History and development of lumbar minimally invasive spinal (MIS) surgery

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The aims of spinal surgery are decompression of compressed neural tissue, reduction of spinal deformity, fixation and fusion of unsteady or incompetent spinal segments. Spine surgeons strive not only to treat the pathology effectively with minimal disturbance of normal anatomy, but also to maintain the long term stability and function of patients with sound clinical evidence.

From laminectomy to fenestration: A great step forward

The effective surgical treatment for refractory sciatica and lumbar radiculopathy secondary to disc prolapse without instability is discectomy. In 1829, Smith started to use laminectomy to treat disc ruptures. In 1909, Oppenheim and Krause reported the successful removal of a ruptured disc. In 1934, Mixter and Barr treated radicular pain with exploratory laminectomy for lumbar disc prolapse[1]. Laminectomy includes excision of the spinous process, interspinous and supraspinous ligaments. The drawback of laminectomy is midline ligament complex destruction which can cause epidural scarring and loss of flexion stability. These ligaments were shown to be able to resist 19% of flexion forces[2]. In 1967, Yaşargil used a microscope in lumbar discectomy. Using an operative microscope, a magnified illuminated binocular operative field can be visualised despite a smaller wound. Caspar then refined the original laminectomy into an open microdiscectomy in 1977[3]. In 1978, William popularised open microdiscectomy with soft-tissue retraction through a small surgical corridor[4]. In 1988, Young described microsurgical fenestration. Limited laminar and facet bone removal is required[5]. The spinous process, midline ligamentous structures and laminar muscle attachment are preserved. Fenestration is an important modification in the surgical technique that has markedly reduced iatrogenic tissue damages.

The importance of multifidus muscle and the development of posterior muscle sparing approach

The next focus in lumbar MIS surgery is the sparing of muscle dissection, especially the multifidus. The multifidus muscle is uniquely short and stout which contracts to create large forces for relatively short distances. From erect standing to forward bending, the multifidus produces more force as the spine flexes protecting the spine. In open posterior lumbar exposure, sub-periosteal elevation and wide retraction of the multifidus will result in muscle atrophy and reduce strength[6]. A muscle sparing tubular retractor was developed to reduce muscle trauma. With fluoroscopy, the paraspinal muscles directly in line with the disc space on the symptomatic side are sequentially dilated rather than dissected. A tubular retractor is then placed over the dilators. The dilators are removed and either a microscope or an endoscope is directed to visualise the operative field allowing the subsequent procedures.

A muscle sparing approach was started in 1991 when Caspar developed tubular retractor systems and low profile instruments[7]. In 1997 Foley and Smith reported microendoscopic discectomy (MED) procedures using endoscopes and cameras[8]. In 1999, Destandau described the use of specific endoscopic devices for lumbar disc surgeries with success[9]. Since the use of self-retaining retractors can induce crush injuries to adjacent tissues, table-mounted tubular-type retractors were developed to minimise this trauma. In 2005, Ruetten described a full endoscopic percutaneous endoscopic interlaminar discectomy, further reducing surgical trauma[10].

Transforaminal percutaneous endoscopic lumbar discectomy (PELD)

Open discectomy or microdiscectomy has been associated with good results. Nonetheless, dorsal muscle trauma in creating a surgical corridor; fenestration of laminar and facet bone, removal of ligamentum flavum to open up the spinal canal, cutting of the posterior longitudinal ligament and annulus to remove the prolapsed disc fragment were required. Innocent tissues including the nucleus pulposus anterior to the prolapsed disc fragment are sacrificed. One consequence is epidural scarring which might be clinically symptomatic or makes revision surgery difficult. Dorsal approach discectomy is also difficult in tackling herniation lateral to the pedicle. Extended facetectomy is required. Instability will result. A paramedian muscle splitting approach to treat extraforaminal herniation is effective with less facet resection and muscle elevation. However, bone resection and muscle retraction, handling of the exiting nerve root and its dorsal root ganglion is still needed. This may cause irritating dysesthesia, reflex sympathetic dystrophy, and chronic back pain. PELD was developed since 1970's to tackle the above mentioned problems (Figure 1).

In 1975 the first percutaneous nucleotomy technique was reported by Hijikata[11]. Kambin is credited with the first percutaneous lumbar discectomy with fluoroscopy assistance in 1987[12]. In 1994, Hoogland introduced special reamers enabling enlargement of the foramen, so that the spinal canal could be accessed with an endoscope and instruments[13]. In 2002, Yeung and Tsou reported favourable outcomes with transforaminal endoscopic discectomy using an inside-out technique[14]. Later in the 2000's, an outside-in technique as described by Ruetten using a far lateral approach[15] and by Choi advocating a targeted fragmentectomy[16] was popularised. Direct placement of instruments to reach the target disc fragment without damage to the mother disc structure anteriorly is advocated.

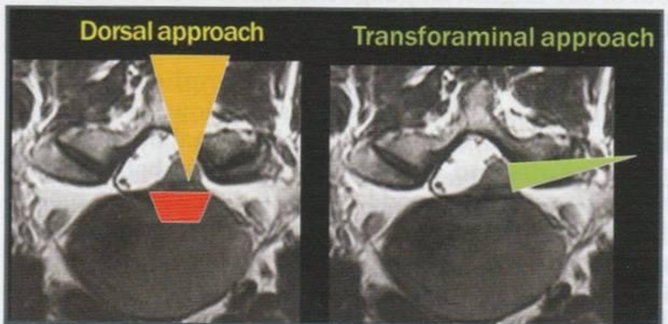

Figure 1. Dorsal vs. Transforaminal approach: different surgical corridors

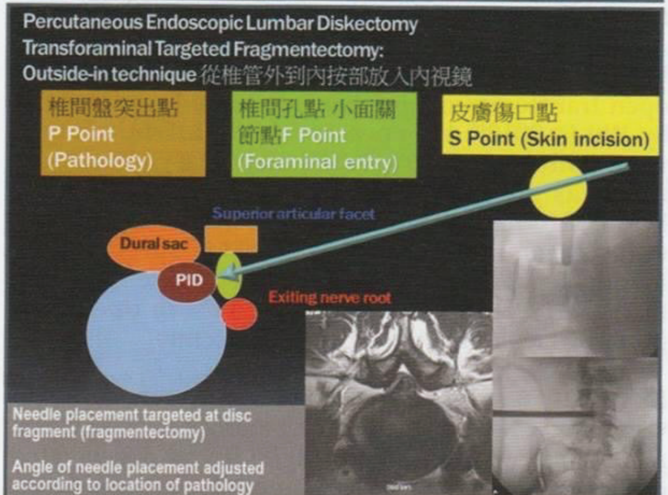

Figure 2. Transforaminal Percutaneous Endoscopic Lumbar Discectomy (PELD)

PELD employs a direct transforaminal approach to reach the prolapsed disc fragment (Figure 2). An atraumatic spinal cannula is inserted from the far lateral position through the intervertebral foramen, directly towards the target prolapsed disc and yet avoiding the nerve structures dorsal to the posterior annulus. A lead wire will then be inserted. A 1cm skin incision is then made. A cannulated dilator followed by a bevelled sheath will be pushed to the intervertebral foramen. The nerves are protected with the sheath. A small diameter (<8mm) long rigid endoscope is inserted inside the sheath. The endoscope and the sheath are gradually advanced to the medial pedicle line visualising the spinal canal. The prolapsed disc fragment is then identified and directly removed with long forceps through the single working channel inside the endoscope under endoscopic vision (Figure 3 & Figure 4).

PELD preserves normal anatomy. The posterior spinal muscle, lamina, the supraspinous and interspinous ligaments & the ligamentum flavum are all preserved (Figure 5). Limited foraminoplasty is only required when facet joint hypertrophy is present. Only the ventral part of the superior articular facet is partially trimmed. The prolapsed disc fragment is reached tangential to the intervertebral disc. The innocent remaining disc will not be breached. The procedure is performed under local anaesthesia. Patients could be discharged on the same operative day. However, the learning curve for PELD is extremely steep. Iatrogenic damages and dysesthesia to exiting nerve roots due to blind endoscope placement and incomplete removal of the disc fragment can happen. The reported failure rates ranged from 7%[15] to 11%[16].

Figure 3. Endoscopic view of prolapsed disc fragment at the centre, cranial and dorsal side at 9 o'clock and 12 o'clock positions respectively

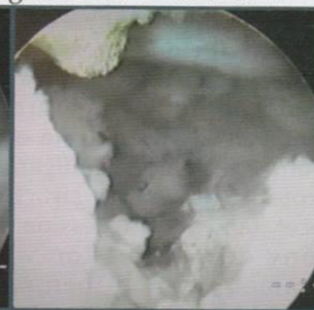

Figure 4. Endoscopic view after prolapsed disc fragment removal; transversing nerve root running from 11 o'clock to 2 o'clock position is free from compression

Figure 5. PELD: Pre-operative and Post-operative lumbar spine MRI: prolapsed disc fragment removal without muscle and bony damage

Minimally Invasive decompression for lumbar spinal stenosis

The traditional treatment for refractory spinal claudication due to facet joints and ligamentum flavum hypertrophy and disc protrusion without instability was wide laminectomy and medial facetectomy. In 1988, Young described microsurgical fenestration preserving the midline ligamentous structures and muscle attachments to the lamina[5]. This is sufficient for most patients. In 1991, McCulloch devised microsurgical bilateral decompression[18] via a unilateral approach which preserves the facet joints, muscle and neural arch of the contralateral side and protects the nervous structure against posterior scarring. Ipsilateral laminotomy was performed first, the ligamentum flavum and the contralateral hypertrophic facet joint and capsule were then undercut. Successful results with this technique were reported[19]. However, the risk of dural tears with this technique can be as high as 13.6%[20,21]. During contralateral bony decompression with undercutting, ipsilateral laminotomy was done and the ligamentum flavum was removed. The transversing nerves at the midline were unprotected and at risk from the passage and pressure of surgical instruments. To reduce such risks, contralateral bony decompression could be done first through a bone tunnel at the junction of the lamina and spinous process of the cranial vertebra. The ligamentun flavum is kept intact protecting the nerve structures during the contralateral facet joint decompression. Only after the contralateral bony decompression was completed, ipsilateral laminotomy and then removal of the ligamentum flavum and contralateral joint capsule will be performed (Figure 6). The author has experience of using this modified technique with no dural tears and nerve injuries occurred so far.

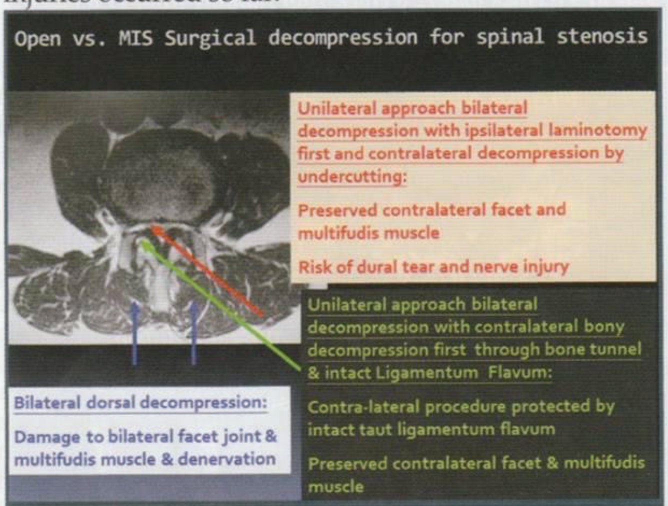

Figure 6. Different MIS surgical techniques in treating spinal stenosis

Minimally invasive lumbar spinal fusion and fixation

Minimally invasive spinal fixation and fusion were also increasingly performed. This MIS technique employed radiological guided or 3-dimensional navigation for hardware placement. Direct visualisation of anatomic landmarks with significant muscular dissection is not required. Complications like wound infections can be reduced. In 2002, Khoo described a minimally invasive percutaneous posterior lumbar interbody fusion (PLIF) technique without sacrificing effectiveness in spinal fusion[22]. In 2003, Foley described the first minimally invasive trans-facet lumbar interbody fusion (mTLIF)[23]. However, the initial learning curve of such technique is steep which can lead to increased complications, neurological deficits, CSF leakage and screw/cage complications[24,25]. The increased use of fluoroscopy also raised the concerns of increased radiation exposure to the patient, surgeon, and operating room staff.

Is there any scientific evidence of better clinical outcome with Minimally Invasive Spine Surgery?

Despite the theoretical advantages of the minimally invasive spinal technique, its clinical superiority is still controversial. High level evidence is still lacking.

In the 2010 systematic review written by Fourney on the use of tubular retractor assisted lumbar MISS, only 13 out of 361 English language literatures met the stringent inclusion criteria[26]. The single large randomised study showed less favourable results for MIS discectomy, but no significant difference in complication rates. The quality of the other studies was low. Overall, the reoperation rate, dural tears, cerebrospinal fluid leakage, nerve injuries and infections were similar between MIS and open surgery. Blood loss was reduced in MIS fusion. In 2016, a meta-analysis comparing minimally invasive unilateral laminectomy for bilateral decompression (ULBD) versus open laminectomy was performed by Phan[27]. From the pooled data, there is moderate quality evidence supporting superior satisfaction rates, reduced hospitalisation, and blood loss, but longer procedures for ULBD.

In a review of 23 studies on the fusion rate for MIS vs open transforaminal lumbar interbody fusion written by Wu in 2010[28], the open and MIS TLIF fusion rates were both high (90.9% vs. 94.8%). The complication rate was similar (12.6% and 7.5% for open and MIS TLIF, respectively) but with a trend towards reduced complications with MIS TLIF surgery. Bone morphogenic protein (BMP) was used more frequently in the MIS TLIF group (50% vs. 12% in open TLIF group) which might influence the outcome.

In the 2016 systematic review and meta-analysis written by Christina[29] comparing studies of open versus minimally invasive fusion (TLIF/PLIF) for degenerative conditions, all studies, including 1 RCT, were found of low quality. It identified the equivalent 2-years patient-reported clinical outcomes with improvements in perioperative measures including the estimated blood loss and the length of hospital stay in patients undergoing MIS surgery. There was no significant difference in the operative time, surgical adverse events, union rate and reoperation rate between the surgical techniques.

Recently, minimally invasive lateral lumbar interbody fusion (LLIF; XLIF) was increasingly performed. It is performed through a lateral, retroperitoneal, transpsoas approach to the anterior spinal column, and uses real-time neuromonitoring to ensure safe passage of tubular retractor and instruments through the psoas muscle, aiming to avoid the nerves of the lumbar plexus. The proposed benefits include the avoidance of vascular, visceral and sexual dysfunction complications associated with open anterior procedures, and paraspinal denervation, dural tears, and neural injuries in posterior approaches, while allowing for a broad discectomy and large graft placement. The anterior and posterior longitudinal ligaments remain intact, providing inherent spinal stability. However, in the 2015 systematic review by Joseph[30], although the intraoperative and wound complications were less for LLIF (1.93% and 0.8%) compared with the minimally invasive TLIF group[MI-TLIF] (3.57% and 1.63%), the total complication rates (19.2% MI-TLIF group and 31.4% LLIF group) and complications related to nerve function (sensory, temporary and permanent) were significantly higher for the LLIF group. No significant differences were noted for medical complications or reoperations.

Conclusion

With improvements of intraoperative radiological or navigation guide localisation, endoscopic and microscopic illumination and visualisation, retractor and surgical instruments designs, fixation implant and biologic bone fusion alternatives, minimally invasive spinal surgery has advanced tremendously. However, there exists no randomised controlled comparisons of clinical and radiological outcomes, and complications between MIS and open procedures. There is a need for high level multicentre RCTs or multicentre observational studies to definitively address the question of the relative safety and effectiveness of minimally invasive spinal surgery.

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