Neuroscience update on minimally invasive decompression for surgical treatment of neural compression in lumbar spinal stenosis

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Abstract. Neuroscience is a neural science that studies the nervous system, especially studying neurons and nerve cells with a multidisciplinary approach. The scope of the study of neuroscience includes molecular cellular, nervous system, behavioral neuroscience, and social neuroscience. Spinal stenosis occurs when the space around the spinal veins narrows, burdening the spinal cord and nerve roots. A minimally invasive approach to lumbar spine decompression is treatment for patients with spinal stenosis and spondylolisthesis. This article was written to carry out a theoretical update of neuroscience with the aim of analyzing what is meant by lumbar spinal stenosis, what are the trends and minimally invasive surgical approaches for the spine and its management? Minimally invasive surgery, may provide the opportunity for a less invasive surgical intervention. It is an approach that bridges the gap between invasive surgery and more conservative treatment for lumbar spinal stenosis.

1. Introduction

Degenerative lumbar spinal stenosis (LSS) can be encountered with degeneration of the lumbar motion segment (1). Typically, it causes spinal stenosis leading to neurogenic claudication or pain in the buttock, thigh, and leg (2) [1]. The two options available to the surgeon had been to either: (1) treat symptoms with conservative measures including physical therapy and injections; or (2) proceed with operative decompression with or without fusion [2]. Surgery should be considered in patients who have failed a full course of conservative treatment and have persistent severe back and predominant leg pain, evidence of instability on imaging, documented progressive spondylolisthesis, a progression of the neurologic deficit, or cauda equina symptoms [3].

The goal of minimally invasive spine (MIS) surgery for degenerative lumbar spinal stenosis is to accomplish the intended goals of treatment, whether they be decompression with/without fusion, and/or realignment [4]. Minimally invasive spine surgery (MISS) has been described as a technique results in less collateral tissue damage, quick recovery time, and decrease in morbidity. The current concept of MISS generally described as follows: (1) Preserve the tendinous attachment of the main muscles (multifidus attachments to the spinous process and superior articular processes); (2) Dissect the neurovascular and muscle compartment based on its anatomical planes; (3) Avoid injury of muscle and soft-tissue and maintain limited surgical window by using self-retaining tubular retractors; (4) Preserve the integrity of the dorsolumbar fascia; (5) Limit bony resection [5,6].

Classic surgical treatment consists of decompression to relieve radicular symptoms and neurogenic claudication. Fusion is added to prevent progression of spondylolisthesis [1]. Emerging MIS surgery
techniques seek to minimize surgical damage and thereby preserve normal function during spondylolisthesis surgery. The use of table mounted, tubular-type retractors can minimize pressure on muscles, vessels, and nerves while limiting the surgical corridor to the minimum necessary to safely expose the surgical target site so that crush injuries of adjacent tissues (osseo ligamentous, neurovascular, and musculotendinous anatomy) are avoidable. The main advantages of this type of surgery include the following: (1) Less invasive access resulting in muscle and tendon sparing; (2) Ability to decompress spinal structures without destabilization; (3) Excellent contralateral exposure of the pathology in question; (4) Indirect decompression with implants, particularly with lateral approaches; (5) Reliance on interbody fusion rather than on posterolateral fusion [5].

The option for surgical approach is based on the functional symptoms, and when surgical technique is chosen, some questions should be posed and the surgical strategy adapted accordingly [7]. Spinal decompression surgery for degenerative lumbal spinal stenosis are supported by Level-II evidence showing a sustained advantages compared with non-operative treatment. Spinal decompression and fusion have a proven role for select cases of degenerative lumbar spondylolisthesis, but recent Level-I evidence comparing decompression alone with spinal decompression and fusion is conflicting with regard to the clinical advantage for stable grade-I or grade-II degenerative spondylolisthesis [8].

Two stabilization techniques have been described: “dynamic” stabilization and (more frequently) fusion. Spinal instrumentation is frequently associated to fusion, in which case, it is essential for fusion position and length to take account of pelvic incidence and the patient’s overall pattern of balance [9]. Indeed, in cases of degenerative lumbar spondylolisthesis, associated fusion or dynamic stabilization are recommended to improve functional outcomes and prevent future destabilization. Risk factors for destabilization, such as angular and anteroposterior mobility, and substantial disc height, have been reviewed in the literature [7]. A multitude of approaches exist to attain segmental lumbar fusion if it is required; no solid evidence supports any single surgical technique for delivering better clinical outcomes. The addition of segmental fusion rises duration of surgery, length of stay, blood loss and hospital charges [8].

2. Methods
The method used in this study is a systematic literature review [10].

3. Results and discussion

3.1. Minimally invasive approaches for managing lumbar spinal stenosis
The basic roles of MIS posterior lumbar techniques are to elude damage to the multi fissus tendon attachment to the spinous process and to preserve dorsolumbar fascia integrity. It is achieved by using paramedian lines rather than midline approaches. Spinal decompression, discectomy, interbody fusion, posterolateral fusion, and pedicle screw instrumentation can be achieved through this approach. Emerging procedures for advanced reconstruction—including posterior corpectomies and strut fusion for tumors, infections, and burst fractures are also achievable [4].

3.1.1. Minimally invasive spinal decompression alone

3.1.1.1. With tubular retractor system. MIS surgery using tubular retractors has become a popular method for decompression in the lumbar spine. MIS surgery with tubular retractors is a harmless and effective option to classic open or microsurgical approaches for dealing with lumbar degenerative disease [11]. Some patients with degenerative lumbar spinal stenosis with spondylolisthesis can be treated with decompression alone or with fusion. Moreover, there is no relationship to obtain fusion success and clinical outcome; meaning, not all pseudoarthroses are hurting nor are all successful fusions trouble-free [2]. MIS laminectomy is a good alternative for the treatment of degenerative lumbar spinal stenosis with spondylolisthesis. There was no major progression of the slippage following the surgery in patients with lumbar spondylolisthesis. Nevertheless, it must be considered that this study included
only patients with “stable” lumbal spondylolisthesis, without movement on flexion/extension x-ray, and with neurogenic claudication in the absence of mechanical back pain [12].

Palmer et al., who studied the feasibility of minimally invasive laminectomy via tubular retractors in 2002, also reported no radiographic progression of the slippage at 3 months’ follow-up in 8 patients with pre-surgery slippage. Based on the small sample size and the short follow-up, conclusions for that study were limited. Results in the current study are consistent with those of Pao et al. and Müslüman et al., who stated no progression of spondylolisthesis after a microsurgical unilateral approach for tubular bilateral decompression after 2 years’ follow-up [12]. The re-operation cases in our report compare favorably with those of Kim et al., who reported a 15% total reoperation cases and 7.1% reoperation cases with fusion after bilateral tubular decompressive surgery through a unilateral approach using tubular retractors. Those authors settled that decompression without fusion is more cost-effective than instrumented fusion for a selected group of patients whom they described as those with leg-dominant pain and stable Grade I lumbal spondylolisthesis [12].

A small number of studies have looked at the result in patients with preoperative lumbar spondylolisthesis treated using other minimally invasive decompressive techniques such as the full-endoscopic interlaminar approach. These studies all reported very low reoperation rates and/or minimal progressive spondylolisthesis postoperatively [12]. The main indication and contraindication of this type of surgery include the following:

- **Indications:** (1) spinal stenosis; (2) stable grade 1 degenerative spondylolisthesis.
- **Contraindications:** (1) unstable grade 1 degenerative spondylolisthesis (anteroposterior hypermobility, angular hypermobility); (2) large disc height or extensive resection; (3) complicated revision cases in which extensive scarring may make tubular surgery problematic; (4) significant lateral listhesis; (5) significant scoliosis [4,11].

Based on strict microsurgical techniques will allow the surgeon to actually tackle bilateral pathology while maintaining stability and minimizing complications. Boukebir shortened what we could achieve with this technique as follows: (1) discectomy; (2) contralateral approach for “over-the-top” foraminotomy; (3) “over-the-top” laminotomy for bilateral decompression of lumbar spinal stenosis, and; (4) contralateral approach for synovial cyst resection in the lumbar spine.

### 3.1.1.2. With endoscopic system

Percutaneous endoscopic procedure has become a representative minimally invasive spine surgery for lumbar disc herniation. Regarding the significant development in the techniques, the paradigm of spinal endoscopy is changing from treatments of soft disc herniation to those of lumbar spinal stenosis. Lumbar spinal stenosis can be classified into three categories according to pathological zone as follows: central stenosis, lateral recess stenosis and foraminal stenosis. Moreover, percutaneous endoscopic decompression (PED) techniques may vary according to the type of lumbar stenosis, including transfaraminal, interlaminar, and endoscopic lumbar foraminotomy [13,14].

### 3.1.2. Minimally invasive spinal decompression with dynamic stabilization

Several studies have shown that the combination of decompression and fusion significantly improves patient outcome compared with decompression alone, a study have hypothesized that irregular load transmission is the principal cause of pain in osteoarthritic joints, in contrast to spinal fusion the dynamic stabilization system was made. The background for the dynamic stabilization system is to alter mechanical loading by unloading the disc but preserving lumbar motion in contrast to fusion [1]. Dynamic stabilization may be an option to standard arthrodesis in mild lumbar spondylolisthesis. However, different from fusion, dynamic implants have the problem of wearing and loosening in the long term. Some reports showed the result of clinical and radiological outcomes of dynamic stabilization were similar to those of MI-TLIF for Grade I degenerative spondylolisthesis at L 4–5 [15]. There are two types of dynamic stabilizers offered: (1) Intraspinous device (ID) and; (2) Pedicle screw-based (PSB) dynamic systems.
Intraspinous process device and pedicle screw-based (PSB) dynamic instrumentation systems have been increasingly in high demand. By indirect or direct decompression, these devices establish less painful segmental motion by lessening pathologic movement. Interspinous devices work by “inducing flexion” in the degenerative segment and result in less buckling of the ligamentum flavum, offloading of the facets, and reduce intra-disc pressures. PSB dynamics systems offload spinal units similar to pedicle-based posterior instrumentation. Since they do not depend on the presence of posterior elements, pedicle-based systems can be used with posterior decompression. This technique has several theoretical advantages over fusion: (1) adjacent level preservation; (2) protection of rotatory pressure to the sacroiliac joint during sitting; (3) maintenance of normal resting posture; (4) shorter OR time; (5) requirement of fewer levels of treatment, because unlike fusion one can stop below adjacent segments with degeneration [2].

Indications for Interspinous Device: (1) Central spinal canal and/or foraminal stenosis with neurogenic claudication; (2) Axial mechanical back pain.

Relative Contraindications for Interspinous Process Device: (1) Osteoporosis; (2) chronic insufficiency fractures of the vertebral bodies; (3) scoliosis; (4) Multiple Disc Slipped; (5) Lateral listhesis [2,4].

Pearls and Pitfalls
- The biggest problem for dynamic stabilization devices is survival against fatigue, despite letting continued motion.
- Elude too much distraction and kyphosis with a PDS device, which increases the poor outcome and device failure.
- Elude using any dynamic stabilization device in the existence of osteoporosis to avoid implant loosening.
- For complex disc degeneration, fusion is still the gold standard.

3.1.3. Total navigation minimally invasive surgery posterior lumbar interbody fusion for spondylolisthesis. The SLIP study found that health-related quality of life is superior for patients treated with fusion but the results of these trials aren’t generalizable to individual patients [16]. The indications for minimally invasive posterior spinal instrumentation are similar to traditional open surgery which is unstable grade I spondylolisthesis. There are no absolute contraindications to minimally invasive posterior spinal instrumentation, relative contraindication includes: (1) Grade II spondylolisthesis; (2) high-grade spondylolisthesis (grade 3 or 4); (3) previous posterior fixation requiring an open approach for removal or extension of instrumentation. Limitations of Minimally Invasive Surgery Posterior Lumbar Interbody Fusion for Spondylolisthesis as follows: (1) Radiation Exposure; (2) Learning Curve.

3.1.3.1. Minimally invasive posterior lumbosacral instrumentation systems. Techniques which are generally used as Minimally Invasive / Mini-Open Transpedicular Lumbar Instrumentation approach as follows: (1) Traditional (“Mini-Open”) Pedicle Screws; (2) Percutaneous Pedicle Screws; (3) Percutaneous Minimally Invasive (MIS) Non-Self Tapping Pedicle Screw; (4) Percutaneous Minimally Invasive (MIS) Guide Wire-less Self-Tapping Pedicle Screw (Garfin et al., 2017). To date, no clinical studies have directly compared the use of traditional pedicle screws placed through a tubular retractor (mini-open) to percutaneous pedicle screws [4].

3.1.3.2. Minimally invasive TLIF. MIS TLIF surgery makes use of rigid or expand- able tubular retractors. The patient is positioned on a Jackson frame with hips extended and knees flexed to 20–30°. Fluoroscopic guidance allows localization of the disc space and corresponding facet joint. It is our preference to place guidewires prior to decompression and TLIF. After adequate placement of guidewires is verified, a 22 mm tubular retractor is docked on the ipsilateral facet joint. Although loupe magnification and headlight can be used, we prefer to utilize the operating micro- scope for the
remainder of the procedure. Facetectomy is performed using a high-speed burr. The interval between thecal sac, exiting and traversing nerve roots, is then identified. Disc preparation is then performed followed by bone grafting and insertion of an interbody device.

**Pearls and Pitfalls**

- When working through a tubular retractor, remember to move the retractor to see what you want to see and to allow you to position instrumentation in the direction you want to direct it. Do not let the retractor dictate what you see and do.
- When first inserting screws over a tubular retractor, make sure to expose the medial portion of the transverse process and the pars.
- Pedicle screw tracks may be easier to prepare before performing the decompression and facetectomy when more bony landmarks are present.
- When placing percutaneous screws, fluoroscopic images must be “perfect” AP and lateral views. Otherwise, percutaneous screw placement may be aberrant.
- Start simple. Surgeons should build confidence and skill beginning with less technically demanding procedures and anatomy.

**Key points**

- Minimally invasive pedicle screw instrumentation is associated with less blood loss and shorter hospital stays but longer initial operative times.
- Minimally invasive instrumentation has a lower infection rate than open instrumentation.
- Obesity is a relative contraindication to minimally invasive instrumentation and fusion, but as a surgeon gains experience, obesity is a relative indication.
- Technical complications have been comparable in minimally invasive instrumentation and open instrumentation.

### 3.2. Total navigation in MISS

Total navigation in MISS has become feasible with the implementation of navigation guide tubes. The study of Navarro-Ramirez et al., presented that intraoperative computed tomography guided navigation (ICT-guided NAV) enhances the accuracy and safety of spinal procedures and improves surgical workflow especially in complex cases.

The ICT was able to intra operatively detect inadequate decompression, suboptimal pedicle screw position, suboptimal inter body spacer position and malposition of a kyphoplasty trocar. Compared to the ICT used by Santos et al., the ICT used in the present study has a higher image quality (especially in terms of soft tissue). ICT NAV provides immediate feedback, thus allowing for repositioning of implants while the patient is still under anesthesia which helps to prevent reoperations, morbidity and additional expenditures. ICT-guided spine surgery was able to reduce radiation exposure received by both the surgical staff and the patient when compared to conventional fluoroscopy. Employment of total navigation allowed the entire OR staff to avoid radiation exposure as the ICT could be activated remotely, and wearing lead shielded vests during surgery was no longer necessary. However, the time investment required to gain sufficient experience with NAV may be ameliorated over time. The ICT NAV was higher in initial cost than conventional NAV systems, and The ICT NAV is associated with costs which are currently not considered in the reimbursement [17]. Waschke et al. reviewed their experience with CT navigation and fluoroscopically guided 4500 pedicle screw placements. They did find a statistically significant improvement in accuracy when utilizing CT navigation and 3D reconstruction and intraoperative CT control of the screw position. This difference was most pronounced in the thoracic spine.

Gelalis and colleagues performed a systematic review of prospective in vivo studies comparing freehand, fluoroscopy-guided, and navigation techniques; 26 studies and 6617 screws were included in their analysis. They concluded that all techniques were considered safe; however, navigation did exhibit
the greatest accuracy and increased safety. The percentage of pedicle screws fully confined within bony anatomy ranged from 69% to 94% in the freehand group, 28% to 85% in the fluoroscopy-guided group, 81% to 92% for the fluoroscopy-based navigation group, and 89% to 100% in the CT-based navigation group [4].

From present study, we found that Airo based navigation greatly facilitates MIS-TLIF throughout the procedure without any need for fluoroscopy. Therefore, an era of “total navigation” was introduced in MISS, that is, the use of navigation for all steps of the procedure such as: (1) Skin incision; (2) Screw size, and planning; (3) Screw placement; (4) Tubular retractor placement; (5) Tubular decompression; (6) Cage placement, and; (7) Rod measurement Pathology localization [18].

4. Conclusion
Minimally invasive lumbar spine decompression is a safe and effective treatment for patients with spinal stenosis and spondylolisthesis. Minimally invasive surgery, in contrast to open decompression, may provide the opportunity for a less invasive surgical intervention. It is an approach that bridges the gap between invasive surgery and more conservative treatment for LSS.

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