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Narrative review

Spinal endoscopy: Evidence, techniques, global trends, and future projections

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Abstract The utilization of indirect visualization during procedures has been increasingly replacing traditional forms of direct visualization across many different surgical specialties. The adoption of arthroscopy, using small cameras placed inside joints, has transformed musculoskeletal care over the last several decades, allowing surgeons to provide the same anatomic solutions with less tissue dissection, resulting in lower requirements for inpatient care, reduced costs, and expedited recovery. For a variety of reasons, spine surgery has lagged behind other specialties in the adoption of indirect visualization. Nonetheless, patient demand for less invasive spine procedures and surgeon drive to provide these solutions and improve care quality has driven global adoption of spinal endoscopy. There are numerous endoscopic platforms and techniques currently utilized, and these systems are rapidly evolving. Additionally, the variance in technology and health system incentives across the globe has generated tremendous regional heterogeneity in the utilization of spinal endoscopic procedures. We present a consolidated review, including the background, evidence, techniques, and trends in spinal endoscopy, so that clinicians can gain a deeper understanding of this rapidly evolving domain of spinal healthcare.

Keywords: Biportal endoscopy; Endoscopic decompression; Endoscopic Spine Surgery; Full Endoscopy; Microendoscopy; Spine endoscopy

Rationale for spinal endoscopy and the role of anatomic perspective during surgery

The vast majority of spinal procedures being performed throughout the world currently rely on direct visualization aided by magnification, either through eyewear (eg, loupes with a headlamp) or the use of an operating microscope. A frequent goal of most spine procedures for degenerative pathologies involves addressing and relieving extrinsic neural compression. As the tools and techniques to perform these procedures have evolved, surgeons have been able to perform these procedures with more limited operative exposures. Furthermore, as the working area of access to the spinal canal decreases, direct external visualization begins to create substantial limitations, and moving the point of

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anatomic perspective into the body of the patient, and closer to the surgical site, dramatically increases the area and quality of visualization. This improvement in anatomic perspective during surgery minimizes surgical dissection, and may allow for reduced requirements for inpatient care, lower surgical expenditures, and expedited recovery [1,2].

History of endoscopic spine surgery

The origins of spine endoscopy date back to the early 1930s, when Burman used arthroscopic instruments to perform the first "myeloscopies" in cadavers, successfully visualizing the spinal cord and the nerve roots [3]. Shortly afterward, Stern developed new instrumentation, termed the "spinascope," and Pool began performing myeloscopies through incisions "not over 2.5 mm" in which he was able to visualize the nerve roots in great detail [4,5]. Following technological advancements in optical lens systems and the development of fiber-optics over the succeeding decades [6,7], the 1970s ushered in a period of great progress in microscopic techniques that developed in concert with endoscopic innovation and reinforced the prospects of minimally invasive spine procedures. In 1978, Williams published on his "extremely conservative microsurgical procedure for the treatment of the virgin herniated lumbar disc" in which he used these techniques and no laminectomy or disc space curettage was performed [8].

Close to 20 years later, important advancements were made in spine endoscopy techniques and technology, wherein two developmental pathways emerged, based on the extraforaminal and interlaminar approaches. The extraforaminal approach was facilitated by improved understanding of Kambin's safe zone [9]. leading surgeons to exploit this working corridor to address foraminal pathology. In 1996, Matthews described foraminal epidural endoscopic surgery and in 1998 Ditsworth published his series of 110 patients with endoscopic transforaminal procedures [10,11]. The interlaminar approach largely developed after 1997, when Foley first described microendoscopic discectomy and demonstrated this technique's utility in addressing the central spinal canal and lateral recesses [12,13].

Since the first descriptions of transforaminal and interlaminar endoscopic approaches, there have been advances in the technology, instruments, and techniques related to endoscopic spine surgery that have led to more widespread adoption and applications. The extraforaminal approach led to the expansion of "full endoscopy" platforms, where there is a single access channel with one available working instrument. Other platforms, including "biportal endoscopy" and "microendoscopy" developed primarily to support the interlaminar approach, where multiple instruments could be used concurrently, broadening endoscopic applications to a wider range of spine pathologies.

Endoscopic spine surgery is now being performed globally for the treatment of cervical, thoracic, and lumbar spine disorders, with a growing body of internationally developed literature demonstrating its efficacy and safety [14−18]. As surgeons increasingly leverage endoscopic approaches to spine care, medical technology companies will likely invest in further technological development and make these procedures increasingly accessible. In this way, clear parallels between spine endoscopy and arthroscopy are appreciated. In the 1950s and 1960s, peripheral joint arthroscopy developed as an alternative to standard open procedures and eventually transitioned from a diagnostic tool to a therapeutic platform [19]. Half a century later, arthroscopic procedures are now among the most commonly performed elective surgeries in the world. Based on the trajectory of arthroscopic interventions in other areas of musculoskeletal medicine, we are likely to see continued growth and utilization of spinal endoscopy, perhaps ultimately becoming a mainstay approach in spine surgical care.

Endoscopic spine techniques and platforms

There are a multitude of endoscopic techniques that can be utilized in the treatment spine disorders. Regardless of the approach, any endoscopic system will rely on indirect visualization, wherein a camera(s) is placed in proximity to the surgical field. In order to place the camera inside the body, and allow instruments to access the spine, there must be a working channel that communicates between the surgical field and the outside. The sizes and the number of working channels are the parameters typically used to categorize the different types of spinal endoscopy. Much of the capabilities of these different systems, and their inherent advantages and disadvantages, are predicated upon these two factors. Further, there are intrinsic trade-offs along the spectrum of these parameters. Specifically, increasing the number or size of the working channel(s) will create more collateral tissue disruption during access to the spinal canal, but allow for the concurrent and independent use of multiple instruments, increasing the breadth of applications and capabilities of the system. The three most commonly utilized techniques include full endoscopy, microendoscopy, and biportal endoscopy (Fig. 1).

Full endoscopy

Full endoscopy typically involves a single working channel, which houses the endoscope and one surgical instrument (Fig. 2). The working channel only allows for the utilization of one instrument at a time. The operator can change the instrument, for example switching from a bone removal device to a cautery device, but the size of the working channel does not allow for the concurrent use of two instruments. Additionally, the small working channel dictates that the camera used for visualization and the tool being used can only be moved in concert, with some modifications allowing for limited independent motion of the distal working end of the instrument. Because the working channel is relatively small and does not itself create a potential space around the surgical field, these techniques require an aqueous environment to

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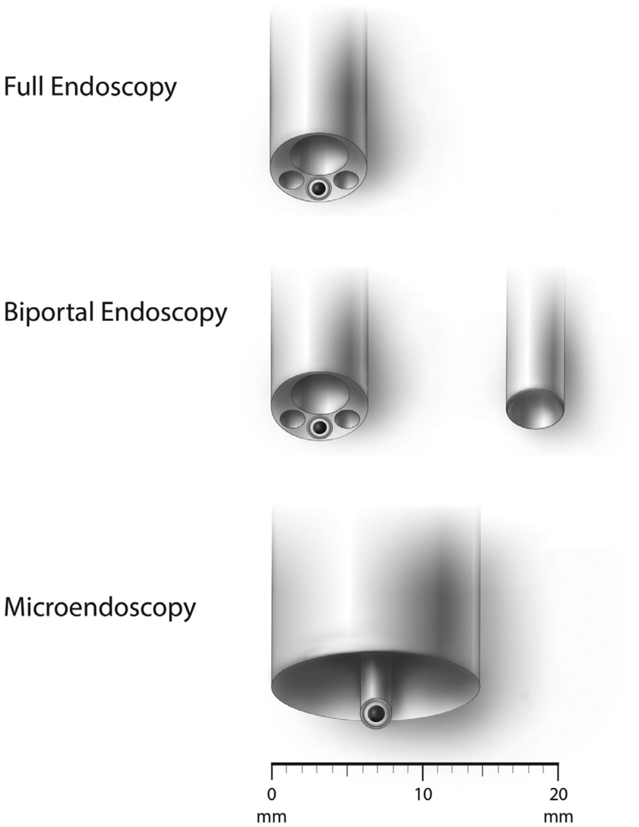

Fig. 1. Diagram demonstrating the relative working channels and size of the most commonly utilized spinal endoscopy techniques.

create space around the surgical field in between tissue planes. The advantage of full endoscopy is that it creates the least amount of collateral tissue damage. Disadvantages stem primarily from the single working channel that precludes multiple concurrent instrument use and independence between the camera and instrument movements. There are many points during spine procedures where it would be advantageous to be able to concurrently retract tissue and use cautery or a bone/tissue removal device, and this technique is limited in this regard. Beveled working channel designs allow surgeons to utilize the working channel itself as a retractor, by displacing structures outside the working and visual field. Additionally, working channel size also creates limitations around device implantation.

Microendoscopy

Microendoscopy involves a single working channel, but the size is large enough to allow for multiple instruments to be used concurrently, and independent of the endoscope (Fig. 3). The broader capabilities of this approach result from this capacity for the operator to have both hands free to utilize multiple instruments at once in the working channel. The increased working channel size also has advantages in terms of medical technologies, creating the potential to use a broader range of tools, and space to implant devices, such as interbody cages and bone graft. The main disadvantage of the microendoscopic technique is the larger portal size, which theoretically results in greater tissue disruption, though the clinical significance of subcentimeter changes in cannula size are not well defined. The other disadvantage of microendoscopy is that it is currently performed in a dry environment, without the potential for an aqueous field to aid in tissue dissection and delineation.

Biportal endoscopy

Biportal endoscopy utilizes two working channels, one for the endoscope and another for instruments, much akin to arthroscopy techniques used in knee or shoulder surgery (Fig. 4). The main advantages of this approach are the

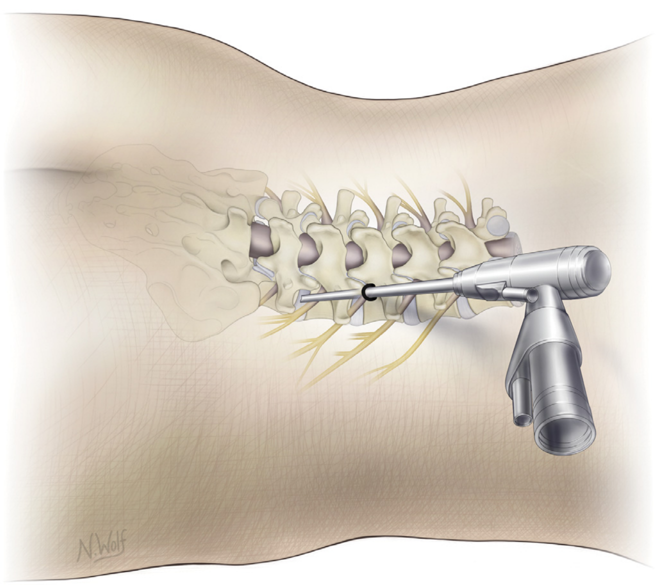

Fig. 2. Full endoscopy representative instrumentation and approach.

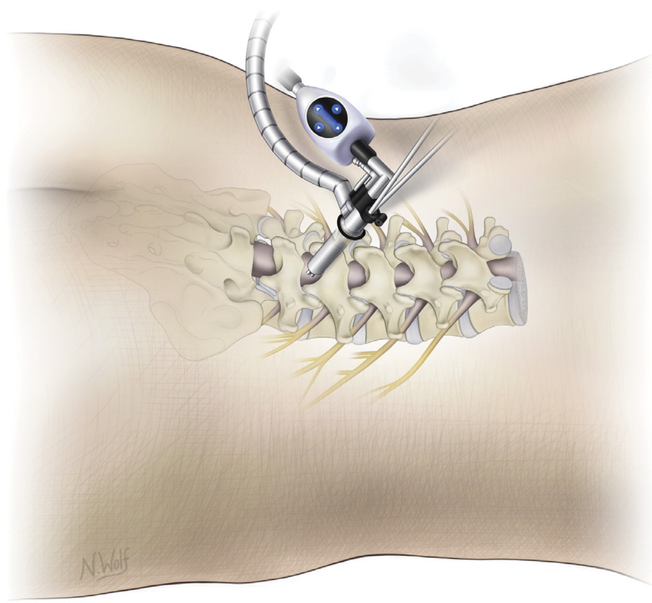

Fig. 3. Microendoscopy representative instrumentation and approach.

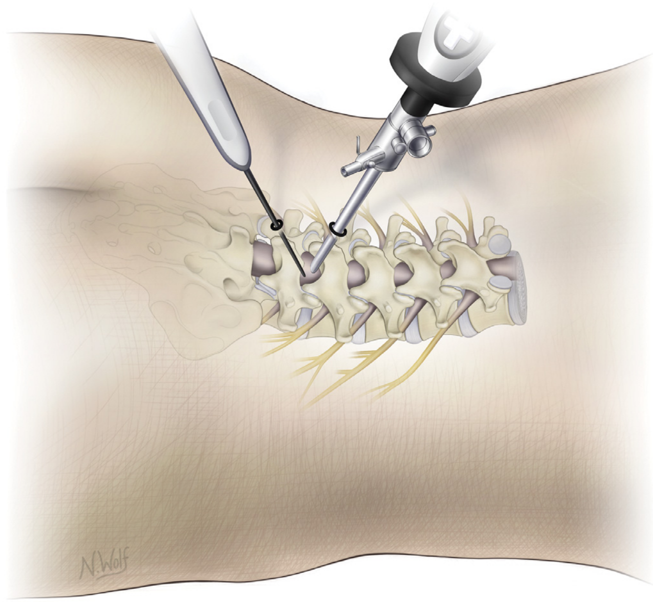

Fig. 4. Biportal endoscopy representative instrumentation and approach.

independence of scope and instrument control, as well as greater degree of freedom for positioning of the instruments. This technique may also have increased affinity for those who have some background with other peripheral joint arthroscopic techniques, as many of the principles are similar. Like full endoscopy, biportal procedures utilize an aqueous environment to create a potential space at the surgical site. Disadvantages derive from reliance on multiple access portals, which create more tissue disruption, and limited ability to implant devices. Additionally, multiple portals and the lack of a contained joint space makes exchanging and co-locating instruments technically more challenging.

Surgical approaches and applications for endoscopic spine surgery

The two most commonly utilized approaches for endoscopic surgery in the cervical, thoracic, and lumbar spine are the posterolateral (or interlaminar) approach and the extraforaminal (or transforaminal). In the interlaminar approach, a paramedian incision is used to access the lamina and interlaminar space, where the surgeon has direct access to the spinal structures within the central canal and lateral recesses (Fig. 5A). This approach has the broadest application, as the majority of spinal disorders involve neural compression in the central and/or lateral recess zones. In the extraforaminal approach, a far lateral incision is used to allow instruments to access the extraforaminal and lateral foraminal zones in the interval commonly referred to as Kambin's triangle (Fig. 5B). This approach provides direct access to the foramen and is most effective for isolated unilateral foraminal conditions or neural compression in the lateral recess or central canal secondary to ventral disc pathology. The disadvantage of this approach includes limited capacity to address many types of lateral recess or

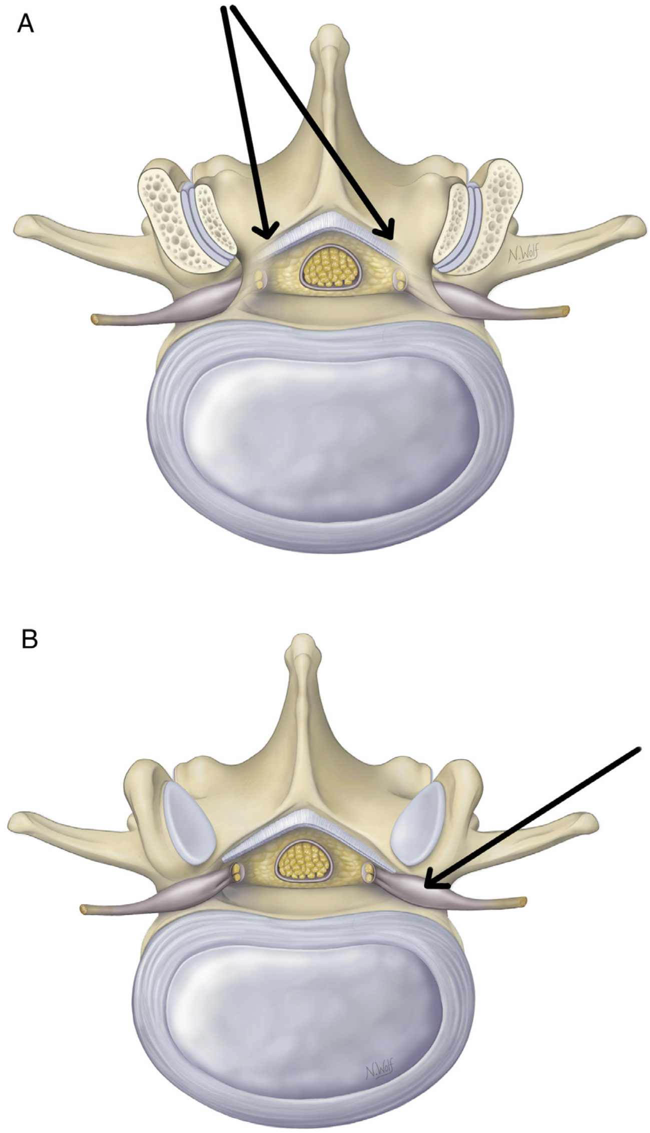

Fig. 5. (A) Interlaminar approach access and trajectory. (B) Extraforaminal approach access and trajectory.

central stenosis, which are primarily resultant from dorsal pathology like facet and ligamentum flavum hypertrophy.

The literature-base supporting endoscopic spine surgery

As a relatively new domain within spinal surgery, the literature supporting the use of endoscopic procedures have evolved fairly rapidly over the last two decades (Fig. 6). Much of the evidence base consists of case series, or the experience of single surgeons or centers, although several randomized trials have also contributed to the contemporary understanding of endoscopic spine surgery.

Lumbar spine

Lumbar disc herniation

The treatment of lumbar disc herniation is the most thoroughly studied application of endoscopic spine surgery, due

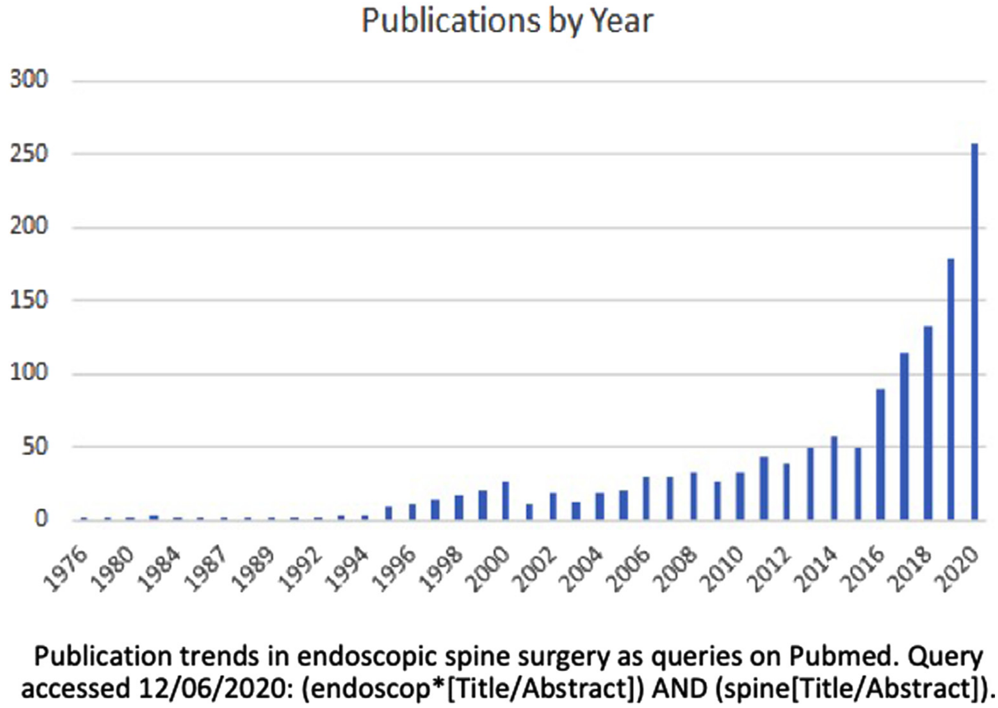

Fig. 6. Publication trends in endoscopic spine surgery.

to both the prevalence of the condition as well as the fact that it can often be addressed through interlaminar or extraforaminal approaches. Several randomized controlled trials have demonstrated equivalent patient reported outcomes when comparing endoscopic and standard minimally invasive or open techniques. The earliest trial, published by Ruetten and colleagues in 2008 [14], examined 178 patients with lumbar disc herniations and found no difference in pain or functional disability between endoscopic and microdiscectomies. Furthermore, they also found no differences in complication or recurrence rates. They did, however, note shorter operative time (22 vs. 43 minutes, p<.0001), lower postoperative pain medication use, and shorter time to return to work (25 vs. 49 days, p<.01) in the endoscopic group. Several other RCTs comparing endoscopic discectomy with standard interventions such as microsurgical laminotomy, microdiscectomy, or open discectomy, have similarly found no differences in patient-reported outcomes [20,21]. Non-randomized cohort studies comparing standard microdiscectomy with endoscopic discectomies have further demonstrated equivalent patient reported outcomes, recurrent disc herniations, and complications [22,23].

When comparing endoscopic approaches, an RCT of 60 patients with L5-S1 lumbar disc herniations undergoing endoscopic discectomy with an interlaminar (n=30) or transforaminal (n=30) technique found equivalent patient reported outcomes and complication rates, with slightly shorter operative times in the interlaminar group (65 vs. 86 minutes, p<.01 [24]. One randomized controlled study comparing transforaminal endoscopic discectomy to microendoscopic discectomy found that the transforaminal endoscopic group had superior improvements in ODI at one year for far lateral disc herniations, whereas the microendoscopic group had greater ODI improvement for paramedian herniations [25]. In contrast, a meta-analysis examining transforaminal endoscopic and microendoscopic discectomy for all herniation types demonstrated lower ODI improvement at one year in the transforaminal group (−0.52 (−0.95 to −0.10), p=.02), with no difference in pain scores [26].

Lumbar spinal stenosis

Several studies have compared endoscopic techniques with minimally invasive or open techniques for central and lateral recess decompression in lumbar spinal stenosis. In general, patient reported outcomes have been largely proven to be equivalent, with inconsistent benefits in reduced operative times and lengths of stay. Length of stay data is challenging to interpret from a global perspective, mainly due to regional and national variation that supersedes procedural aspects of care. For instance, patients often spend much longer periods in the hospital in Japan than in the US for the same procedure, so comparing length of stay data externally without attention to the country of origin may be misleading. One randomized controlled trial from Korea evaluated 64 patients with lumbar spinal stenosis treated by laminectomy via a biportal endoscopic (n=32) or microscopic (n=32) approach [27]. The study demonstrated equivalent improvements in pain scores and physical function at all times points up to 1-year following surgery. In contrast, a retrospective cohort study performed in the US concluded that unilateral endoscopic laminotomy showed longer surgical time by 62 minutes (p<.001) with shorter length of stay by 1.7 days (p<.01) and lower disability scores (20.7 vs. 35.9, p<.01) [28]. Within the realm of endoscopic surgery, retrospective comparisons between full endoscopic laminectomy and microendoscopic laminectomy have demonstrated equivalent patient-reported outcomes and satisfaction [29,30].

Lumbar spondylolisthesis

While not as well studied as lumbar spinal stenosis, endoscopic procedures have demonstrated early promise in surgical management of lumbar stenosis in the context of degenerative spondylolisthesis. Some studies suggest that endoscopic approaches may preserve enough soft tissue integrity that decompression without fusion can accomplish symptomatic relief while minimizing the prospect of postoperative instability. Minamide and colleagues published their experience with 304 single level degenerative spondylolisthesis patients who underwent microendoscopic laminotomy without fusion, stratified into mild or advanced spondylolisthesis (spondylolisthesis greater than 20%, or posterior opening angle greater than 5 degrees on lateral flexion-extension views) [31]. Not only were patient-reported outcomes equivalent in the two groups, but the percentage slip at an average follow-up of 4.6 years remained unchanged. These results are further supported by another study comparing patients with lumbar spinal stenosis alone to those with degenerative spondylolisthesis following posterior endoscopic decompression with laminectomy. The authors maintained equivalent improvements in pain, physical function and disability scores up to 2 years postoperatively, with no differences in radiographic slip progression [32].

Lumbar facet cysts

Preliminary data suggests that endoscopic excision of facet cysts results in symptomatic improvement with rates ranging from 81.8 to 89% [33−35]. One study demonstrated no recurrence of facet cysts when treated endoscopically at 3 year follow-up, compared to 51.4% recurrence with cyst enucleation, though this study was limited in patient numbers [36]. More recent work from Murata et al. evaluated microendoscopic decompression of patients with lumbar facet cysts using an adjunctive cyst dyeing method to improve intraoperative cyst delineation and demonstrated good outcomes with reduced procedure time and lower risk of durotomy [37].

Adjacent Segment Disease

In the setting of adjacent segment neural compression following prior lumbar fusion, there is a theoretical benefit to the use of less disruptive endoscopic techniques that might avoid the need for concurrent fusion. Similar to findings for lumbar stenosis or discectomy, comparison studies have shown equivalent patient reported outcomes with shorter operative times and decreased blood loss and length of stay [36−38]. One study compared endoscopic decompression with revision posterior lumbar interbody fusion (PLIF) and found equivalent outcomes in patients with stable Adjacent Segment Disease. For those patients with unstable Adjacent Segment Disease, however, the PLIF group did better with regard to function and leg pain at 2 years [38].

Lumbar fusion

The philosophy of employing endoscopic approaches for neural decompression in general is to mitigate collateral tissue damage and destabilization, allowing the avoidance of fusion. In certain patients where fusion is indicated, however, endoscopy may be utilized for the placement of interbody devices. Currently, tubular retractors are commonly used with microscopic visualization during MIS TLIF procedures, in order to achieve neural decompression and access the interbody space for preparation and interbody cage placement. Endoscopic platforms can be used to perform these same tasks, while allowing for smaller working channels, and accordingly, less tissue disruption. The most significant disadvantages of endoscopic-assisted fusion are resultant from the limitations in device size that can be implanted via smaller access channels, though the development of expandable interbody cages may mitigate the impact of this restriction.

Endoscopic assisted fusions have demonstrated favorable results in limited case series and comparative studies, though there are currently no robust randomized controlled trials differentiating additional value over conventional MIS fusions [39−42]. Kim and colleagues retrospectively reviewed 87 patients with degenerative or isthmic spondylolisthesis undergoing either biportal endoscopic TLIF (n=32) or MIS TLIF (n=55) [39]. This study examined only the early postoperative course and found no difference in pain or disability at 2 weeks and 2 months. Though not comparative studies, there are several case series of endoscopic TLIFs that have reported good results. One of the larger studies was conducted by Kamson et al., who examined 85 patients undergoing percutaneous endoscopic TLIF and found significant improvements in VAS score and high patient satisfaction rates, although did not report fusion rates [40]. Heo and colleagues similarly examined 69 patients undergoing biportal endoscopic TLIF and found significant improvements in VAS and ODI scores with no pseudoarthrosis in a study with a minimum follow-up of 12 months [41]. Given that we are still early on the adoption curve for endoscopic fusion, we can expect rapid proliferation of small case series of these procedures, as demonstrated in a recent systematic review [42]. Future studies should emphasize comparative and prospective study designs to provide more robust evidence.

Cervical spine

Posterior cervical discectomy and foraminotomy

Posterior endoscopic cervical foraminotomy (PECF) and posterior endoscopic cervical discectomy have both demonstrated equivalent patient-reported outcomes with lower blood loss and fewer complications when compared with traditional anterior cervical discectomy and fusion (ACDF). Level I evidence is available only for PECF, in which Ruetten et al. randomized 175 patients to either a PECF or ACDF and found no differences between groups in pain, function, or the development of adjacent segment disease [14]. Furthermore, complication rates were similar, although the ACDF group demonstrated three cases of transient dysphagia which was absent in the PECF group. Meta-analyses of level II and III data comparing PECF to ACDF demonstrated significantly greater improvement in arm pain scores in the PECF group (5.71 points vs. 2.27 points, p=.03). The pooling of data from cohort studies comparing posterior endoscopic cervical discectomy and ACDF, however, showed no differences in patient-reported outcomes [43−47].

Posterior cervical laminotomy

The majority of the literature on cervical endoscopic surgery has focused on decompression of the cervical foramen, however, some studies have reported on endoscopic approaches to decompression of the spinal canal for central stenosis. Minamide retrospectively reviewed 61 patients with cervical spondylotic myelopathy who underwent either cervical microendoscopic laminotomy or conventional laminoplasty [48]. The authors found similar functional outcomes at 5-year follow-up, although the endoscopic group had less postoperative axial neck pain and improved lordosis with less likelihood of postoperative kyphosis. These findings were supported in subsequent work comparing microendoscopic interlaminar decompression and conventional laminoplasty [49].

Thoracic spine

Endoscopic techniques have been utilized in the treatment of thoracic spine pathology for decades, though the literature is not as common or robust as that for lumbar and cervical conditions [18,50−58]. Early iterations began in the 1990s, when Rosenthal adapted techniques used in video-assisted thoracoscopy and pioneered what was described as transthoracic thoracoscopy for treatment of thoracic disc herniations [54]. Although this technique was effective in terms of pain reduction and neurologic outcomes; the transthoracic approach, involving selective lung collapse and violation of the pleura, carried with it high postoperative morbidity, including the risk (3.6%) of serious pulmonary complications [52,57]. This complication profile, coupled with the need for chest tube placement and prolonged hospitalization, prompted other surgeons to develop alternate techniques.

In the late 1990s and early 2000s, authors began to report on posteriorly-based approaches that could be utilized in the treatment of both ventral and dorsal pathology [18,50,51,53,55,56,59]. Multiple authors have demonstrated the feasibility of posterior endoscopic techniques in clinical practice via interlaminar, transforaminal, or extraforaminal approaches [18,50,51,53,55,56]. Variations on these surgical techniques include robotic assistance [50]. the use of a 70°-angled endoscope for easier viewing ventrally [51], and surgery performed on awake patients with local anesthesia and light sedation [53,55]. In perhaps the largest case series of thoracic spine endoscopy, Ruetten et al. reported on 55 patients who underwent thoracic endoscopic decompression for disc herniation or stenosis, using uniportal extraforaminal or interlaminar endoscopy [18]. The authors noted significant improvements in pain and disability, although there was a 19% complication rate, including episodes of epidural hematoma and durotomies. While the results of thoracic endoscopic decompressions are good and demonstrate lower morbidity than traditional open approaches, addressing ventral thoracic pathology endoscopically is associated with the same challenges and higher risk profiles as compared to dorsal decompressions.

Spine infections

Recently, interest has grown in treating infectious spinal conditions, including osteodiscitis and epidural abscess, less aggressively whenever practical [60]. Conceptually, endoscopic approaches may lend themselves as adjunctive therapies for paraspinal infections, allowing less disruptive decompression and irrigation of the paraspinal and epidural spaces. Endoscopic techniques have been utilized for a wide variety of infectious disorders of the spine, from seriously comorbid patients [61] to early intervention in infectious course [62], resistant fungal infections [63], and as a means of pathogen identification [62,64−66]. Most of the literature is focused on infections of the thoracic and lumbar spine, though isolated case reports of endoscopic techniques for cervical spine infections are also available [67].

Rather than replace the open and extensile surgery that is traditionally utilized for infections that have failed medical management, most authors have leveraged endoscopic techniques as an adjunct approach with medical therapies to facilitate more rapid mechanical pathogen clearance while avoiding the need for extensive surgery in an often immunocompromised patient. Additionally, there may be a role for endoscopy in pathogen identification, as targeted antibiotic therapy is an important predictor of paraspinal infection treatment outcomes. For example, the reported rate of pathogen identification with CT-guided biopsy in cases of vertebral osteomyelitis is widely variable, ranging from 30.4% to 90.7% [68,69]. By contrast, endoscopic techniques have consistently high pathogen yields [64,66]. In a head to head comparison, Yang et al. showed that endoscopic biopsy determined a causative pathogen in 18 out of 20 cases versus 15 out of 32 with CT-guided biopsy (p=.002). Ito et al. documented that in six of nine (66.7%) patients who had previously false negative CT-guided biopsies, pathogen identification was subsequently achieved via an endoscopic surgery [61]. Results such as these suggest that endoscopic techniques may be a useful intermediary step between non-operative and traditional open operative management of spine infections, both in terms of guiding medical therapies and directly impacting the infectious process.

Spinal tumors

In the 1990s, Rosenthal et al. adapted their transthoracic endoscopic technique to address neoplastic processes [70]. In their cases series, the authors detail four cases whereby this technique was employed for vertebrectomy, vertebral reconstruction, and stabilization. Standardized outcome measures were not reported, but all patients were discharged by postoperative day eight and were independent, ambulatory, and had reduced pain at discharge and subsequent follow-up. Similar thoracoscopic techniques have been utilized by other authors with encouraging results [71]. Posteriorly-based approaches have also been documented [72,73], as have endoscopically-assisted open procedures [74]. The summary of these works indicate the potential for minimally invasive technique for the treatment of appropriately selected spinal neoplasms. Nonetheless, these approaches have not yet gained widespread adoption.

Current trends in spine endoscopy utilization

Global trends in spinal endoscopy utilization demonstrate the highest utilization and growth in Asian and European markets. In a recent global survey, 96.7% of Asian surgeons indicated that they perform modern minimally invasive (MIS) and endoscopic spinal (ES) surgery compared to 81.6% of non-Asian surgeons (p=.001) [75]. Approximately 70% of Asian surgeons performed spine endoscopy, compared to 55% of non-Asian surgeons (p=.015). Of note, survey recipients were identified through the investigators' networks, likely resulting in a selection bias for surgeons more inclined to perform endoscopic procedures. Furthermore, innovation within the field of spinal endoscopy, such as the development of biportal endoscopy, is largely driven by Asian scientists and surgeons [76]. In examining this discrepancy between Asia and the US in the adoption of this technology, Yoon and Wang identified several key differences: (1) Lack of US billing codes supporting endoscopic surgery; (2) Poor reimbursement for endoscopic procedures; and (3) Lack of interest on the part of major US medical device manufacturers [77].

In the United States, in particular, there are strong fiscal incentives for surgeons to perform fusion procedures and utilize instrumentation due to the increased reimbursement associated with these types of procedures. Similarly, medical technology companies have clear recurring revenue streams that derive from the use of surgical implants (eg, pedicle screws, plates, interbody cages), while the adoption of endoscopic techniques requires capital equipment sales and more innovative business models.

Further limitations to the adoption of endoscopic procedures include the lack of available sites for training on these procedures, as well as the learning curve associated with safely applying endoscopic approaches in practice [78−80]. Additionally, it should be recognized that much of the literature, including RCTs, tend to derive from providers and centers who are very experienced in patient selection for, and execution of, endoscopic surgery. As a result, the question remains as to how translatable the findings from the current body of literature are in general practice. These factors represent demonstrable obstacles toward acceptance and implementation of spine endoscopy in the US. As the scientific literature grows in support of this technique and as its practice is refined and popularized in Asia, these barriers will need to be addressed to permit greater access to spine endoscopy in the US.

Future projections

Spine surgery, as is the case with all surgical specialties, continues to progress in the direction of procedural solutions that achieve the same anatomic goals with less collateral tissue disruption. The evolution of arthroscopy has dramatically changed the landscape of orthopaedic surgery, and arthroscopic procedures are now among the most commonly performed elective interventions worldwide. Similarly, endoscopic spine surgery is not a specific procedure, but a platform that facilitates optimal visualization and access to the spine while mitigating damage to surrounding healthy tissue. While there are certainly benefits to minimizing collateral tissue damage to the spine, demonstrating incremental benefits over traditional MIS approaches requires more robust series with longer-term follow up that are inherently less available in the earlier phases of endoscopic adoption.

Endoscopic spine surgery, unlike arthroscopy, does face unique headwinds that have likely restrained growth. Traditional larger medical technology companies involved in spine care generate large portions of their revenue from implants like pedicle screws and interbody cages used in fusion procedures. As such, these companies are fiscally disincentivized to redirect resources to innovating and manufacturing endoscopic technologies that rely on capital equipment sales, may have less lucrative recurring revenue streams, and may displace a portion of current fusion-related business. Because the growth of endoscopic spine surgery is highly dependent on medical technology companies to improve these platforms and make them more accessible and user-friendly for surgeons, there is a strong interdependence that is currently contributing to the constraint on endoscopic spine surgery growth. As patient and surgeon demand for these endoscopic solutions grows and the potential consumer market reaches a critical mass, medical technology companies may become increasingly interested and redirect resources in support of endoscopic spine procedures.

Several extrinsic forces and trends are likely to lead to growing interest in endoscopic spine surgery. First, healthcare systems globally continue to move toward value based care programs that financially favor lower cost outpatient neural decompressions. Additionally, patients have increased access to information about procedural options and endoscopic spine solutions have direct-to-consumer appeal for patients exploring potential spine surgery. In terms of supportive technology, there has been tremendous advancement in navigation and automation tools that can assist surgeons in overcoming the challenges of anatomic localization inherent to less invasive techniques. While the extent of endoscopic spine growth is uncertain, consideration of these factors and their associated system dynamics makes it hard to imagine a future state where spinal endoscopy does not occupy a recognizable portion of the standard spine surgical armamentarium.

Declarations of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Pranata R, Lim MA, Vania R, July J. Biportal endoscopic spinal surgery versus microscopic decompression for lumbar spinal stenosis: a systematic review and meta-analysis. World Neurosurg 2020;138: e450–8. https://doi.org/10.1016/j.wneu.2020.02.151.

[2] Barber SM, Nakhla J, Konakondla S, Fridley JS, Oyelese AA, Gokaslan ZL, et al. Outcomes of endoscopic discectomy compared with open microdiscectomy and tubular microdiscectomy for lumbar disc herniations: a meta-analysis. J Neurosurg Spine 2019:1–14. https://doi.org/10.3171/2019.6.SPINE19532.

[3] Burman MS. Myeloscopy or the direct visualization of the spinal canal and its contents. JBJS 1931;13.

[4] Stern EL. The spinascope: a new instrument for visualizing the spinal canal and its contents. Med Rec 1936;143:31–2.

[5] Pool JL. Direct visualization of dorsal nerve roots of the cauda equina by means of a myeloscope. Arch Neurol Psychiatry 1938;39:1308–12. https://doi.org/10.1001/archneurpsyc.1938.02270060198013.

[6] Ooi Y, Morisaki N. Intrathecal lumbar endoscope. Clin Ortop Surg 1969;4:295–7.

[7] Ooi Y, Satoh Y, Sugawara S, Mikanagi K, Morisaki N. Myeloscopy. Int Orthop 1977;1:107–11. https://doi.org/10.1007/BF00576312.

[8] Williams RW. Microlumbar discectomy: a conservative surgical approach to the virgin herniated lumbar disc. Spine (Phila Pa 1976) 1978;3:175–82.

[9] Kambin P. Diagnostic and therapeutic spinal arthroscopy. Neurosurg Clin N Am 1996;7:65–76. https://doi.org/10.1016/S1042-3680(18)30406-6.

[10] Mathews HH. Transforaminal endoscopic microdiscectomy. Neurosurg Clin N Am 1996;7:59–64. https://doi.org/10.1016/S1042-3680(18)30405-4.

[11] Ditsworth DA. Endoscopic transforaminal lumbar discectomy and reconfiguration: a postero-lateral approach into the spinal canal. Surg Neurol 1998;49:588. https://doi.org/10.1016/s0090-3019(98)00004-4.

[12] Foley KT. Microendoscopic discectomy. Tech Neurosurg 1997;3:301–7.

[13] Foley KT, Smith MM, Rampersaud YR. Microendoscopic approach to far-lateral lumbar disc herniation. Neurosurg Focus 1999;7. e5−e5.

[14] Ruetten S, Komp M, Merk H, Godolias G. Full-endoscopic cervical posterior foraminotomy for the operation of lateral disc herniations using 5.9-mm endoscopes: a prospective, randomized, controlled study. Spine (Phila Pa 1976) 2008;33:940–8. https://doi.org/10.1097/BRS.0b013e31816c8b67.

[15] Zhang B, Liu S, Liu J, Yu B, Guo W, Li Y, et al. Transforaminal endoscopic discectomy versus conventional microdiscectomy for lumbar discherniation: a systematic review and meta-analysis. J Orthop Surg Res 2018;13:169. https://doi.org/10.1186/s13018-018-0868-0.

[16] Pan L, Zhang P, Yin Q. Comparison of tissue damages caused by endoscopic lumbar discectomy and traditional lumbar discectomy: a randomised controlled trial. Int J Surg 2014;12:534–7. https://doi.org/10.1016/j.ijsu.2014.02.015.

[17] Wu P-F, Liu B-H, Wang B, Li Y-W, Dai Y-L, Qing Y-L, et al. Complications of full-endoscopic versus microendoscopic foraminotomy for cervical radiculopathy: a systematic review and meta-analysis. World Neurosurg 2018;114:217–27. https://doi.org/10.1016/j.wneu.2018.03.099.

[18] Ruetten S, Hahn P, Oezdemir S, Baraliakos X, Merk H, Godolias G, et al. Full-endoscopic uniportal decompression in disc herniations and stenosis of the thoracic spine using the interlaminar, extraforaminal, or transthoracic retropleural approach. J Neurosurg Spine 2018;29:157–68. https://doi.org/10.3171/2017.12.SPINE171096.

[19] Treuting R. Minimally invasive orthopedic surgery: arthroscopy. Ochsner J 2000;2:158–63.

[20] Kong L, Shang X-F, Zhang W-Z, Duan L-Q, Yu Y, Ni W-J, et al. Percutaneous endoscopic lumbar discectomy and microsurgical laminotomy : A prospective, randomized controlled trial of patients with lumbar disc herniation and lateral recess stenosis. Orthopade 2019;48:157–64. https://doi.org/10.1007/s00132-018-3610-z.

[21] Teli M, Lovi A, Brayda-Bruno M, Zagra A, Corriero A, Giudici F, et al. Higher risk of dural tears and recurrent herniation with lumbar micro-endoscopic discectomy. Eur Spine J 2010;19:443–50. https://doi.org/10.1007/s00586-010-1290-4.

[22] Choi K-C, Shim H-K, Hwang J-S, Shin SH, Lee DC, Jung HH, et al. Comparison of surgical invasiveness between microdiscectomy and 3 different endoscopic discectomy techniques for lumbar disc herniation. World Neurosurg 2018;116:e750–8. https://doi.org/10.1016/j.wneu.2018.05.085.

[23] Jarebi M, Awaf A, Lefranc M, Peltier J. A matched comparison of outcomes between percutaneous endoscopic lumbar discectomy and open lumbar microdiscectomy for the treatment of lumbar disc herniation: a 2-year retrospective cohort study. Spine J 2020. https://doi.org/10.1016/j.spinee.2020.07.005.

[24] Nie H, Zeng J, Song Y, Chen G, Wang X, Li Z, et al. Percutaneous endoscopic lumbar discectomy for L5-S1 disc herniation via an interlaminar approach versus a transforaminal approach: a prospective randomized controlled study with 2-year follow up. Spine (Phila Pa 1976) 2016;41 (Suppl 1):B30–7. https://doi.org/10.1097/BRS.0000000000001810.

[25] Chen Z, Zhang L, Dong J, Xie P, Liu B, Wang Q, et al. Percutaneous transforaminal endoscopic discectomy compared with microendoscopic discectomy for lumbar disc herniation: 1-year results of an ongoing randomized controlled trial. J Neurosurg Spine 2018;28:300–10. https://doi.org/10.3171/2017.7.SPINE161434.

[26] Yu P, Qiang H, Zhou J, Huang P. Percutaneous transforaminal endoscopic discectomy versus micro-endoscopic discectomy for lumbar disc herniation: Two-year results of a randomized controlled trial. Spine (Phila Pa 1976) 2020;45:493–503. https://doi.org/10.1097/BRS.0000000000003314.

[27] Park S-M, Kim G-U, Kim H-J, Choi JH, Chang B-S, Lee C-K, et al. Is the use of a unilateral biportal endoscopic approach associated with rapid

recovery after lumbar decompressive laminectomy? a preliminary analysis of a prospective randomized controlled trial. World Neurosurg 2019;128:e709–18. https://doi.org/10.1016/j.wneu.2019.04.240.
[28] McGrath LB, White-Dzuro GA, Hofstetter CP. Comparison of clinical outcomes following minimally invasive or lumbar endoscopic unilateral laminotomy for bilateral decompression. J Neurosurg Spine 2019:1–9. https://doi.org/10.3171/2018.9.SPINE18689.
[29] Iwai H, Inanami H, Koga H. Comparative study between full-endoscopic laminectomy and microendoscopic laminectomy for the treatment of lumbar spinal canal stenosis. J Spine Surg (Hong Kong) 2020;6:E3–11. https://doi.org/10.21037/jss-20-620.
[30] Komatsu J, Muta T, Nagura N, Iwabuchi M, Fukuda H, Kaneko K, et al. Tubular surgery with the assistance of endoscopic surgery via a paramedian or midline approach for lumbar spinal canal stenosis at the L4/5 level. J Orthop Surg (Hong Kong) 2018;26:2309499018782546. https://doi.org/10.1177/2309499018782546.
[31] Minamide A, Yoshida M, Simpson AK, Nakagawa Y, Iwasaki H, Tsutsui S, et al. Minimally invasive spinal decompression for degenerative lumbar spondylolisthesis and stenosis maintains stability and may avoid the need for fusion. Bone Joint J 2018;100-B:499–506. https://doi.org/10.1302/0301-620X.100B4.BJJ-2017-0917.R1.
[32] Youn MS, Shin JK, Goh TS, Son SM, Lee JS. Endoscopic posterior decompression under local anesthesia for degenerative lumbar spinal stenosis. J Neurosurg Spine 2018;29:661–6. https://doi.org/10.3171/2018.5.SPINE171337.
[33] Oertel JM, Burkhardt BW. Endoscopic surgical treatment of lumbar synovial cyst: detailed account of surgical technique and report of 11 consecutive patients. World Neurosurg 2017;103:122–32. https://doi.org/10.1016/j.wneu.2017.02.075.
[34] Tacconi L, Spinelli R, Serra G, Signorelli F, Giordan E. Full-endoscopic removal of lumbar juxtafacet cysts: a prospective multicentric study. World Neurosurg 2020;141:e414–22. https://doi.org/10.1016/j.wneu.2020.05.166.
[35] Komp M, Hahn P, Ozdemir S, Merk H, Kasch R, Godolias G, et al. Operation of lumbar zygoapophyseal joint cysts using a full-endoscopic interlaminar and transforaminal approach: prospective 2-year results of 74 patients. Surg Innov 2014;21:605–14. https://doi.org/10.1177/1553350614525668.
[36] Kim K-H, Kim S-Y, Ok H-G, Kim T-K. A staged treatment of symptomatic lumbar intraspinal synovial cysts. Pain Physician 2019;22:E451–6.
[37] Murata S, Minamide A, Takami M, Iwasaki H, Okada S, Nonaka K, et al. Microendoscopic decompression for lumbar spinal stenosis caused by facet joint cyst: a novel technique with cyst dyeing protocol and cohort comparison study. J Neurosurg Spine 2021;Jan 15:1–7 In press. https://doi.org/10.3171/2020.8.SPINE201209.
[38] Li T, Zhu B, Liu X. Revision strategy of symptomatic lumbar adjacent segment degeneration: full endoscopic decompression versus extended posterior interbody fusion. World Neurosurg 2020;142:e215–22. https://doi.org/10.1016/j.wneu.2020.06.168.
[39] Kim J-E, Yoo H-S, Choi D-J, Park EJ, Jee S-M. Comparison of minimal invasive versus biportal endoscopic transforaminal lumbar interbody fusion for single-level lumbar disease. Clin Spine Surg 2020. https://doi.org/10.1097/BSD.0000000000001024.
[40] Kamson S, Lu D, Sampson PD, Zhang Y. Full-endoscopic lumbar fusion outcomes in patients with minimal deformities: a retrospective study of data collected between 2011 and 2015. Pain Physician 2019;22:75–88.
[41] Heo DH, Son SK, Eum JH, Park CK. Fully endoscopic lumbar interbody fusion using a percutaneous unilateral biportal endoscopic technique: technical note and preliminary clinical results. Neurosurg Focus 2017;43:E8. https://doi.org/10.3171/2017.5.FOCUS17146.
[42] Ahn Y, Youn MS, Heo DH. Endoscopic transforaminal lumbar interbody fusion: a comprehensive review. Expert Rev Med Devices 2019;16:373–80. https://doi.org/10.1080/17434440.2019.1610388.
[43] Ji-Jun H, Hui-Hui S, Zeng-Wu S, Liang Z, Qing L, Heng-Zhu Z. Posterior full-endoscopic cervical discectomy in cervical radiculopathy: A prospective cohort study. Clin Neurol Neurosurg 2020;195:105948. https://doi.org/10.1016/j.clineuro.2020.105948.
[44] Yuan H, Zhang X, Zhang L-M, Yan Y-Q, Liu Y-K, Lewandrowski K-U. Comparative study of curative effect of spinal endoscopic surgery and anterior cervical decompression for cervical spondylotic myelopathy. J Spine Surg (Hong Kong) 2020;6:S186–96. https://doi.org/10.21037/jss.2019.11.15.
[45] Ahn Y, Keum HJ, Shin SH. Percutaneous endoscopic cervical discectomy versus anterior cervical discectomy and fusion: a comparative cohort study with a five-year follow-up. J Clin Med 2020;9. https://doi.org/10.3390/jcm9020371.
[46] Akiyama M, Koga H. Early experience of single level full endoscopic posterior cervical foraminotomy and comparison with microscope-assisted open surgery. J Spine Surg (Hong Kong) 2020;6:391–6. https://doi.org/10.21037/jss-20-491.
[47] Kim CH, Kim KT, Chung CK, Park SB, Yang SH, Kim SM, et al. Minimally invasive cervical foraminotomy and diskectomy for laterally located soft disk herniation. Eur Spine J 2015;24:3005–12. https://doi.org/10.1007/s00586-015-4198-1.
[48] Minamide A, Yoshida M, Simpson AK, Yamada H, Hashizume H, Nakagawa Y, et al. Microendoscopic laminotomy versus conventional laminoplasty for cervical spondylotic myelopathy: 5-year follow-up study. J Neurosurg Spine 2017;27:403–9. https://doi.org/10.3171/2017.2.SPINE16939.
[49] Oshima Y, Kato S, Doi T, Matsubayashi Y, Taniguchi Y, Tanaka S. Comparison of microendoscopic selective laminectomy versus conventional laminoplasty in patients with degenerative cervcical myelopathy: a minimum 2-year follow-up study. BMC Musculoskelet Disord 2019;20:471. https://doi.org/10.1186/s12891-019-2884-6.
[50] Cho JY, Lee S-H, Jang SH, Lee H-Y. Oblique paraspinal approach for thoracic disc herniations using tubular retractor with robotic holder: a technical note. Eur Spine J 2012;21:2620–5. https://doi.org/10.1007/s00586-012-2438-1.
[51] Jho HD. Endoscopic microscopic transpedicular thoracic discectomy. Technical note. J Neurosurg 1997;87:125–9. https://doi.org/10.3171/jns.1997.87.1.0125.
[52] Rosenthal D. Endoscopic approaches to the thoracic spine. Eur Spine J 2000;9(Suppl 1):S8–16. https://doi.org/10.1007/pl00010017.
[53] Wagner R, Telfeian AE, Iprenburg M, Krzok G, Gokaslan Z, Choi DB, et al. Transforaminal endoscopic foraminoplasty and discectomy for the treatment of a thoracic disc herniation. World Neurosurg 2016;90:194–8. https://doi.org/10.1016/j.wneu.2016.02.086.
[54] Rosenthal D, Rosenthal R, de Simone A. Removal of a protruded thoracic disc using microsurgical endoscopy. A new technique. Spine (Phila Pa 1976) 1994;19:1087–91. https://doi.org/10.1097/00007632-199405000-00018.
[55] Choi KY, Eun SS, Lee SH, Lee HY. Percutaneous endoscopic thoracic discectomy; transforaminal approach. Minim Invasive Neurosurg 2010;53:25–8. https://doi.org/10.1055/s-0029-1246159.
[56] Xiaobing Z, Xingchen L, Honggang Z, Xiaoqiang C, Qidong Y, Haijun M, et al. “U” route transforaminal percutaneous endoscopic thoracic discectomy as a new treatment for thoracic spinal stenosis. Int Orthop 2019;43:825–32. https://doi.org/10.1007/s00264-018-4145-y.
[57] Quint U, Bordon G, Preissl I, Sanner C, Rosenthal D. Thoracoscopic treatment for single level symptomatic thoracic disc herniation: a prospective followed cohort study in a group of 167 consecutive cases. Eur Spine J 2012;21:637–45. https://doi.org/10.1007/s00586-011-2103-0.
[58] Fiani B, Siddiqi I, Reardon T, Sarhadi K, Newhouse A, Gilliland B, et al. Thoracic endoscopic spine surgery: a comprehensive review. Int J Spine Surg 2020;14:762–71. https://doi.org/10.14444/7109.
[59] Isaacs RE, Podichetty VK, Sandhu FA, Santiago P, Spears JD, Aaronson O, et al. Thoracic microendoscopic discectomy: a human cadaver study. Spine (Phila Pa 1976) 2005;30:1226–31. https://doi.org/10.1097/01.brs.0000162275.95579.ee.

[60] Cornett CA, Vincent SA, Crow J, Hewlett A. Bacterial spine infections in adults: evaluation and management. J Am Acad Orthop Surg 2016;24:11–8. https://doi.org/10.5435/JAAOS-D-13-00102.

[61] Ito M, Abumi K, Kotani Y, Kadoya K, Minami A. Clinical outcome of posterolateral endoscopic surgery for pyogenic spondylodiscitis: results of 15 patients with serious comorbid conditions. Spine (Phila Pa 1976) 2007;32:200–6. https://doi.org/10.1097/01.brs.0000251645.58076.96.

[62] Yang S-C, Chen W-J, Chen H-S, Kao Y-H, Yu S-W, Tu Y-K. Extended indications of percutaneous endoscopic lavage and drainage for the treatment of lumbar infectious spondylitis. Eur Spine J 2014;23:846–53. https://doi.org/10.1007/s00586-013-3157-y.

[63] Iwata A, Ito M, Abumi K, Sudo H, Kotani Y, Shono Y, et al. Fungal spinal infection treated with percutaneous posterolateral endoscopic surgery. J Neurol Surg A Cent Eur Neurosurg 2014;75:170–6. https://doi.org/10.1055/s-0032-1329268.

[64] Fu T-S, Chen L-H, Chen W-J. Minimally invasive percutaneous endoscopic discectomy and drainage for infectious spondylodiscitis. Biomed J 2013;36:168–74. https://doi.org/10.4103/2319-4170.112742.

[65] Chen H-C, Huang T-L, Chen Y-J, Tsou H-K, Lin W-C, Hung C-H, et al. A minimally invasive endoscopic surgery for infectious spondylodiscitis of the thoracic and upper lumbar spine in immunocompromised patients. Biomed Res Int 2015;2015:780451. https://doi.org/10.1155/2015/780451.

[66] Yang S-C, Fu T-S, Chen L-H, Chen W-J, Tu Y-K. Identifying pathogens of spondylodiscitis: percutaneous endoscopy or CT-guided biopsy. Clin Orthop Relat Res 2008;466:3086–92. https://doi.org/10.1007/s11999-008-0441-y.

[67] Roselli R, Iacoangeli M, Pompucci A, Trignani R, Restuccia D, Di Lazzaro V, et al. Anterior cervical epidural abscess treated by endoscopy-assisted minimally invasive microsurgery via posterior approach. Minim Invasive Neurosurg 1998;41:161–5. https://doi.org/10.1055/s-2008-1052034.

[68] Sehn JK, Gilula LA. Percutaneous needle biopsy in diagnosis and identification of causative organisms in cases of suspected vertebral osteomyelitis. Eur J Radiol 2012;81:940–6. https://doi.org/10.1016/j.ejrad.2011.01.125.

[69] Chew FS, Kline MJ. Diagnostic yield of CT-guided percutaneous aspiration procedures in suspected spontaneous infectious diskitis. Radiology 2001;218:211–4. https://doi.org/10.1148/radiology.218.1.r01ja06211.

[70] Rosenthal D, Marquardt G, Lorenz R, Nichtweiss M. Anterior decompression and stabilization using a microsurgical endoscopic technique for metastatic tumors of the thoracic spine. J Neurosurg 1996;84:565–72. https://doi.org/10.3171/jns.1996.84.4.0565.

[71] Kan P, Schmidt MH. Minimally invasive thoracoscopic approach for anterior decompression and stabilization of metastatic spine disease. Neurosurg Focus 2008;25:E8. https://doi.org/10.3171/FOC/2008/25/8/E8.

[72] Joo Y-C, Ok W-K, Baik S-H, Kim H-J, Kwon O-S, Kim K-H. Removal of a vertebral metastatic tumor compressing the spinal nerve roots via a single-port, transforaminal, endoscopic approach under monitored anesthesia care. Pain Physician 2012;15:297–302.

[73] Telfeian AE, Choi DB, Aghion DM. Transforaminal endoscopic surgery under local analgesia for ventral epidural thoracic spinal tumor: Case report. Clin Neurol Neurosurg 2015;134:1–3. https://doi.org/10.1016/j.clineuro.2015.03.022.

[74] Cofano F, Di Perna G, Marengo N, Ajello M, Melcarne A, Zenga F, et al. Transpedicular 3D endoscope-assisted thoracic corpectomy for separation surgery in spinal metastases: feasibility of the technique and preliminary results of a promising experience. Neurosurg Rev 2020;43:351–60. https://doi.org/10.1007/s10143-019-01204-2.

[75] Kim J-S, Yeung A, Lokanath YK, Lewandrowski K-U. Is Asia truly a hotspot of contemporary minimally invasive and endoscopic spinal surgery? J Spine Surg (Hong Kong) 2020;6:S224–36. https://doi.org/10.21037/jss.2019.12.13.

[76] Kim J-E, Choi D-J, Park EJJ, Lee H-J, Hwang J-H, Kim M-C, et al. Biportal endoscopic spinal surgery for lumbar spinal stenosis. Asian Spine J 2019;13:334–42. https://doi.org/10.31616/asj.2018.0210.

[77] Yoon JW, Wang MY. The evolution of minimally invasive spine surgery. J Neurosurg Spine 2019;30:149–58. https://doi.org/10.3171/2018.11.SPINE181215.

[78] Nomura K, Yoshida M. Assessment of the learning curve for microendoscopic decompression surgery for lumbar spinal canal stenosis through an analysis of 480 cases involving a single surgeon. Glob Spine J 2017;7:54–8. https://doi.org/10.1055/s-0036-1583943.

[79] Sharif S, Afsar A. Learning curve and minimally invasive spine surgery. World Neurosurg 2018;119:472–8. https://doi.org/10.1016/j.wneu.2018.06.094.

[80] Marappan K, Jothi R, Paul Raj S. Microendoscopic discectomy (MED) for lumbar disc herniation: comparison of learning curve of the surgery and outcome with other established case studies. J Spine Surg (Hong Kong) 2018;4:630–7. https://doi.org/10.21037/jss.2018.06.14.