Review Article

A narrative review of endoscopic spine surgery: history, indications, uses, and future directions

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Background and Objective: The concept of endoscopic surgery began in the 1930s and has since undergone numerous advancements in both technology and surgical indications. Its main benefit is providing the opportunity to perform surgery while minimizing disruption to surrounding structures. The purpose of this review is to summarize the history, uses, and future directions for spine endoscopic surgery.

Methods: A review of national databases was performing using key terms "endoscopic", "spine" and "surgery" for literature from 1900 to 2023. Studies that aimed to describe the utilities of endoscopic surgeries, associated outcomes, limitations, and future directions were included. Studies that were not in English were excluded.

Key Content and Findings: This review includes a brief overview of the history of endoscopic surgery and its current two main approaches, transforaminal and interlaminar approaches. It then summarizes the main indications and utilization of endoscopic surgery in the lumbar, cervical and thoracic spine, as well as expansion in managing spine tumors, infections, and outpatient surgical cases.

Conclusions: There are many rising indications and uses for endoscopic spine surgery in nearly every aspect of the spine. Compared to conventional spine surgery, there is early evidence showing endoscopic surgery is associated with less post-operative pain, shorter hospital stays, and possibly quicker recovery times. As current trends in spine surgery move towards minimally invasive techniques, it is anticipated that the use of endoscopic surgery will continue to expand.

Keywords: Endoscopic; spine; surgery; history

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Introduction

Endoscopic spine surgery is becoming increasingly popular in modern day spine surgery. It originated in the early 1900s when orthopedic surgeons were using arthroscopic tools to visualize the spinal cord (1) and has since undergone several technological advancements with the goal of performing spine surgery with minimal disruption to surrounding structures. Early studies have demonstrated associations with less post-operative pain, shorter hospital stays, and subsequently fewer complications or need for revision surgeries compared to conventional open surgeries. However, endoscopic surgery is also associated with its own

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Table 1 Search strategy summary

Items	Specification
Dates of search	July 1–July 31, 2023
Databases and other sources searched	PubMed, SCOPUS
Search terms used	"Endoscopic"; "spine"; "surgery"
Timeframe	1900–2023
Inclusion criteria	English language; PubMed-indexed journal
Selection process	Conducted by all authors independently; all sources reviewed and selected by senior author (H.Z.)

unique complications related to its steep learning curve for spine surgeons. Due to the rapid advancements in spine surgery, it is important to understand current indications and uses for endoscopic spine surgery. The purpose of this review is to summarize indications, different utilities, and surgical settings of endoscopic spine surgery. We present this article in accordance with the Narrative Review reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-23-112/rc).

Methods

A review of national databases (PubMed and SCOPUS) was performed using literature from 1900 to 2023. Keywords included terms "Endoscopic", "Spine" and "Surgery". Studies that aimed to describe the utilities of endoscopic surgeries, clinical and radiological outcomes, limitations, and future directions were included (*Table 1*). Studies unavailable in English were excluded.

History of endoscopic spine surgery

The concept of endoscopic spine surgery originated in the 1930s when Burman utilized arthroscopic instruments to perform "myeloscopies", visualizing the spinal cord and nerves roots in cadavers (1,2). Shortly afterwards, Pool and Ooi (3-5) began performing myeloscopies on patients with notable improved visualization of neurologic structures. Since then, technological advancements in optic and microscopic systems have made minimally invasive spine (MIS) surgery a fast-growing innovation. Initial attempts to reach the disc space percutaneously began in the 1970s when Kambin and Sampson (6) and Hijikata (7) introduced a fluoroscopic-guided approach for percutaneous discectomy via cannula (8). The transforaminal approach was facilitated by understanding of Kambin's safe zone, describing the safe triangular zone for docking and addressing foraminal pathology (9). This subsequently led to Kambin *et al.* (10) reporting direct visualization using endoscopes in 1988 and Schreiber *et al.* (11) using arthroscopic instruments for removal of disc material under direct visualization in 1989 for sciatica symptoms.

In the 1990s, Yeung developed the first fully functional uniportal endoscopic system and described successful outcomes in management of disc herniation (12). Water-based endoscopy utilizes continuous irrigation to cleanse the field and provide constant visualization. At the same time, Caspar innovated the tubular approach and Foley performed the first tubular-based microendoscopic discectomy and demonstrated its utility in addressing central spinal canal and lateral recesses (13,14). Unfortunately, tubular retractors require a microscope and full uniportal endoscopic surgery is technically challenging as it utilizes a single portal for the light source, irrigation, and instrumentation (15). As a result, biportal endoscopic surgery was developed, one portal for visualization and the other for instrumentation, to improve surgical visualization and ability to manipulate instruments (15). De Antoni *et al.*'s 1996 technical note (16) was the first documentation of use of endoscopes and instruments inserted separately through two portals; the authors subsequently demonstrated use of standard arthroscopic instruments for magnification, illumination, and irrigation and reported good clinical results (17). More recently, Soliman *et al.* reported surgical outcomes using unilateral biportal endoscopic surgery techniques with independent portals for disc herniation and spinal stenosis, demonstrating methods similar to current ones (18). Subsequent literature has demonstrated that unilateral biportal endoscopic surgery offers low blood loss, early discharge, familiar working space, and adequately wide

visualization (19). Since these developments in MIS surgery, there have been significantly more advances in technology and techniques in endoscopic spine surgery, leading to more widespread adoption and utilization.

Approaches

The two most utilized approaches for endoscopic spine surgery are the transforaminal and interlaminar approaches. The transforaminal approach is the most common method used in endoscopic spine surgery for discectomy (8). It initially started as an intra-discal or "inside-out" procedure until Yeung described performing foraminoplasty to expand foramen and improve visualization post-discectomy (20). By the mid-2000s, Schubert and Hoogland described their technique for transforaminal endoscopic discectomy using reamers to expand the foraminal window and removing the ventral portion of the superior articular process (21). This marked the beginning of an "outside-in" approach in which visualization was required to perform discectomy. Now, the main draw of transforaminal endoscopic surgery is that it is considered a "bypass surgery", representing a direct approach to the area of pathology through a safe foraminal window. In this approach, a far lateral incision is used to allow instruments to access the extraforaminal and lateral foraminal zones in Kambin's triangle. Kambin's triangle was initially described as an anatomical corridor bordered anteriorly by the exiting root, inferiorly by the proximal plate of the lower lumbar segment, posteriorly by the proximal articular process of the inferior vertebra, and medially by the traversing nerve root and dural sac (22). Since then, many variations have existed regarding its exact dimensions and the term "Kambin's prism" includes the assignment of the superior articular process as a border to standardize this approach in spine surgery (22). It is most effective for isolated unilateral foraminal conditions or disc pathology causing neural compression in the central canal or lateral recess. In foraminal stenosis patients, the transforaminal approach is successful with good long-term outcomes (23). However, it remains limited in addressing other sources of central stenosis, including facet and ligamentum flavum hypertrophy (2) and in reaching lower levels such as L5/S1 as the iliac crest blocks it.

These limitations inspired the development of the interlaminar approach, which provides visualization similar to conventional open surgery. Current interlaminar techniques mirror those of tubular techniques with the added advantage of improved visualization via endoscope which can be maneuvered at the surgeon's discretion (20). In this approach, a paramedian incision is used to access the lamina and interlaminar space, allowing the surgeon direct access to spinal structures within the central canal and lateral recesses. It also allows better access to lower spine levels, such as L5/S1 which has a larger interlaminar window. Utilization of endoscopes helps preserve bony anatomy and bilateral facet joints more effectively than conventional open surgery (8).

In addition to these main surgical approaches, there is also the option of uniportal versus biportal endoscopy. Uniportal endoscopy was described first with excellent clinical outcomes. However, there was noted to be limitations in handling surgical instruments, specifically nerve root retractors, around neural structures due to small working spaces (24). Biportal endoscopic spinal surgery includes separates endoscopic viewing and working channels which involves the use of one portal for the endoscopic and the other for instrumentation (25). Many studies have demonstrated that endoscopic spine surgery provides more favorable results than microscopic techniques, however which endoscopic technique is most effective remains inconclusive (20,24,25). This review paper will describe the current utilization of both uniportal and bipolar techniques in cervical, thoracic, and lumbar endoscopic spine surgery.

Uses

Lumbar spine

The transforaminal approach has been primarily used for endoscopic lumbar discectomies and foraminotomies and can be used for partial resection of the pedicle and foramen in complex cases. Studies have demonstrated that compared to open surgery, endoscopic decompression surgery produces good results and lower complication rates (26). However, Chen *et al.* (27) found that patients with prolapsed disc herniation, higher degenerative severity, higher lumbar level involvement, and longer pre-operative symptom duration were associated with less satisfactory outcomes after endoscopic discectomy and higher re-operation rates. The interlaminar approach is more often used to treat central stenosis and lower spinal levels. Because of its high resolution, endoscopic surgery has shown similar or superior results compared to conventional central decompression technique. It is also associated with shorter hospital stays and subsequently fewer complications and revisions compared to minimally invasive surgery (28). In

patients with mild central stenosis and unilateral foraminal stenosis, endoscopic lumbar fusion is a growing treatment option. However, patients with severe central stenosis, bilateral foraminal stenosis, or high-grade spondylolisthesis may have limitations (29,30).

The motivation for using endoscopic approaches for decompression is to minimize soft tissue damage and spinal destabilization to avoid the need for fusion. However, endoscopy can be used in patients in whom fusion with placement of interbody devices is indicated. It is now common for spine surgeons to utilize tubular retractors for microscopic visualization during minimally invasive transforaminal lumbar interbody fusion (TLIF) procedures to accomplish neural decompression and interbody space preparation and cage placement. Endoscopic setups can be utilized for these same tasks with the theoretical advantage of smaller working channels with subsequently less tissue disruption. A disadvantage to endoscopic fusion includes limitations in interbody size due to smaller access channels, though some have suggested the development of expandable interbody cages may limit the impact of this restriction (2).

It has been shown that endoscopic lumbar interbody fusions can adjust foraminal and disc height, improve overall alignment and listhesis, and minimize soft tissue damage during interbody insertion (30). The most common and well-described procedure is the endoscopic TLIF. Several studies have demonstrated that biportal endoscopic TLIF and minimally invasive TLIF show no differences in clinical outcomes (31-33). Specifically, those undergoing uniportal endoscopic fusion have been demonstrated to have better recovery, fewer consumed opioids, earlier mobilization, and shorter length of hospital stay (30). There have been no significant differences reported in early and midterm outcomes and fusion rates between biportal and full endoscopic fusion groups (31). Overall, current studies find that both uniportal and biportal endoscopy are safe and effective in treating lumbar degenerative disease as a whole (20). It should be noted, however, that fusion rates over 2 years, long-term clinical outcomes, and randomized controlled trials are yet to be reported (33). Furthermore, there is the possibility of selection bias in pre-existing studies as surgeons may be selecting patients with less severe degenerative disease for endoscopic surgery given its relative novelty.

Recent studies have also explored endoscopic lateral lumbar interbody fusions (LLIF). The endoscopic indications for LLIF are largely the same and are associated with improved post-operative pain, faster rehabilitation, and improved long-term patient-reported outcome measures compared to open procedures (29). However, endoscopic surgery is associated with its own unique complications secondary to steep learning curves by practicing spine surgeons (34). Most commonly described complications include persistent pain or symptoms, dural tear, incomplete decompression, and nerve injury (35). Dorsal root ganglion injuries have been noted with the transforaminal approach leading some surgeons to adopt the endoscopic trans-superior articular process approach in patients with advanced degeneration and distorted anatomy (36). Endoscopic spine surgery also has the unique water-based complications of tissue edema but a mean pressure of 30 mmHg is safe for irrigation-based surgeries, and constant irrigation improves overall visualization (37).

Endoscopic spine surgery in revision cases has demonstrated early promising results in terms of foraminal decompression in previously fused segments and removal of hardware. However, decompression of adjacent segments remains challenging and further studies are required (38). One study compared endoscopic decompression with revision posterior lumbar interbody fusion (PLIF) and found equivalent outcomes in patients with stable adjacent segment disease but improved outcomes in the PLIF group for patients with unstable adjacent segment disease, particularly in regard to function and leg pain 2 years postoperatively (39).

Cervical spine

Percutaneous endoscopic cervical discectomy (PECD) has emerged as a safe and effective procedure in treating cervical spine pathology and has been mainly divided into anterior transdiscal approach and posterior interlaminar approach (40). Radiculopathy due to foraminal disc herniation or foraminal stenosis are the main indications for PECD. Reduction of incision size and less muscle dissection could result in lower blood loss, periosteal stripping, and bony removal compared to open cases (41). Compared to traditional anterior cervical discectomy and fusion (ACDF), PECD has demonstrated equivalent patient-reported outcomes with lower blood loss and fewer complications, though pooling of data from cohort studies comparing PECD and ACDF showed no differences in patient-reported outcomes (42-46). Ruetten *et al.* (47) performed a level I randomized trial between posterior endoscopic discectomy and fusion (PEDF) and ACDF and found no differences in outcomes between the groups, with lower

rates of dysphagia in the PECF group. Moreover, meta-analyses using level II and III studies comparing PECF to ACDF demonstrated significantly greater improvement in arm pain scores in the PECF group (42-46).

Although most studies have focused on decompression of cervical foramen, some have reported on endoscopic decompression for central stenosis in the cervical spine. Compared to conventional laminotomy, patients who underwent cervical microendoscopic laminotomy for cervical spondylotic myelopathy were found to have similar functional outcomes with less post-operative neck pain and improved lordosis (48). Additionally, some cases of cervical laminoplasty have been reported as well with good outcomes and fewer perioperative complications for cervical myelopathy (49). However, further studies are required to better characterize the utility of endoscopic surgery in central decompression in the cervical spine.

If the primary pathology is located at the lateral border of the spinal cord, the posterior approach may be preferred as it is more accessible than the anterior approach. However, the anterior approach may be more effective for central or paracentral pathology to reduce spinal cord retraction (50). ACDF has long been the gold standard of surgical technique in cervical disc herniation. Several recent studies have demonstrated favorable clinical outcomes of anterior full endoscopic cervical discectomy in patients with soft central/paracentral disc herniations, unilateral radiculopathy, and myelopathy in high-risk surgical patients (50-52). Ahn *et al.* demonstrated 5-year postoperative outcomes of anterior full endoscopic discectomy for soft disc herniation and showed comparable results with conventional ACDF (44). Zhang *et al.* (53) reported successful clinical outcomes and shorter operation times and subsequent hospital stays compared to conventional ACDF surgeries. Attempts at full endoscopic anterior cervical discectomies are reportedly in process but relevant research has yet to be reported. The majority of published data on endoscopic surgery in the cervical spine utilizes uniportal endoscopic techniques. The biportal technique is currently only used in posterior approaches and primarily for treating disk herniations but its indications are growing and becoming increasingly studied (54).

Thoracic spine

While endoscopic techniques have been used to treat thoracic spine pathology for several decades, there is a relative paucity of literature (55-64). Most conventional open thoracic spine approaches require extensive resection of ribs and soft tissues and are associated with pulmonary complications and intensive care unit stays (65,66). In an attempt to decrease complication rates of conventional thoracic approaches, Choi *et al.* (61) performed a 5-year follow-up for endoscopic transforaminal thoracic discectomy on 14 patients with thoracic disc herniation. This study demonstrated significant post-operative improvement in Visual Analogue Scale and Oswestry Disability Index scores. Ruetten *et al.* (55) evaluated the technical implementation and outcomes of a full-endoscopic uniportal technique in 55 patients with symptomatic disc herniation and stenosis in the thoracic spine, concluding on average that sufficient decompression was achieved. However, there was a 19% complication rate, including episodes of epidural hematoma and durotomies. There are several permutations in surgical techniques, including robotic assistance (56), use of a 70° angled endoscope (57), and surgery performed on patients with local anesthesia and light sedation (59,61). Ultimately, initial outcomes for thoracic endoscopic decompression appear to be promising but still associated with elevated risk for post-operative complications. Furthermore, there is an even greater paucity of biportal endoscopy in the thoracic spine. Kim *et al.* recently published a study on the efficacy of biportal endoscopic posterior thoracic approach in treating spondylotic myelopathy secondary to ossification of the ligamentum flavum. However, only 16 patients were included and they commented on how technically demanding the procedure was (67). Further studies are required to better evaluate the utility of current endoscopic techniques in thoracic spine surgery.

Tumor

Currently, few studies describe the potential utility of endoscopic spine surgery in tumor cases. Endoscopic spine surgery may be of particular benefit in cancer patients with spinal metastasis who are poor medical candidates for invasive open surgical interventions. In this patient population, endoscopic intervention may play a role in palliative surgical management, namely to remove tumor mass, provide pain relief, and preserve neurologic function (68). In 2020, Telfeian *et al.* presented three cases of metastatic cancer in the thoracic or lumbar spine that were resected endoscopically through a transforaminal approach (69). Although these procedures were performed without complication, one noted limitation with endoscopic resection of an epidural spinal tumor is that the surgeon is unable to visualize what is happening to the spinal cord

during tumor manipulation. In the largest cohort to date, a worldwide network of spine surgeons reported on 29 patients who underwent palliative endoscopic treatment of spine metastasis (70). An endoscopic interlaminar approach was performed on 73.33% of the patients compared to a transforaminal approach on 26.67% of patients, and all achieved good to excellent outcomes including neurologic improvement, decreased pain, and shorter hospital length of stay. However, given the limited available literature, further studies are required to better evaluate the indications and techniques for endoscopic surgery in tumor cases.

Infection

Several studies have suggested endoscopic techniques as a viable adjunct for treating spine infections such as discitis and epidural abscesses that are unable to be treated by medical management alone. Endoscopy allows for the direct observation of infected tissue or disc space to confirm adequate sampling for diagnostic examination and sufficient local debridement and eradication. A recent systematic review of 14 studies of patients with spondylodiscitis treated with endoscopic debridement noted treatment failure rates ranging from 0 to 33%, although indications for endoscopic approaches were poorly defined (71). One perceived benefit noted in studies is a diagnostic superiority with endoscopic biopsy of vertebral osteomyelitis when compared to the traditional method of computed tomography (CT)-guided interventional radiology (IR) biopsy (2). The diagnostic accuracy of image-guided IR biopsy for discitis is variable in literature, with a metanalysis by McNamara *et al.* suggesting a moderate yield of only 48% (72). In 2014, Yang *et al.* demonstrated endoscopic biopsy to determine the respective pathogen in 18 out of 20 cases, compared to 15 out of 32 cases with CT-guided biopsy (P=0.002) (73). Furthermore, a considerable percentage of patients with spinal infections tend to be immunocompromised with significant medical comorbidities, oftentimes with varying degrees of nutritional status (74,75). A less invasive, percutaneous endoscopic lavage and drainage of a spinal infection with medical management may be of considerable clinical benefit in these patients in situations where it is felt an extensive and open debridement can be reasonably avoided. However, further studies are required to support this theory and standardize endoscopic techniques in treating spine infections.

Surgical setting

As the utilization of outpatient spine surgery overall continues to increase, increasing trends of MIS surgery and endoscopic spine surgery will likely contribute to this trend (76). MIS surgery techniques, such as endoscopic discectomy or fusions, have the potential to incur less trauma to the body and thus morbidity during surgery than standard open procedures. Literature has shown it can lead to a reduction in postoperative narcotic pain medication and decreased blood loss, variables favorable for outpatient surgery (77). Lee *et al.* found a decrease in hospital stay in patients who underwent transforaminal endoscopic discectomy (0.9 days) compared to patients that underwent open discectomy (3.8 days) (78). In a retrospective study of 1,839 consecutive patients, Lewandrowski *et al.* reported significantly lower complication rates with outpatient transforaminal endoscopic decompression with significant cost savings when compared to inpatient (26). In regard to endoscopic MIS fusion approaches and techniques, success in the ambulatory setting is documented concerning endoscopic TLIF, while a paucity of literature remains on other endoscopic fusion techniques as it relates to the outpatient setting (79).

Conclusions

Advancements in endoscopic spine surgery are occurring rapidly as there are increasing trends towards utilizing of MIS surgery techniques. Endoscopic surgery already has several uses within all levels of the spine, as well as more complex tumor and infection cases. The benefit endoscopic surgery is direct visualization of the operative level with minimal disruption to surrounding bony and soft tissue structures. This subsequently reduces the morbidity associated with larger open surgeries, speeding up recovery time with the goal of achieving equivalent or improved functional results. As the indications for endoscopic surgery continue to grow, we anticipate more spine surgeons incorporating its use into their practices. Future studies are required to better characterize outcomes of endoscopic surgery compared to conventional open surgeries and the impact of its unique complications on functional outcomes.

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