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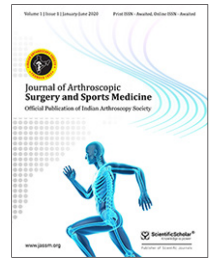
Journal of Arthroscopic Surgery and Sports Medicine



Spine *Review Article*

Recent advances and future trends in microendoscopic spine surgery

Sameer Ruparel[1], Ankit Patel[2], Vishal Kundnani[2,3], Ram Chaddha[1,3]

[1]Jaslok Hospital and Research Centre, [2]Bombay Hospital and Medical Research Centre, [3]Lilavati Hospital and Research Centre, Mumbai, Maharashtra, India.

***Corresponding author:**
Sameer Ruparel,
Jaslok Hospital and Research Centre, Mumbai, Maharashtra, India.

ruparelsameer@gmail.com

Received : 05 June 2020
Accepted : 09 June 2020
Published : 15 July 2020

DOI
10.25259/JASSM_26_2020

Quick Response Code:

ABSTRACT

Micro Endoscopic Spine Surgery (MISS) aims to achieve the goals of conventional techniques with minimum collateral damage. Though initial reports date back to the early 20th century, drive to implement these in routine practice have been recent with technological advances. Presently, the indications and its applications are ever expanding such that they can be used to tackle most pathologies right from cervical to lumbar spine. The advantages of MIS techniques like faster recover and less post-operative pain have been documented in numerous studies but so are also its drawbacks related to the learning curve and radiation exposures. To tackle these, we see future trends like Navigation and Robotics, along with ever decreasing incision size supplementing Endoscopic procedures. This manuscript aims to give a brief outlook of recent advances and future trends in MISS.

Keywords: Micro endoscopic surgery, Endoscopic spine surgery, Minimally invasive spine surgery, Recent advances

INTRODUCTION

It has been a constant endeavor of spine surgeons around the world to achieve optimum surgical results with minimum collateral damage. This forms the basis of minimally invasive spine surgery (MISS). Any procedure which reduces the morbidity of a conventional technique and accomplishes the surgical goals is a MISS technique. Reports of MISS procedures date back to the early 20th century.[1] However, it was only in the 1990s with the development of microscopic, fluoroscopic, and endoscopic systems that the quest for MIS technology gained momentum. Minimizing muscle damage through progressive dilation of intermuscular planes led to the development of tubular retractors. Tubular access to the lumbar disc was first reported by Faubert and Caspart in 1991. The first description of microendoscopic discectomy then came from Foley and Smith in 1997.[2] The initial system used endoscopes and was quickly adapted by orthopedic surgeons due to their familiarity with arthroscope. These slowly evolved to introduce the ease of using microscopes into this technique in 2003 using the METRx system (Medtronic, Inc., USA). The efficacy and safety of these techniques led to its widespread adaptation.[3,4] The ability of the tubes to address multilevel, contralateral pathologies through the same incision preserving the posterior midline structures expanded the indications of using tubular endoscopes to address numerous lumbar degenerative conditions. With the advent of percutaneous pedicle screw fixation (PPSF), fusion was also now possible to treat instability patterns. Although initially used to treat degenerative lumbar pathologies, MISS techniques now have applications in treating traumatic, neoplastic, infective, and structural pathologies of the entire spine. Anthony Yeung

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(1999) was first to popularize the use of transforaminal endoscopic discectomy through the safe zone of "Kambin triangle" (1990) by inside-out approach (Yeung Endoscopic Spine System) followed by the development of interlaminar and outside-in transforaminal endoscopic techniques by Kim *et al*. With the rapid development of endoscopic techniques in the past decade, the scope of MIS has widened to almost all degenerative pathologies of the spine. This manuscript focusses on the application of microendoscopic surgical techniques and its recent advances in the field of spine surgery.

Rationale

The key principle that guides MIS approaches is its ability to minimize muscular injury using known intermuscular planes, thus treating the pathology leaving the "smallest footprint" [Figure 1]. The posterior lumbar musculature along with dorsolumbar fascia is responsible for generating spinal movements while maintaining stability.[5,6] Spine surgery inherently causes damage to surrounding muscles.[7] This can be followed by muscle atrophy and loss of function. Among the different approaches to the spine, the injury to muscle is greatest when using posterior midline approach.[8] The posterior midline approach is a muscle stripping approach rather than a muscle splitting approach unlike MISS. One of the factors responsible for injury is the likely use of forceful self-retaining retractors as documented by Kawaguchi *et al*.[9-11] The radiological and pathological effects of this injury are documented in numerous studies. Stevens *et al*.[12] assessed post-surgical appearance of magnetic resonance imaging (MRI). They found marked intermuscular and intramuscular edema in patients operated with open transforaminal lumbar interbody fusion (TLIF) at 6 months while a normal appearance of MRI in patients operated with MIS TLIF. Kim *et al*.[13] found 2–7-fold increase in markers of skeletal muscle injury (IL-6, IL-8, aldolase, etc.) in patients operated with conventional techniques as compared to MIS procedures. They also found[14] that patients undergoing percutaneous instrumentation displayed more than 50% improvement in extension strength while their open surgical counterparts had none. Serial dilation using sequentially larger concentric tubes through intermuscular planes and a retractor holder mounted to the table rather than a "self-retaining" mechanism greatly reduces muscle injury. Although biological studies demonstrate the superiority of MISS procedures, compelling evidence is based on clinical outcomes. Significant reduction in operative blood loss, length of stay, and post-operative pain has been documented in numerous studies[15-17] with matched long-term results with respect to fusion rates and function. Significant reduction in wrong level surgery in MISS is attributable to the use of C-arm for tube docking and percutaneous pedicle screw insertion. One of the notable benefits is the decrease in surgical site infections in MIS surgeries. This is due to less exposure, protection of surgical site from skin edge by tubular retractors and reduced dead space after tissue closure.[18,19] Decreased dead space also serves as a boon in cases of dural leaks and patients on anti-coagulants. In such cases, better wound healing rates and decreased chances of pseudomeningocele have been noted [Table 1].

Applications of MIS

The applications of MIS in spine surgery are myriad and evolving further day by day. To begin with lumbar discectomy is one of the most basic and commonly performed procedures. Microendoscopic discectomy (MED) being one of the first procedures performed using tubular retractors is now widely accepted due to its proven safety and efficacy [Figure 2].[3,4] MED has been compared with traditional discectomy and has shown similar results with advantage of less invasiveness.[4,20,21] Not only short-term outcomes but even long-term results of 10 years post-operative[22] have been reported with satisfactory outcomes. Similarly, lumbar spinal stenosis is one of the most common pathologies in patients over age 65 years for which spine surgery is contemplated to improve quality of life.[23,24] The ability to perform a thorough ipsilateral-contralateral and multilevel decompression through a small unilateral portal is one of the biggest advantages of this technique. The applicability of micro-endoscopic decompression has expanded even further to include synovial cysts and

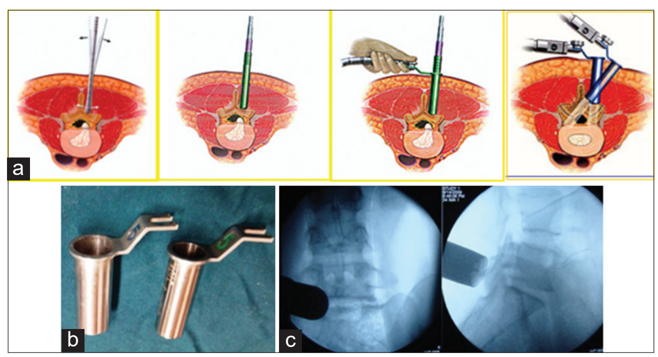

Figure 1: (a) Sequential dilatation through thoraco-lumbar fascia and tube docking, (b) Tubular retractor system. (c) AP and lateral X-rays showing tubular dilator docked at L5-S1 level.

Table 1: Advantages of minimally invasive spine surgeries.
Less post-operative pain and need for analgesia
Decreased blood loss
Small incisions, better cosmesis
Less muscle damage
Low infection rates
Early return to work
Daycare surgeries – cost efficient

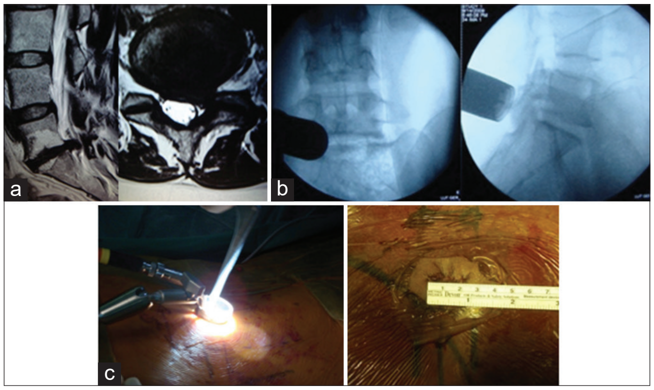

Figure 2: (a) Sagittal and axial T2W magnetic resonance imaging showing classic paracentral prolapsed intervertebral disc L5-S1, (b) AP and lateral X-rays showing tubular dilator docked at L5-S1 level, (c) Docked tubular retractor with discectomy done under magnification using an operating microscope with 2 cm post-operative scar.

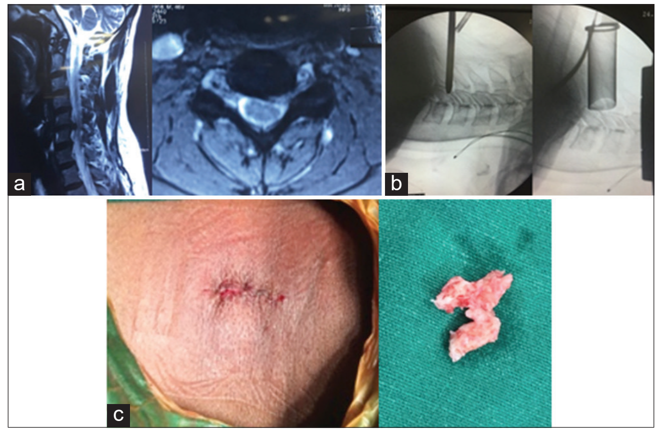

Figure 3: (a) Sagittal and axial T2W magnetic resonance imaging showing C 5-6 foraminal disc herniation, (b) Intraoperative lateral C-arm imaging showing tubular dilator and retractor docking in line with the C 5-6 disc space, (c) Post-operative scar and removed herniated disc fragment.

stable degenerative spondylolisthesis.[25] In a study of 30 patients without gross instability, microendoscopic stand-alone decompressions had good to excellent results with no reported cases of recurrence/reoperation and a minimum follow-up of 3 years.[26] Those patients demonstrating instability require spinal fusion procedure. With the advent of percutaneous pedicle screw fixation techniques, it was now possible to perform arthrodesis through MIS techniques. The advantages of MIS TLIF as compared to conventional TLIF – decreased blood loss, early ambulation, shorter length of stay, better pain relief, and comparable fusion rates have been echoed in numerous studies.[27-29] Recently, even high-grade mobile spondylolisthesis has been treated successfully with MIS techniques. Pedicle screws with special reduction extenders having capacity to pull proximal screws without placing excessive stress on implants help in such cases. Today, MIS techniques are gaining a strong foothold to even treat cervical spine pathologies. Minimally invasive tubular endoscopic posterior cervical foraminotomy is beneficial for single-level lateral/foraminal soft disc protrusions [Figure 3]. When overall cost of foraminotomy was compared to anterior cervical discectomy and fusion (ACDF), it was found that cost of ACDF was 89% more than the former, as there is no need for fusion or instrumentation. Motion preservation is achieved in 93–96% of cases with low recurrence rates.[30] The authors have immense experience in treating upper cervical pathologies with minimally invasive techniques. In a cohort of 82 patients with mobile atlantoaxial instability, microscope-assisted stand-alone transarticular screw fixation without Gallie supplementation was used at the author's institution. Fusion was noted in 97.5% of cases with significant improvement in clinical parameters.[31]

Apart from cervical and lumbar degenerative conditions, microendoscopic surgeries are pursued for infections, tumors, trauma, and deformities throughout the spine. For spinal infections, MIS techniques can be used to procure specimens for culture, drainage of epidural abscess, percutaneous debridement of early discitis, anterior/transforaminal debridement, and reconstruction followed by percutaneous screw fixation. These are extremely useful in sick, immunocompromised, and elderly morbid patients. Ashizwa *et al.*[32] performed percutaneous transpedicular biopsies and found 92% accuracy without significant complications. Using tubular endoscopes, hemilaminectomy can be performed to drain purulent material. Tschugg *et al.*[33] on comparison of open versus MIS TLIF for infective spondylodiscitis concluded that patients in latter group had significantly less post-operative pain, blood loss, and duration of stay. Similarly, video-assisted thoracoscopic surgeries (VATSs) have been utilized for debridement of spinal infections;[34] however, the application of MIS in spinal infections also depends to a great extent on surgeon's expertise and experience. Numerous surgeons have employed tubular endoscopes for treating spinal tumors.[35,36] The ideal case is a benign eccentric tumor spanning <3 spinal lumbar levels. Similarly, MIS techniques have been a boon in polytrauma patients requiring stabilization in view of damage control orthopedics (DCO). In chance fractures (flexion-distraction injuries of the spine), where in anterior column, restoration and decompression are not required, percutaneous fixation can be employed. However, in burst fractures, anterior minimal access decompression and stabilization augmented with percutaneous posterior pedicle screw fixation is done. In non-healing osteoporotic wedge compression fractures, Kummels lesion can very well be treated with vertebroplasty/kyphoplasty MIS techniques [Figure 4].[37] Complex deformities, particularly adult spinal deformities, can now be treated with various MIS techniques. There is a

Figure 4: (a) Pre-operative Lat (sitting and supine) X-rays showing D12 Osteoporotic compression fracture with Kummel's Lesion, (b) Post-operative X-rays showing D12 vertebroplasty with MIS percutaneous pedicle screw fixation D11-L1, (c) Intra and post-operative wound showing 'key-hole' incisions.

Table 2: Applications of MISS: (Cervical/Thoracic/ Lumbar – Anterior and Posterior).

Spinal degenerative conditions	Endoscopic discectomy Endoscopic decompression Degenerative instability patterns Cervical laminoforaminotmy MIS C1-2 trans-articular screw fixation
Spinal infections	Transpedicular biopsy Endoscopic decompression and debridement Endoscopic drainage of epidural abscess Anterior/transforaminal debridement and reconstruction – video-assisted thoracoscopy (VATS)
Spinal trauma	Percutaneous vertebroplasty/kyphoplasty Chance fractures – Percutaneous pedicle screw fixations Anterior minimal access decompression and stabilization supplement with percutaneous screws
Spinal deformities	Adult deformities – anterior/lateral minimal access- XLIF/ALIF/OLIF with percutaneous screws Congenital and adolescent deformities
Spinal tumors	Intra- and extra-medullary tumors

resurgence of anterolateral MIS techniques such as extreme lateral interbody fusion and oblique lumbar interbody fusion due to their ability to correct spinopelvic sagittal parameters, robust fusion, and immediate stability along with inherent advantages of MIS techniques. These techniques combined with posterior percutaneous fixation have shown to provide significant improvements in pain and disability with good radiographic correction of deformity [Table 2].[38]

Drawbacks

With every technique employed, there are benefits and limitations. With numerous benefits as discussed above for microendoscopic spine surgeries, one cannot turn a blind eye to its drawbacks. One of the major concerns raised by critics is radiation exposure. During percutaneous pedicle screw fixation, accurate needle positioning and direction of trajectory is required prompting surgeons to shoot at high radiation dosages. Studies have shown that these procedures expose surgeons to 10–12 times the radiation dose required when compared to non-spinal musculoskeletal procedures.[39] Bindal *et al.*[40] noted that mean fluoroscopy time during MIS TLIF was 1.69 min/case. With this amount of exposure, the annual dose limits could easily be exceeded at centers performing large number of fluoroscopically guided procedures. Authors recommend simple maneuvers like keeping the X-ray tube on opposite side of table, "hands off" technique, maintaining a distance of 3 ft from the source, collimation and adequate centering of images, and last but not the least wearing radioprotective lead aprons, thyroid collars, preferably lead gloves, and glasses. Another concern of employing MIS in daily practice is the steep learning curve. Orientation of microscopes and endoscopes, complex assembly of tubular retractors, and the ability to operate through narrow corridors require experience. Nowitzke evaluated learning curve for tubular decompression and noted that 3 of the first 7 but none of the subsequent 28 cases required conversion to open.[41] Similarly, Lee *et al.*[42] studied learning curve of 60 patients who underwent MIS TLIF. Using logarithmic curve regression analysis, they concluded first 22 patients as early cases. The operative time and blood loss were significantly greater in early cases; however, functional scores did not differ between the groups. Dhall *et al.*[43] found higher rate of perioperative complications. Guide wire-related complications such as inadvertent durotomy during initial docking, advancement of guide wires during screw insertion steps, and superior facet joint violations[44] are known to occur. Adequate training and cadaveric hands-on experience have been shown to reduce these adverse events. Similarly, navigation-guided surgeries are a boon to reduce these complications and limitations. Another concern is the cost of expensive equipment. Microscopes, high-end fluoroscopes, high-speed burrs, specialized instruments, and implants are a must and increase the expenditure. We believe that with the development of indigenous equipment and its easy availability, MIS surgeries can be brought within the reach of the majority of the population [Table 3].

Future trends

In future trends [Table 4] increasing popularity of microendoscopic techniques along with constant endeavor to tackle the drawbacks of percutaneous pedicle screw fixation as discussed above is now paving the way to modern-day navigation and robotic spine surgery. The principle navigation-assisted guidance is to couple patient's images acquired by pre- and intraoperative 2D-3D fluoroscopy or CAT scans making it available on a virtual platform hence giving the surgeon a real-time feedback which can be utilized for spinal instrumentation with extreme precision and no radiation. This technique is very useful in the treatment complex deformities, cervical and thoracic spine instrumentation. Authors routinely use this technique for MIS TLIF [Figure 5] and complex cases like navigation-guided MIS C1-2 transarticular screw fixation. At the author's institute, a comparative study of navigated versus non-navigated MIS TLIF found effective dose of radiation

Table 3: Limitations of MISS.

Increased radiation exposure
Steep learning curve
Guide wire-related complications
Resource intensive
Superior facet joint violations
Skill-based reproducibility of results
Higher implant cost
Indications limited in complex cases

Table 4: Future trends.

3D navigation-guided surgeries
Robotic-assisted surgeries
Guide wireless surgeries
Fusion less surgeries
Full endoscopic interbody fusion techniques

6.23 times higher in the latter group. Similarly, there was 3% perforation rate of 64 navigated screws compared with 9% with non-navigated group, though no critical breach was found in any of the groups.[45] There is a learning curve associated with the use of navigation which increases the surgical time in initial few cases. However, the benefits of accuracy and decreased radiation doses outweigh these to a great extent. To make the surgeons job easier, precise, and accurate, robotic spine surgery is the latest tool in one's armamentarium. Latest robots with arms are integrated to navigation systems which help plan, guide, and execute accurate screw trajectories in real time. The robotic system eliminates the need for the surgeon to navigate the spine and complex hand eye coordination which is needed to align surgical instruments to pre-planned trajectories required in navigated surgeries [Figure 6]. Numerous studies have documented the accuracy and safety of navigated pedicle screw insertion techniques.[46,47] Thus, with technological advances, future of spine surgery is shaping in the direction of minimally invasive surgeries for the benefit of both the surgeons and patients [Table 5].

Not only in instrumented spine surgeries, surgeons have managed to achieve great strides in uninstrumented surgeries also. With expertise, it is now possible to perform discectomy and decompression surgeries with tubes as small as 14 mm.[48] Similarly, with innovations in endoscopic spine surgery, procedures with even smaller incisions under local anesthesia as daycare techniques are undertaken. Transforaminal and interlaminar discectomy approaches have smaller footprints of collateral damage and achieve optimal clinical and functional results. The third-generation endoscopy is epitomized by endoscopic decompression and lumbar fusion for stenosis and spondylolisthesis due to rapid development in techniques

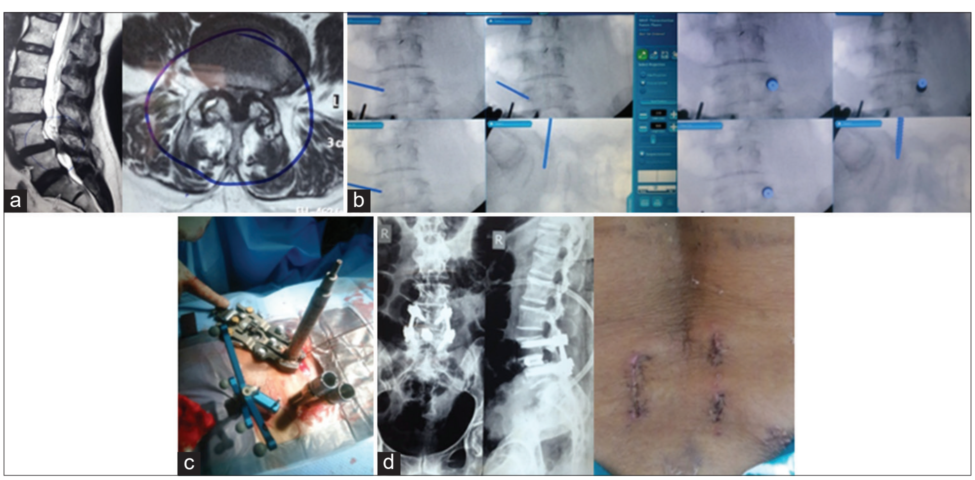

Figure 5: (a) Sagittal and axial T2W images of L4-5 Degenerative Spondylolisthesis with stenosis and facet arthropathy, (b) Navigation screen showing the steps of percutaneous pedicle screw trajectory planning and measurement of screw dimensions, (c) Intraoperative picture showing the tubular retractor docked over the left L4-5 facet, Pedicle screw extenders and the Reference frame fixed in the Right PSIS aiding the navigation process, (d) Post-operative X-rays and Post-operative wound scar MIS TLIF.

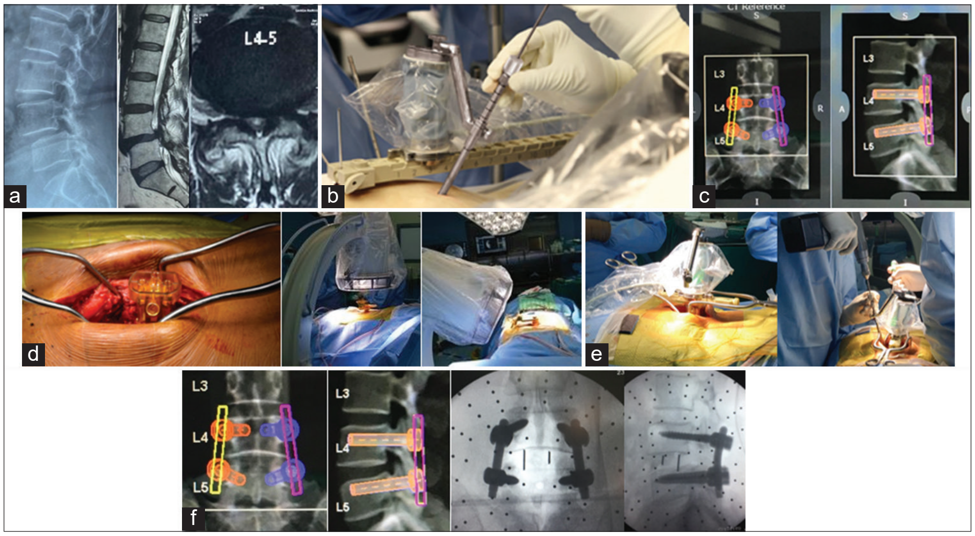

Figure 6: (a) Pre-operative X-rays (Lat) and magnetic resonance imaging (T2 Sag and Axial) showing L4-5 degenerative spondylolisthesis, (b) The mazor robotics renaissance guidance system, (c) Pre-operative planning of pedicle screws, (d) Intra operative imaging (taken in 2 planes) to correlate between real time patient positioning and pre- operative planning with spine clamp attached, (e) Robotic arm guiding the pedicle trajectory and subsequent drilling of pedicle, (f) Comparison of pre-op planning and intra-op execution showing extreme precision of robotic guidance.

Table 5: Benefits of navigation/robotics in minimally invasive spine surgery.
Decreases radiation exposure
Enhances precision
Reduces surgical time
Widens applications of minimally invasive spine surgeries to numerous spine pathologies and regions
Reduces surgical "skill-based" errors with "technological" check

and equipment as well as optics. Endoscopic decompression requires least bone resection, muscle damage, and minimal blood loss due to tamponade effect of the irrigation fluid and can yield sufficient decompression despite the minimal neural retraction mainly due to the excellent up close visualization of the spinal canal and the underwater dissection aided by the irrigation fluid pressure. The advantage of endoscopic spine surgery is that it not only provides sufficient decompression but also effectively treats multiple lesions and preserves both the facet joint and the paraspinal muscle. Recent reports show that endoscopic treatment is being extended to more advanced lesions such as intradural lesions. At the rate of current development, it is reasonable to predict that endoscopy will be an option to treat all spine disorders in future. Steep learning curve and limited applicability of endoscopes to degenerative lumbar pathologies are primary deterrents to its widespread acceptance. However, with every new technique, we believe that these will surely expand the horizons of MISS in near future.

Thus, with each passing day, it would not be surprising to see microendoscopic surgeries being the new "gold standard." Widespread applications to tackle numerous spinal pathologies with extreme precision and safety and achieving excellent clinical and functional outcomes have prompted most surgeons to want to perform MIS procedures. Innovations toward fusionless, guide wireless, and radiation less surgeries are underway. Numerous methods to tackle the steep learning curve of these procedures with cadaveric workshops, academic programs, and virtual simulators are possible. No longer are minimally invasive approaches regarded as emerging. MISS techniques are now very well established and we are now moving in a direction of constant evolution with wider acceptability and applicability eventually becoming the gold standard as in other domains of surgery, where laparoscopic and endoscopic techniques are the norm.

Declaration of patient consent

Patient's consent not required as patients identity is not disclosed or compromised.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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How to cite this article: Ruparel S, Patel A, Kundnani V, Chaddha R. Recent advances and future trends in microendoscopic spine surgery. J Arthrosc Surg Sports Med 2020;1(1):146-53.