal muscle dissection. Kim *et al*[38] revealed that percutaneous *vs* open instrumentation was associated with decreased multifidus muscle atrophy, a superior postoperative trunk muscle strength, lower blood loss and less postoperative narcotic use. However, the authors did not find an improved clinical outcome in terms of patient satisfaction and pain scores. Muscle damage is also related to direct compression by muscle retractors, which result in ischemia of the compressed muscle groups and can lead to postoperative muscle necrosis. Percutaneous pedicle screw placement allows the surgeon to more easily achieve an ideal lateral-to-medial trajectory, especially advantageous in obese patients. The advantage of a minimally traumatic access to the lumbar spine carries the disadvantages of longer operative times and increased radiation exposure, both dependent on surgeon experience and comfort level.

Several authors have demonstrated reduced intraoperative EBL, perioperative risk of transfusion, improved cosmesis, decreased post-operative pain and narcotic use, decreased LOS, faster return to activity and reduced overall costs[39-43]. To date, however, there exists no high-quality literature to support the notion that MIS pedicle screw instrumentation is superior to the traditional open technique. Most of the studies evaluating open *vs* percutaneous pedicle techniques do so in context of interbody fusion techniques with no study directly evaluating the two instrumentation techniques alone. Lehmann *et al*[34] compared open *vs* percutaneous pedicle screw insertion in a sheep model and found that EBL and muscle damage markers were significantly lower in the percutaneous group while radiation time was significantly longer in the percutaneous group. In terms of compartment pressure, blood flow and electromyography measurements at different time points during the operative procedure, no significant differences were revealed.

Many technical challenges unique to the percutaneous pedicle screw placement technique and a steep learning curve exists, requiring different technical, psychomotor and cognitive skills. Mobbs *et al*[44] noted several challenges in percutaneous screw placement including changing direction of screw placement following initial pedicle cannulation, L5/S1 screw head proximity, cannulation of small pedicles, skin incision selection and insertion of rod for multi-segmental fixation, and difficult Jamshidi placement in hard pedicles. Surgeon experience plays a key role in perioperative outcomes of MIS techniques. It is recommended that surgeons have adequate experience with open techniques before attempting MIS fixation techniques and that they begin with simple MIS procedures[44].

Despite all the encouraging clinical data (Table 1), prospective outcomes studies with long-term follow up comparing percutaneous instrumented fusion to conventional open instrumented fusion are required to determine the safety, effectiveness and clinical benefit of MIS spinal fixation.

MIS transforaminal lumbar interbody fusion

The TLIF is a versatile surgical procedure modified from the posterior lumbar interbody fusion (PLIF) and pioneered by Harms and Rolinger in 1982[45]. Transforaminal lumbar interbody fusion (TLIF) utilizes the principles of load sharing to provide a circumferential fusion consisting of an anterior column support and a posterior tension band. It is designed to restore lumbar lordosis, widen neural foramina, restore disc height and indirectly relieve spinal stenosis. TLIF has been effective in the treatment of lumbar spondylosis with or without spondylolisthesis and has also been used successfully in the treatment of lumbar degenerative disc disease, recurrent lumbar disc herniation and complex lumbar stenosis. One of the main disadvantages to TLIF is the significant postoperative morbidity due to the extensive paraspinal muscle and soft tissue dissection and retraction required in order to provide access to the vertebral column. This approach-related morbidity can potentially affect short- and long-term patient outcomes due to increased postoperative pain, delayed rehabilitation and impaired spinal function.

MIS TLIF was first described by Foley *et al*[46] in 2003 and has since become an increasingly popular MIS method to achieve lumbar arthrodesis[47-50]. MIS TLIF has been shown to have short- and long-term clinical outcomes comparable to open TLIF with the additional benefits of decreased postoperative pain, decreased EBL, faster recovery times, reduced postoperative narcotic use, faster postoperative ambulation and shorter LOS[51-54] (Table 1).

Seng *et al*[51] retrospectively analyzed 40 cases of MIS TLIF compared to 40 open TLIFs and compared fluoroscopic times, operative times, EBL, LOS, postoperative narcotic use, complication rates and patient outcomes. The authors found a statistically significant increase in fluoroscopic times in the MIS TLIF group (MIS: 55.2 s, open 16.4 s, $P < 0.001$) as well as a statistically insignificant increase in operative times for the MIS TLIF group (MIS: 185 min, open: 166 min, $P = 0.085$). MIS had less EBL than open (127 cc *vs* 405 cc, $P < 0.001$). Postoperative morphine use for the MIS group was significantly less than the open group (8.5 mg *vs* 24.2 mg, $P = 0.006$). The authors also found that patient in the MIS TLIF group ambulated on average 1.5 d earlier ($P < 0.001$) and had an overall shorter LOS (MIS: 3.6 d, open: 5.9 d, $P < 0.001$). The overall complication rate was 15% for the MIS group and 20% for the open group, however this did not reach statistical significance ($P = 0.774$). Fusion rates, assessed by the Bridwell classification, showed that grade 1 fusion was achieved in 97.5% of both groups at 5 years. Both groups showed significant improvement in ODI, neurogenic symptom score, back and leg pain and SF-36 scores at follow-ups of 6 mo up to 5 years with no significant differences between them.

Parker *et al*[55] prospectively evaluated 100 patients undergoing TLIF (50 MIS *vs* 50 open) for back-related medical resource use, missed work, and QALY. The authors found that LOS and time to return to work were less for MIS compared to open TLIF ($P = 0.006$ and $P = 0.03$, respectively). MIS and open TLIF patients demonstrated similar improvements in patient-reported outcomes assessed. MIS was associated with a reduction in mean hospital cost of $1758, indirect cost of $8474, and total 2-year social cost of $9295 ($P = 0.03$), but similar 2-year direct health care cost and QALYs gained. The authors concluded that while both MIS and open TLIF are effective treatments for degenerative spondylolisthesis, MIS TLIF may represent a valuable and cost-saving advancement from a societal and hospital perspective.

Disadvantages of the MIS TLIF are related to the decreased visualization of the surgical field and a steep learning curve for the procedure resulting in increased fluoroscopic times and operative times which may be more significant in less experienced surgeons.

MIS direct lateral approaches

The lateral transpsoas, retroperitoneal approach, also known as extreme lateral interbody fusion (XLIF) or direct lateral interbody fusion (DLIF) is a minimally invasive technique that has become an increasingly common method to achieve fusion in the lumbar spine. This MIS approach was intially described in by Pimenta[56] (DLIF) in 2001, and later by Ozgur *et al*[57] (XLIF) in 2006. The MIS direct lateral approach differs from the traditional anterior lumbar interbody fusion (ALIF) and open posterior interbody fusion techniques in several important ways. In addition to being an MIS technique, the direct lateral approach requires the patient to be in the lateral decubitus position. The technique utilizes specialized retractors allowing for direct visualization of the surgical approach corridor. Continual neurophysiologic monitoring and fluoroscopic guidance during the approach phase of the procedure is necessary as the psoas splitting technique exposes the lumbar plexus and predisposes it to injury, which can result in psoas muscle weakness and thigh numbness[58,59].

Initial studies evaluating the safety and postoperative results of the MIS transpsoas approach concluded that the MIS technique was safe and allowed for exposure of the lumbar spine without mobilization of the great vessels or sympathetic plexus[60,61].

Smith *et al*[62] compared the long term outcome of XLIF compared to ALIF in a group of 202 patients (115 XLIF *vs* 87 ALIF) and found that the overall general surgical complication rate was significantly lower for XLIF compared to ALIF (8.2% *vs* 16.7%). Rodgers *et al*[63] described the complications in a large prospective series of 600 patients who underwent XLIF. The authors found the overall incidence of perioperative complications was 6.2% (1.5% in-hospital surgery-related, 2.8% in-hospital medical events, 1.0% out-of-hospital surgery-related, and 0.8% out-of-hospital medical events). There were no wound infections, no vascular injuries, no intraperitoneal visceral injuries and a 0.7% transient postoperative neurologic deficit rate. These complication rates compared favorably to the ALIF risk of vascular injury (1.9%-3%)[64-66]. Another major risk of open ALIF approach is retrograde ejaculation, occurring in 0.6%-4.5% of men[67]. There are currently no reports of retrograde ejaculation following %g MIS lateral interbody fusion which can be attributed to the fact that the sympathetic plexus is not mobilized during the transpsoas approach. Motor deficits after MIS lateral interbody fusion have been reported to range from 0.3%-2.9% with the majority of cases resolving spontaneously within three months[63,68,69]. These rates are comparable to the reported motor deficit rates after PLIF (1.0%-6.1%) and MIS TLIF (4.1%) procedures[70-73].

Rodgers *et al*[74] retrospectively compared lumbar fusion outcomes in geriatric patients over 80 years of age who underwent XLIF or open PLIF. The authors observed a significantly lower complication rate in the XLIF group compared to the open TLIF group (7.5% *vs* 60%) we well as less blood loss (hemoglobin change, 1.4 g *vs* 2.7 g), a lower transfusion rate (0% *vs* 70%) and shorter LOS (1.3 d *vs* 5.3 d). The authors also described a lower overall mortality rate in the lateral interbody group compared to the open PLIF group (2.5% *vs* 30%).

Deluzio *et al*[75] retrospectively reviewed 210 patients (109 MIS *vs* 101 open) who underwent 2-level lumbar spine fusion from L1-2 to L4-5. They found the average LOS in the MIS group to be 49% shorter than in the open group (1.2 d *vs* 3.2 d). The authors noted that the average cost for the entire perioperative period, including both surgical and post-surgical costs out to 45 d, showed an average savings of 9.6% or $2563/patient in the MIS group.

The MIS lateral interbody fusion appears to present a safe and effective technique for treating degenerative lumbar disorders (Table 1). Long-term outcome studies and cost-analysis and value studies are needed to further clarify the benefits of this MIS approach.

CONCLUSION

In the recent years, there has been a growing trend in MIS approaches for the treatment of degenerative diseases of the lumbar spine. Although traditional open approaches are still performed by the majority of spine surgeons, the body of evidence supporting the safety and efficacy of MIS approaches in appropriately selected patients is growing. MIS approaches for lumbar microdiscectomy, laminectomy, and lumbar interbody fusion by way of the transforaminal or direct lateral approach have shown favorable complication profiles and clinical outcomes compared to traditional open approaches. MIS interspinous process devices have shown poor long-term outcomes as well as high complication and reoperation rates.

While the disadvantages of MIS techniques are the steep learning curve, narrow operative corridor and diminished visual field, these are outweighed by the benefits of MIS techniques in many instances. Going forward, long-term outcome studies and cost-effectiveness studies will be needed to fully assess the benefits of MIS techniques for treating degenerative disease of the lumbar spine.

REFERENCES

1 **Faubert C**, Caspar W. Lumbar percutaneous discectomy. Initial experience in 28 cases. *Neuroradiology* 1991; **33**: 407-410 [PMID: 1749470 DOI: 10.1007/BF00598613]

2 **Foley KT**, Smith MM. Microendoscopic discectomy. *Tech Neurosurg* 1997; **3**: 301-307

3 **American Academy of Neurological Surgeons.** Minimally Invasive Spine Surgery (MIS). Patient Information. [accessed 2014 July 25]. Available from: URL: http: //www.aans.org/Patient Information/Conditions and Treatments/Minimally Invasive Spine Surgery MIS.aspx

4 **Society for Minimally Invasive Spine Surgery.** Benefits and Testimonials. [accessed 2014 June 24]. Available from: URL: http: //www.smiss.org/benefits-and-testimonials

5 **Barbagallo GM**, Yoder E, Dettori JR, Albanese V. Percutaneous minimally invasive versus open spine surgery in the treatment of fractures of the thoracolumbar junction: a comparative effectiveness review. *Evid Based Spine Care J* 2012; **3**: 43-49 [PMID: 23526905 DOI: 10.1055/s-0032-1327809]

6 **Snyder LA**, O'Toole J, Eichholz KM, Perez-Cruet MJ, Fessler R. The technological development of minimally invasive spine surgery. *Biomed Res Int* 2014; **2014**: 293582 [PMID: 24967347 DOI: 10.1155/2014/293582]

7 **Kim CW**, Siemionow K, Anderson DG, Phillips FM. The current state of minimally invasive spine surgery. *Instr Course Lect* 2011; **60**: 353-370 [PMID: 21553786]

8 **Atlas SJ**, Chang Y, Kammann E, Keller RB, Deyo RA, Singer DE. Long-term disability and return to work among patients who have a herniated lumbar disc: the effect of disability compensation. *J Bone Joint Surg Am* 2000; **82**: 4-15 [PMID: 10653079]

9 **Dewing CB**, Provencher MT, Riffenburgh RH, Kerr S, Manos RE. The outcomes of lumbar microdiscectomy in a young, active population: correlation by herniation type and level. *Spine* (Phila Pa 1976) 2008; **33**: 33-38 [PMID: 18165746 DOI: 10.1097/BRS.0b013e31815e3a42]

10 **Lau D**, Han SJ, Lee JG, Lu DC, Chou D. Minimally invasive compared to open microdiscectomy for lumbar disc herniation. *J Clin Neurosci* 2011; **18**: 81-84 [PMID: 20851604 DOI: 10.1016/j.jocn.2010.04.040]

11 **Kamper SJ**, Ostelo RW, Rubinstein SM, Nellensteijn JM, Peul WC, Arts MP, van Tulder MW. Minimally invasive surgery for lumbar disc herniation: a systematic review and meta-analysis. *Eur Spine J* 2014; **23**: 1021-1043 [PMID: 24442183 DOI: 10.1007/s00586-013-316-2]

12 **Bae HW**, Rajaee SS, Kanim LE. Nationwide trends in the surgical management of lumbar spinal stenosis. *Spine* (Phila Pa 1976) 2013; **38**: 916-926 [PMID: 23324922 DOI: 10.1097/BRS.0b013e3182833e7c]

13 **Atlas SJ**, Keller RB, Robson D, Deyo RA, Singer DE. Surgical and nonsurgical management of lumbar spinal stenosis: four-year outcomes from the maine lumbar spine study. *Spine* (Phila Pa 1976) 2000; **25**: 556-562 [PMID: 10749631 DOI: 10.1097/00007632-200003010-00005]

14 **Alimi M**, Hofstetter CP, Torres JM, Cong GT, Njoku I, Hartl R. Unilateral tubular approach for bilateral laminectomy: effect on ipsilateral and contralateral buttock and leg pain. *Global Spine J* 2014; **4:** 149 [DOI: 10.1055/s-0034-1376720]

15 **Rihn JA**, Currier BL, Phillips FM, Glassman SD, Albert TJ. Defining the value of spine care. *J Am Acad Orthop Surg* 2013; **21**: 419-426 [PMID: 23818029 DOI: 10.5435/JAAOS-21-07-419]

16 **Rahman M**, Summers LE, Richter B, Mimran RI, Jacob RP. Comparison of techniques for decompressive lumbar laminectomy: the minimally invasive versus the „classic" open approach. *Minim Invasive Neurosurg* 2008; **51**: 100-105 [PMID: 18401823 DOI: 10.1055/s-2007-1022542]

17 **Anderson DG**, Patel A, Maltenfort M, Vaccaro AR, Ratliff J, Hilibrand A, Harrop JS, Sharan AD, Ponnappan RK, Rihn J, Albert TJ. Lumbar decompression using a traditional midline approach versus a tubular retractor system: comparison of patient-based clinical outcomes. *Spine* (Phila Pa 1976) 2011; **36**: E320-E325 [PMID: 21178844 DOI: 10.1097/BRS.0b013e3181db1dfb]

18 **Khoo LT**, Fessler RG. Microendoscopic decompressive laminotomy for the treatment of lumbar stenosis. *Neurosurgery* 2002; **51**: S146-S154 [PMID: 12234442]

19 **Asgarzadie F**, Khoo LT. Minimally invasive operative

management for lumbar spinal stenosis: overview of early and long-term outcomes. *Orthop Clin North Am* 2007; **38**: 387-399; abstract vi-vii [PMID: 17629986 DOI: 10.1016/j.ocl.2007.02.006]
20 **Palmer S**, Turner R, Palmer R. Bilateral decompression of lumbar spinal stenosis involving a unilateral approach with microscope and tubular retractor system. *J Neurosurg* 2002; **97**: 213-217 [PMID: 12296681]
21 **O'Toole JE**, Eichholz KM, Fessler RG. Surgical site infection rates after minimally invasive spinal surgery. *J Neurosurg Spine* 2009; **11**: 471-476 [PMID: 19929344 DOI: 10.3171/2009.5.SPINE08633]
22 **Tian NF**, Zhang XL, Wu YS, Jiang LB, Xu HZ, Chi YL. Fusion after interspinous device placement. *Orthopedics* 2012; **35**: e1822-e1825 [PMID: 23218645 DOI: 10.3928/01477447-20121120-33]
23 **Epstein NE**. A review of interspinous fusion devices: High complication, reoperation rates, and costs with poor outcomes. *Surg Neurol Int* 2012; **3**: 7 [PMID: 22347676 DOI: 10.4103/2152-7806.92172]
24 **Bono CM**, Vaccaro AR. Interspinous process devices in the lumbar spine. *J Spinal Disord Tech* 2007; **20**: 255-261 [PMID: 17473649 DOI: 10.1097/BSD.0b013e3180331352]
25 **US Food and Drug Administration.** Medical Devices. X STOP® Interspinous Process Decompression System (XSTOP) – P040001. [accessed 2014 September 20]. Available from: URL: http: //www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/DeviceApprovalsandClearances/Recently-ApprovedDevices/ucm078378.htm
26 **Kuchta J**, Sobottke R, Eysel P, Simons P. Two-year results of interspinous spacer (X-Stop) implantation in 175 patients with neurologic intermittent claudication due to lumbar spinal stenosis. *Eur Spine J* 2009; **18**: 823-829 [PMID: 19387698 DOI: 10.1007/s00586-009-0967-z]
27 **Bowers C**, Amini A, Dailey AT, Schmidt MH. Dynamic interspinous process stabilization: review of complications associated with the X-Stop device. *Neurosurg Focus* 2010; **28**: E8 [PMID: 20568923 DOI: 10.3171/2010.3.FOCUS1047]
28 **Brussee P**, Hauth J, Donk RD, Verbeek AL, Bartels RH. Self-rated evaluation of outcome of the implantation of interspinous process distraction (X-Stop) for neurogenic claudication. *Eur Spine J* 2008; **17**: 200-203 [PMID: 17972111 DOI: 10.1007/s00586-007-0540-6]
29 **Kim DH**, Tantorski M, Shaw J, Martha J, Li L, Shanti N, Rencu T, Parazin S, Kwon B. Occult spinous process fractures associated with interspinous process spacers. *Spine* (Phila Pa 1976) 2011; **36**: E1080-E1085 [PMID: 21343860 DOI: 10.1097/BRS.0b013e318204066a]
30 **Verhoof OJ**, Bron JL, Wapstra FH, van Royen BJ. High failure rate of the interspinous distraction device (X-Stop) for the treatment of lumbar spinal stenosis caused by degenerative spondylolisthesis. *Eur Spine J* 2008; **17**: 188-192 [PMID: 17846801 DOI: 10.1007/s00586-007-0492-x]
31 **Barbagallo GM**, Olindo G, Corbino L, Albanese V. Analysis of complications in patients treated with the X-Stop Interspinous Process Decompression System: proposal for a novel anatomic scoring system for patient selection and review of the literature. *Neurosurgery* 2009; **65**: 111-119; discussion 119-120 [PMID: 19574832 DOI: 10.1227/01.NEU.0000346254.07116.31]
32 **Motosuneya T**, Asazuma T, Tsuji T, Watanabe H, Nakayama Y, Nemoto K. Postoperative change of the cross-sectional area of back musculature after 5 surgical procedures as assessed by magnetic resonance imaging. *J Spinal Disord Tech* 2006; **19**: 318-322 [PMID: 16826001 DOI: 10.1097/01.bsd.0000211205.15997.06]
33 **Stokes IA**, Gardner-Morse M, Henry SM, Badger GJ. Decrease in trunk muscular response to perturbation with preactivation of lumbar spinal musculature. *Spine* (Phila Pa 1976) 2000; **25**: 1957-1964 [PMID: 10908940]
34 **Lehmann W**, Ushmaev A, Ruecker A, Nuechtern J, Grossterlinden L, Begemann PG, Baeumer T, Rueger JM, Briem D. Comparison of open versus percutaneous pedicle screw insertion in a sheep model. *Eur Spine J* 2008; **17**: 857-863 [PMID: 18389291 DOI: 10.1007/s00586-008-0652-7]
35 **Foley KT**, Gupta SK. Percutaneous pedicle screw fixation of the lumbar spine: preliminary clinical results. *J Neurosurg* 2002; **97**: 7-12 [PMID: 12120655]
36 **Lowery GL**, Kulkarni SS. Posterior percutaneous spine instrumentation. *Eur Spine J* 2000; **9** Suppl 1: S126-S130 [PMID: 10766069]
37 **Teitelbaum GP**, Shaolian S, McDougall CG, Preul MC, Crawford NR, Sonntag VK. New percutaneously inserted spinal fixation system. *Spine* (Phila Pa 1976) 2004; **29**: 703-709 [PMID: 15014282]
38 **Kim DH**, Albert TJ. Update on use of instrumentation in lumbar spine disorders. *Best Pract Res Clin Rheumatol* 2002; **16**: 123-140 [PMID: 11987935]
39 **Weber BR**, Grob D, Dvorák J, Müntener M. Posterior surgical approach to the lumbar spine and its effect on the multifidus muscle. *Spine* (Phila Pa 1976) 1997; **22**: 1765-1772 [PMID: 9259789 DOI: 10.1097/00007632-199708010-00017]
40 **Harris EB**, Massey P, Lawrence J, Rihn J, Vaccaro A, Anderson DG. Percutaneous techniques for minimally invasive posterior lumbar fusion. *Neurosurg Focus* 2008; **25**: E12 [PMID: 18673041 DOI: 10.3171/FOC/2008/25/8/E12]
41 **Hsieh PC**, Koski TR, Sciubba DM, Moller DJ, O'Shaughnessy BA, Li KW, Gokaslan ZL, Ondra SL, Fessler RG, Liu JC. Maximizing the potential of minimally invasive spine surgery in complex spinal disorders. *Neurosurg Focus* 2008; **25**: E19 [PMID: 18673048 DOI: 10.3171/FOC/2008/25/8/E19]
42 **Assaker R**. Minimal access spinal technologies: state-of-the-art, indications, and techniques. *Joint Bone Spine* 2004; **71**: 459-469 [PMID: 15589424 DOI: 10.1016/j.jbspin.2004.08.006]
43 **Kerr SM**, Tannoury C, White AP, Hannallah D, Mendel RC, Anderson DG. The role of minimally invasive surgery in the lumbar spine. *Operative Techniques in Orthopaedics* 2007; **17**: 183-189 [DOI: 10.1053/j.oto.2007.04.005]
44 **Mobbs RJ**, Sivabalan P, Li J. Technique, challenges and indications for percutaneous pedicle screw fixation. *J Clin Neurosci* 2011; **18**: 741-749 [PMID: 21514165 DOI: 10.1016/j.jocn.2010.09.019]
45 **Harms J**, Rolinger H. [A one-stager procedure in operative treatment of spondylolistheses: dorsal traction-reposition and anterior fusion (author's transl)]. *Z Orthop Ihre Grenzgeb* 1982; **120**: 343-347 [PMID: 7113376 DOI: 10.1055/s-2008-1051624]
46 **Foley KT**, Holly LT, Schwender JD. Minimally invasive lumbar fusion. *Spine* (Phila Pa 1976) 2003; **28**: S26-S35 [PMID: 12897471 DOI: 10.1097/01.BRS.0000076895.52418.5E]
47 **Isaacs RE**, Podichetty VK, Santiago P, Sandhu FA, Spears J, Kelly K, Rice L, Fessler RG. Minimally invasive microendoscopy-assisted transforaminal lumbar interbody fusion with instrumentation. *J Neurosurg Spine* 2005; **3**: 98-105 [PMID: 16370298 DOI: 10.3171/spi.2005.3.2.0098]
48 **Jang JS**, Lee SH. Minimally invasive transforaminal lumbar interbody fusion with ipsilateral pedicle screw and contralateral facet screw fixation. *J Neurosurg Spine* 2005; **3**: 218-223 [PMID: 16235705 DOI: 10.3171/spi.2005.3.3.0218]
49 **Mummaneni PV**, Rodts GE. The mini-open transforaminal lumbar interbody fusion. *Neurosurgery* 2005; **57**: 256-261; discussion 256-261 [PMID: 16234672 DOI: 10.1227/01.NEU.0000176408.95304.F3]
50 **Ozgur BM**, Yoo K, Rodriguez G, Taylor WR. Minimally-invasive technique for transforaminal lumbar interbody fusion (TLIF). *Eur Spine J* 2005; **14**: 887-894 [PMID: 16151713 DOI: 10.1007/s00586-005-0941-3]
51 **Seng C**, Siddiqui MA, Wong KP, Zhang K, Yeo W, Tan SB, Yue WM. Five-year outcomes of minimally invasive versus open transforaminal lumbar interbody fusion: a matched-pair comparison study. *Spine* (Phila Pa 1976) 2013; **38**: 2049-2055 [PMID: 23963015 DOI: 10.1097/BRS.0b013e3182a8212d]

52 **Lee KH**, Yue WM, Yeo W, Soeharno H, Tan SB. Clinical and radiological outcomes of open versus minimally invasive transforaminal lumbar interbody fusion. *Eur Spine J* 2012; **21**: 2265-2270 [PMID: 22453894 DOI: 10.1007/s00586-012-2281-4]
53 **Peng CW**, Yue WM, Poh SY, Yeo W, Tan SB. Clinical and radiological outcomes of minimally invasive versus open transforaminal lumbar interbody fusion. *Spine* (Phila Pa 1976) 2009; **34**: 1385-1389 [PMID: 19478658 DOI: 10.1097/BRS.0b013e3181a4e3be]
54 **Adogwa O**, Parker SL, Bydon A, Cheng J, McGirt MJ. Comparative effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion: 2-year assessment of narcotic use, return to work, disability, and quality of life. *J Spinal Disord Tech* 2011; **24**: 479-484 [PMID: 21336176 DOI: 10.1097/BSD.0b013e3182055cac]
55 **Parker SL**, Mendenhall SK, Shau DN, Zuckerman SL, Godil SS, Cheng JS, McGirt MJ. Minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis: comparative effectiveness and cost-utility analysis. *World Neurosurg* 2014; **82**: 230-238 [PMID: 23321379 DOI: 10.1016/j.wneu.2013.01.041]
56 **Pimenta L.** Lateral endoscopic transpsoas retroperitoneal approach for lumbar spine surgery. VIII Brazilian Spine Society Meeting. Brazil: Belo Horizonte, Minas Gerais, 2001
57 **Ozgur BM**, Aryan HE, Pimenta L, Taylor WR. Extreme Lateral Interbody Fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. *Spine J* 2006; **6**: 435-443 [PMID: 16825052 DOI: 10.1016/j.spinee.2005.08.012]
58 **Knight RQ**, Schwaegler P, Hanscom D, Roh J. Direct lateral lumbar interbody fusion for degenerative conditions: early complication profile. *J Spinal Disord Tech* 2009; **22**: 34-37 [PMID: 19190432 DOI: 10.1097/BSD.0b013e3181679b8a]
59 **Benglis DM**, Vanni S, Levi AD. An anatomical study of the lumbosacral plexus as related to the minimally invasive transpsoas approach to the lumbar spine. *J Neurosurg Spine* 2009; **10**: 139-144 [PMID: 19278328 DOI: 10.3171/2008.10.SPI08479]
60 **Malham GM**, Ellis NJ, Parker RM, Seex KA. Clinical outcome and fusion rates after the first 30 extreme lateral interbody fusions. *Scientific World Journal* 2012; **2012**: 246989 [PMID: 23213282 DOI: 10.1100/2012/246989]
61 **Bergey DL**, Villavicencio AT, Goldstein T, Regan JJ. Endoscopic lateral transpsoas approach to the lumbar spine. *Spine* (Phila Pa 1976) 2004; **29**: 1681-1688 [PMID: 15284517 DOI: 10.1097/01.BRS.0000133643.75795.EF]
62 **Smith WD**, Christian G, Serrano S, Malone KT. A comparison of perioperative charges and outcome between open and mini-open approaches for anterior lumbar discectomy and fusion. *J Clin Neurosci* 2012; **19**: 673-680 [PMID: 22236486 DOI: 10.1016/j.jocn.2011.09.010]
63 **Rodgers WB**, Gerber EJ, Patterson J. Intraoperative and early postoperative complications in extreme lateral interbody fusion: an analysis of 600 cases. *Spine* (Phila Pa 1976) 2011; **36**: 26-32 [PMID: 21192221 DOI: 10.1097/BRS.0b013e3181e1040a]
64 **Sasso RC**, Best NM, Mummaneni PV, Reilly TM, Hussain SM. Analysis of operative complications in a series of 471 anterior lumbar interbody fusion procedures. *Spine* (Phila Pa 1976) 2005; **30**: 670-674 [PMID: 15770183 DOI: 10.1097/01.brs.0000155423.18218.75]
65 **Fantini GA**, Pappou IP, Girardi FP, Sandhu HS, Cammisa FP. Major vascular injury during anterior lumbar spinal surgery: incidence, risk factors, and management. *Spine* (Phila Pa 1976) 2007; **32**: 2751-2758 [PMID: 18007256 DOI: 10.1097/BRS.0b013e31815a996e]
66 **Brau SA**, Delamarter RB, Schiffman ML, Williams LA, Watkins RG. Vascular injury during anterior lumbar surgery. *Spine J* 2004; **4**: 409-412 [PMID: 15246301 DOI: 10.1016/j.spinee.2003.12.003]
67 **Sasso RC**, Kenneth Burkus J, LeHuec JC. Retrograde ejaculation after anterior lumbar interbody fusion: transperitoneal versus retroperitoneal exposure. *Spine* (Phila Pa 1976) 2003; **28**: 1023-1026 [PMID: 12768143 DOI: 10.1097/01.BRS.0000062965.47779.EB]
68 **Pumberger M**, Hughes AP, Huang RR, Sama AA, Cammisa FP, Girardi FP. Neurologic deficit following lateral lumbar interbody fusion. *Eur Spine J* 2012; **21**: 1192-1199 [PMID: 22130617 DOI: 10.1007/s00586-011-2087-9]
69 **Youssef JA**, McAfee PC, Patty CA, Raley E, DeBauche S, Shucosky E, Chotikul L. Minimally invasive surgery: lateral approach interbody fusion: results and review. *Spine* (Phila Pa 1976) 2010; **35**: S302-S311 [PMID: 21160394 DOI: 10.1097/BRS.0b013e3182023438]
70 **Okuda S**, Miyauchi A, Oda T, Haku T, Yamamoto T, Iwasaki M. Surgical complications of posterior lumbar interbody fusion with total facetectomy in 251 patients. *J Neurosurg Spine* 2006; **4**: 304-309 [PMID: 16619677 DOI: 10.3171/spi.2006.4.4.304]
71 **Krishna M**, Pollock RD, Bhatia C. Incidence, etiology, classification, and management of neuralgia after posterior lumbar interbody fusion surgery in 226 patients. *Spine J* 2008; **8**: 374-379 [PMID: 17433779 DOI: 10.1016/j.spinee.2006.09.004]
72 **Kim KT**, Lee SH, Lee YH, Bae SC, Suk KS. Clinical outcomes of 3 fusion methods through the posterior approach in the lumbar spine. *Spine* (Phila Pa 1976) 2006; **31**: 1351-1357; discussion 1358 [PMID: 16721298 DOI: 10.1097/01.brs.0000218635.14571.55]
73 **Villavicencio AT**, Burneikiene S, Bulsara KR, Thramann JJ. Perioperative complications in transforaminal lumbar interbody fusion versus anterior-posterior reconstruction for lumbar disc degeneration and instability. *J Spinal Disord Tech* 2006; **19**: 92-97 [PMID: 16760781 DOI: 10.1097/01.bsd.0000185277.14484.4e]
74 **Rodgers WB**, Gerber EJ, Rodgers JA. Lumbar fusion in octogenarians: the promise of minimally invasive surgery. *Spine* (Phila Pa 1976) 2010; **35**: S355-S360 [PMID: 21160400 DOI: 10.1097/BRS.0b013e3182023796]
75 **Deluzio KJ**, Lucio JC, Rodgers WB. Value and cost in less invasive spinal fusion surgery: Lessons from a community hospital. *SAS J* 2010; **4**: 37-40 [DOI: 10.1016/j.esas.2010.03.004]

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