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REVIEW ARTICLE

Why Endoscopic Spine Surgery? An In-depth Look at Its Benefits and Rationale

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Abstract

The objectives of spinal surgery include the effective decompression of neural structures, ensuring spinal stability, and the proper fixation of an unstable vertebral column. Such surgical aims necessitate unavoidable harm to healthy tissues, such as the spine and adjacent soft tissues, once spinal surgery commences. Significant injury to the normal vertebral structure and adjacent paraspinal tissues during the procedure can result in negative outcomes characterized by ongoing axial discomfort and the need for further operations due to new instances of spinal instability. A variety of strategies, including the use of microscopes, tubular retractor systems, percutaneous tools, and the exploration of innovative surgical techniques, have been employed to minimize damage to healthy tissues and enhance surgical results. Introduced approximately thirty years ago, endoscopic spine surgery (ESS) represents a less invasive approach and has gained widespread acceptance with the advancement of endoscopic surgical tools and the introduction of novel endoscopic techniques over the last two decades. In theory, ESS could be considered the optimal method for spinal operations due to its reduced impact on tissues and superior visualization of the operative area. Nonetheless, surgeons are often reluctant to adopt ESS because of its challenging learning curve and the absence of robust evidence supporting its surgical outcomes. This article examines the logic and benefits of ESS by analyzing relevant literature.

Key words: Endoscopy, Spine, Surgery

Introduction

Maintaining a healthy spine alignment and the neuromuscular structures surrounding it is crucial for leading an active life. With the increase in life expectancy, there has been a surge in the number of patients suffering from spinal diseases (1). The primary symptoms of spinal diseases, such as axial back pain, leg pain radiating from the spine, and neurogenic claudication, can be managed with conservative treatments. These treatments include rest, pain medications, physical therapy, and lumbar epidural blocks. In cases where conservative treatments are ineffective or when neurological deficits are present, it may be necessary to consider decompression of neural structures or stabilization of the spinal column (2, 3). Various procedures, such as decompressive laminectomy, discectomy, and fusion surgery, can be performed in an open surgical field to address spinal issues. However, these

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procedures can result in damage to the paraspinal soft tissues or the spinal column, including the facet joint. This damage may sometimes necessitate additional spinal surgery (4, 5).

In the past thirty years, there has been significant advancement in minimal invasive spine surgery (MISS) to minimize harm to the spine's normal anatomy and enhance recovery outcomes. MISS is primarily categorized into two types: [1] surgeries employing a tubular retractor system and [2] endoscopic spine surgery (ESS). The use of a tubular retractor in MISS helps to lessen the injury to the muscles and ligaments surrounding the spine when compared to conventional open surgeries. However, the limited view provided by this method can lead to challenges and a higher possibility of damaging nerve tissue (6). Additionally, it is not possible to completely prevent soft tissue damage while exposing the surgical area. ESS, another key method in MISS, initially began with a slow process using a transforaminal route to extract disc herniations on the posterolateral or central side (7).

Initially, ESS faced several challenges, including limited surgical tools, poor visibility due to inadequate camera systems, excessive exposure to radiation, and a difficult learning process. Nonetheless, over the past twenty years, ESS has seen a swift expansion to include treatments for cervical and thoracic conditions, propelled by advancements in endoscopic technology and the introduction of novel surgical techniques, such as the interlaminar and biportal endoscopic approaches (8-10). This article provides a review of the literature and discusses the underlying principles and benefits of ESS.

Methods

A comprehensive review of national databases was conducted using the keywords "Endoscopic," "Spine," and "Surgery" for literature spanning from 1900 to 2024. The review included studies that aimed to describe the utilities of endoscopic surgeries, associated outcomes, limitations, and future directions. Studies not published in English were excluded.

Results

Tracing the path of spine surgery; from open to microscopic and endoscopic methods

Herniated lumbar discs and spinal stenosis are prevalent conditions of spinal degeneration that lead to motor and sensory impairments, as well as neurogenic claudication in the impacted nerve roots. Understanding the evolution of spinal surgery for these common issues, which often necessitate surgical intervention, is crucial for grasping the trajectory of future surgical advancements in this field. Historically, open surgeries involving complete or partial laminectomy were the norm to alleviate pressure on the thecal sac and nerve roots despite the risk of significant damage to surrounding muscles and ligaments (11). While such procedures could alleviate radicular pain by decompressing the nerve roots, they also posed a risk of harming healthy tissue, potentially leading to suboptimal clinical outcomes (12).

In 1978, a less invasive interlaminar technique utilizing microscopes was introduced and documented in The Spine Journal, quickly becoming the preferred method for treating lumbar disc herniations. This technique was favored for its ability to limit damage to the spine and surrounding tissues compared to traditional open surgeries (13). The widespread adoption of this microscopic approach allowed for thorough decompression of nerve roots while minimizing harm to the spinal structure and adjacent soft tissues, leading to better patient outcomes over an extended period. However, in spite of these improvements, issues such as facet joint damage and trauma to the muscles and ligaments can still contribute to ongoing back pain and hasten spinal degeneration. The advent of tools to measure functional outcomes has spurred the innovation of surgical methods and strategies aimed at conserving the integrity of the spinal column and surrounding tissues, thereby enhancing functional recovery (14).

During the evolution of the interlaminar approach with the aid of microscopes, the initial attempts at percutaneous discectomy were guided by fluoroscopy. Despite its potential, this method failed to gain widespread acceptance initially. The “Kambin triangle,” identified by Kambin as a secure access point to the lumbar disc space, was established to facilitate percutaneous surgery without harming adjacent structures, thereby reducing post-surgical back pain and aiding quicker recovery (15). Following the establishment of this technique, pioneers in spinal endoscopy began performing percutaneous discectomies, which yielded positive results. Nonetheless, for the first two decades, endoscopic discectomy did not become mainstream due to subpar endoscopic visuals, inadequate surgical tools, limited applicability, and a challenging learning curve (16-18).

Advancements in endoscopic equipment, including drills, punches, hooks, and improved camera systems, have brought endoscopic lumbar discectomy to the forefront of spinal surgery

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discussions over the past twenty years. These tools have enabled surgeons to decompress the central spinal canal, intervertebral foramen, and extraforaminal regions through various surgical pathways, such as transforaminal, ipsilateral interlaminar, contralateral interlaminar, and translaminar approaches. Biportal ESS, in particular, has gained popularity in Asia, especially in Korea (10). Although it is not considered a fully endoscopic technique, its relatively easier adoption by novices in ESS may offer an advantage in navigating the steep learning curve associated with ESS. The primary goal of lumbar spine surgery remains to minimize damage to the spinal structure and adjacent soft tissues, thereby improving functional outcomes and facilitating a faster return to normal activities. To this end, ESS has broadened its scope from treating lumbar conditions and simple decompressions to addressing cervical and thoracic spinal diseases and, ultimately, fusion surgeries (19).

The current landscape of ESS: indications, outcomes, and complications

To grasp the underlying principles of ESS, it is necessary to examine its present state, clinical applications, results, and potential risks by analyzing scholarly literature.

Indications

A PubMed search performed in April 2024 with the term "Endoscopic spine surgery" yielded a total of 4,828 articles. The majority of the literature from the late 20th century focused on transforaminal endoscopic lumbar discectomy (TELD), making up about 10% of all ESS-related articles. Since then, there has been a significant increase, with around 90% of ESS articles being published in the 21st century. The scope of ESS covered in these articles has broadened from TELD to include interlaminar endoscopic lumbar discectomy, spinal canal decompression techniques, such as unilateral laminotomy bilateral decompression (ULBD), posterior cervical endoscopic foraminotomy, thoracic decompression or discectomy, and lumbar spinal fusion surgery (20, 21). Spinal cord-level decompression is also being performed with generally positive outcomes, as reported in regional spine surgery conferences and publications (22, 23).

Biportal ESS, initially introduced in 1996 by Antoni through arthroscopy, was not widely adopted in its early years (24). However, it has recently become a prominent topic in MISS, particularly in Asia. The biportal ESS approach has evolved from an interlaminar lumbar method to include paraspinal, posterior cervical approaches, and lumbar interbody fusion surgeries, showing promising results in short-term follow-up studies (10, 25, 26). Surgeons with experience in open microscopic spine surgery may find biportal ESS easier to adopt due to the familiarity with surgical anatomy, instrument handling, and the clear, magnified view provided by large-diameter endoscopic cameras and continuous irrigation, as opposed to full-ESS. Consequently, biportal ESS could potentially minimize surgery-related complications for ESS novices, offering a valuable technique with positive outcomes and reduced collateral damage. Given these advantages, interest in ESS is growing, and its applications are extending to cover nearly all spinal conditions (19).

Outcomes

Numerous studies have evaluated the results of ESS. Initially, comparisons were drawn between percutaneous endoscopic discectomy and microdiscectomy. According to a meta-analysis by Qin et al. (27), no significant differences were found in the Visual Analog Scale (VAS) or Oswestry Disability Index (ODI) scores between the two procedures. The rates of surgery-related complications, operation duration, and recurrence were comparable. However, the percutaneous endoscopic discectomy group experienced shorter hospital stays and quicker returns to work. Another meta-analysis echoed these findings, with similar rates of complications, recurrence, and functional outcomes for both techniques. However, endoscopic discectomy was associated with shorter operation times and reduced hospital stays (28).

Percutaneous lumbar discectomy demonstrated superior mid-term and long-term outcomes in terms of back pain and ODI scores when compared to micro-endoscopic lumbar discectomy, although there were no significant differences in complication rates, recurrence, or reoperations (29). These findings suggest that percutaneous endoscopic lumbar discectomy may facilitate faster recovery and mobility, with less damage to anatomical structures and better preservation of back muscle function than traditional open microdiscectomy. Nonetheless, a recent systematic review and meta-analysis indicated that TELD yields comparable results to open microdiscectomy in terms of leg pain and functional status over intermediate and long-term periods (30). Many reports, including the aforementioned meta-analysis (30), have highlighted the benefits of quicker recovery and return to work following percutaneous lumbar discectomy. In A comprehensive study by Saghebdoust et al., conducted in a developing country, two groups

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undergoing TELD and microscopic discectomy were compared. The results showed a significant reduction in ODI and VAS scores for both groups. While perioperative complications and clinical outcomes were similar between the groups, the TELD group experienced significantly less intraoperative bleeding, shorter hospital stays, and a quicker return to work. Additionally, inpatient costs were significantly lower for the TELD group (31).

The endoscopic interlaminar technique, pioneered by Ruetten et al. (32), has been particularly embraced for addressing L5-S1 disc herniations. Prior to this innovation, ESS was primarily utilized for lumbar disc herniation cases. The advent of this interlaminar method, along with the development of specialized endoscopic equipment, such as drills and punches, has enabled surgeons to carry out decompression procedures for lumbar central and lateral recess stenosis. Clinical trials comparing this endoscopic approach to traditional open microscopic decompression for such stenosis have revealed comparable outcomes. However, the endoscopic ULBD group reported fewer complications and a reduced need for revision surgeries (33).

Biportal ESS, which evolved from the interlaminar approach, is predominantly used for discectomy and canal decompression. While theoretically more invasive than the uniportal approach, biportal ESS still offers the benefits of minimally invasive surgery when compared to conventional open microscopic methods. Its surgical anatomy is akin to that of open surgery, and the instruments are well-known to spine surgeons, potentially easing the learning process relative to full-endoscopic procedures. Reports indicate favorable results for biportal ESS, including reduced blood loss, less postoperative discomfort, and shorter hospital stays. Moreover, biportal endoscopic decompression has been shown to effectively alleviate spinal canal stenosis, leading to positive clinical outcomes (25).

A meta-analysis encompassing five comparative studies and four randomized controlled trials, with a total of 994 patients, assessed the efficacy of interlaminar endoscopic ULBD against microscopic decompression for lumbar spinal stenosis (34). The findings highlighted that the endoscopic approach significantly reduced back and leg pain and lowered the risk of complications, although no significant differences were observed in operation times or ODI scores between the two methods. Although the evidence supporting endoscopic interlaminar ULBD for lumbar spinal stenosis is not particularly robust, the technique has demonstrated promising results under the minimally invasive paradigm. Future research should focus on evaluating cost-effectiveness, postoperative satisfaction, and quality of life to further establish the surgical merit of endoscopic interlaminar ULBD.

Lumbar fusion surgery is intended to be a definitive treatment at the specific level of the spine. Traditional fusion surgery often results in unavoidable damage to adjacent tissues. To mitigate this, various lumbar fusion techniques have been developed that aim to minimize harm to healthy spinal and paraspinal tissues while ensuring effective decompression and stable fusion. Endoscopic Lumbar Interbody Fusion (ELIF), a minimally invasive procedure, has been introduced and documented. This technique can be performed through the Kambin triangle under local anesthesia, representing the least invasive fusion method. However, initial findings indicate a relatively high incidence (20%-30%) of complications, including temporary nerve damage, subsidence, and failure to fuse (35, 36).

Due to the constraints of the trans-Kambin approach for interbody fusion, a posterolateral method, such as Minimally Invasive Transforaminal Lumbar Interbody Fusion, has been adopted for endoscopic fusion. This technique allows for adequate direct decompression of the spinal canal and clear visualization of the fusion site for endplate preparation (26). The use of 3D-printed cages and advanced fusion materials, including bone morphogenetic proteins and demineralized bone matrix, are considered crucial for achieving successful long-term fusion. A systematic review and meta-analysis have indicated no significant differences in clinical outcomes or safety between ELIF and minimally invasive transforaminal lumbar interbody fusion for treating lumbar degenerative conditions (37). While endoscopic fusion surgery may require a longer operation time, it offers the benefits of reduced tissue damage and quicker postoperative recovery. Nonetheless, further research into the long-term fusion rates and quality of life, supported by randomized controlled trials, is necessary to provide high-quality evidence of its efficacy.

While numerous studies have been conducted on surgeries for cervical and thoracic spinal issues, there remains a scarcity of high-quality research featuring a substantial number of participants and extensive follow-up. Ruetten et al. have found in a controlled trial that full-endoscopic posterior cervical foraminotomy has a high success rate of 96% (38). This minimally invasive procedure can lessen intraoperative bleeding, reduce surgery duration, and alleviate immediate post-surgical pain compared to traditional open surgeries. Endoscopic foraminotomy, with or without

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discectomy, has been shown to be less invasive and yield positive clinical results compared to open microscopic foraminotomy (39).

Decompression at the spinal cord level presents greater challenges, and serious complications may arise post-surgery. Nonetheless, some experts have begun performing spinal cord-level decompression for conditions such as cervical spondylotic myelopathy or thoracic stenosis, reporting encouraging outcomes (21, 40). However, the evidence supporting spinal cord-level decompression via ESS is limited, and there is a risk of severe complications, including quadriplegia and paraplegia. Therefore, meticulous trials and a gradual approach are essential for the safe establishment of ESS for spinal cord-level decompression, taking into account the potential for serious complications.

Regarding the efficacy of ESS, lumbar ESS procedures, including decompression and fusion, have been associated with faster recovery times compared to conventional open microscopic surgery. The body of evidence supporting this is growing, bolstered by some randomized controlled trials and meta-analyses. ESS for cervical or thoracic conditions has also shown promising results, benefiting from the minimally invasive nature of the technique. However, further high-quality, evidence-based research is needed.

Intraoperative complications

Hematoma

Continuous saline irrigation provides a clear surgical area and applies hydrostatic pressure to the epidural venous plexus and the exposed spongy bone, aiding in the management of bleeding during surgery. Nonetheless, bleeding might resume once the saline irrigation and its hydrostatic pressure are discontinued in the operative field. To avert an epidural hematoma, it is advisable to place a drainage tube in the epidural space that does not irritate the nerve roots (19).

Increased intracranial pressure

Excessive hydrostatic pressure due to inadequate drainage can result in increased intracranial pressure. This may cause postoperative headaches and, in severe instances, potentially fatal seizures. Should a dural tear happen during the decompression surgery, it is crucial to conclude the operation swiftly (19).

Incidental Durotomy or Neural Tissue Injury

At present, endoscopic visuals are two-dimensional, heightening the likelihood of dural tears or damage to neural structures during endoscopic boring or other decompressive methods. It is advised to finish the bone-related tasks with the endoscopic drill prior to the full excision of the ligamentum flavum to diminish the chances of dural tears or harm to neural tissues. Subsequent bone work with petite osteotomes or slanted Kerrison punches becomes safer following the total removal of the ligamentum flavum. In instances where a dural tear occurs during the operation, most minor tears can be managed with collagen fibrin patches, avoiding the need to switch to open surgery. Nevertheless, for larger dural defects (exceeding 1 cm), an open direct suture at the site of the defect should be contemplated (19).

Benefits of Endoscopic Spine Surgery

Less Collateral Damage and Better Preservation of Facet Joint

In open microscopic decompression surgeries, including fusion, it is essential to cut and retract paraspinal soft tissues, such as muscles and ligaments. The depth of the lesion and the duration of soft tissue retraction are closely linked to the levels of serum creatinine kinase (CK), indicating that a rise in CK levels post-surgery may reflect the extent of accidental muscle damage incurred during the procedure (41). Choi et al. observed that patients undergoing open microdiscectomy experienced a greater increase in serum CK levels compared to those undergoing endoscopic discectomy (42). Additionally, the microdiscectomy group reported more postoperative back pain and longer hospital stays than the endoscopic group, suggesting that an endoscopic approach that minimizes harm to paraspinal tissues could facilitate quicker recovery and return to work.

Violating the facet joint is also a necessary part of spine surgery to ensure thorough decompression of neural elements. Failure to achieve this can lead to suboptimal surgical results due to incomplete decompression of the canal, dynamic stenosis, or early restenosis. Microscopic techniques provide a direct view of the decompression target area, often necessitating the removal of about 30% of the ipsilateral facet joint for effective decompression of the central canal and lateral recess (43). However, post-microscopic decompression can lead to increased segmental-level slippage (44). Full-endoscopic tools, with their 15° angle, allow for undercutting the facet joint, thus preserving it more effectively than microscopic surgery. The increasingly popular biportal ESS utilizes 0° and 30° endoscopy angles, which may help preserve the facet joint while enhancing the surgical view. ESS is known to lessen iatrogenic damage to both paraspinal soft tissues and the facet joint, improving

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functional outcomes and shortening hospital stays for spinal disease patients.

The use of angled endoscopy and flexible drills in ESS has led to successful decompression of foraminal lesions. Previously, fusion surgery was the primary option for severe foraminal stenosis or associated foraminal disc herniations. However, advancements in ESS instruments now allow for the treatment of lumbar foraminal lesions solely through decompression surgery, without the need for fusion. Kim et al. reported successful decompression of L5-S1 foraminal and extra-foraminal stenosis using a uniportal endoscopic contralateral approach (45). Without the development of ESS, these coexisting foraminal and extraforaminal lesions might require fusion surgery.

View Magnification and Clean Endoscopic View through Continuous Irrigation

Advancements in spinal endoscopy have enhanced the enlargement of the surgical view, thereby diminishing the risk of harming neural structures and the dura mater. Furthermore, the progression of endoscopic techniques and tools has made it feasible to entirely excise pathological tissues, leading to improved patient outcomes. Under traditional open microscopy, imprecise separation of neural and pathological tissues could result in damage to the dura or neural tissues. In contrast, spinal endoscopy offers superior magnification, aiding significantly in the differentiation between healthy and diseased areas. Additionally, the practice of continuous irrigation helps maintain a pristine surgical environment by flushing away bone fragments and other excised materials, while the hydrostatic pressure on the exposed spongy bone or venous plexus helps to keep the field clear by minimizing epidural bleeding (25).

Low risk of infection

Discitis, spondylitis, and epidural abscesses are potential serious post-surgical complications. Minimizing infections after spinal operations is crucial for reducing postoperative discomfort, shortening hospital stays, and cutting down on the medical expenses tied to each surgical technique. In the era of prophylactic antibiotics, the incidence of infections following spinal surgeries is about 4.4% (46). Yet, reports of such infections following ESS are uncommon. The minimal skin incision used in ESS may help prevent airborne particles from contaminating the surgical site. Moreover, the use of continuous irrigation during surgery could significantly contribute to lowering the risk of postoperative spinal infections.

Fusion Bed Preparation

Fusion surgery ought to be the definitive choice for treating pathological levels. Achieving both thorough decompression and successful fusion is critical for positive outcomes. While some spinal surgeons may doubt the suitability of endoscopic spinal fusion due to concerns such as inadequate decompression, potential damage to neural structures from limited surgical space, or failure of the fusion, ELIF has been introduced by some innovators with promising results as a MISS technique (26, 35, 36). The meticulous removal of cartilaginous endplates and the conservation of the bony endplate are crucial for a successful, stable fusion without collapse. Heo et al. have demonstrated that the preparation of the endplate can be effectively done under a clear endoscopic view, and angled spinal endoscopy enables the complete preparation of the opposite endplate (26). The advancement of fusion materials, precisely engineered 3D-printed cages, and expandable interbody cages are expected to significantly contribute to the success of endoscopic fusion surgeries as a minimally invasive fusion method.

Cost-effectiveness

Determining the most cost-effective surgical method is crucial. ESS is a safe and effective option, offering higher patient satisfaction, less blood loss during surgery, and shorter hospital stays compared to traditional open surgery. Additionally, medical costs for the endoscopic group may be lower due to quicker recovery from postoperative pain. However, while shorter hospital stays and faster recovery can lead to an earlier return to work, the long-term outcomes of ESS might not differ significantly from those of conventional open surgery (31). There are limited studies comparing the cost-effectiveness of these two methods. Recently, Choi et al. (47) found that the incremental cost-effectiveness ratio is higher for microdiscectomy than for endoscopic discectomy one year post-surgery. More independent, high-quality, randomized controlled trials with large sample sizes and cost-effectiveness analyses are needed.

Conclusions

Employing microscopy in spinal surgery reduces neural damage by enlarging the view of pathological lesions. However, early postoperative pain and ongoing back pain from collateral damage during open microscopic surgery remain significant concerns, potentially leading to post-spinal surgery

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syndrome. Spinal endoscopy, despite initial challenges, including subpar image quality and limited approaches, has evolved significantly over the past 30 to 40 years. Advances in ESS technology, such as increased magnification, continuous irrigation, and angled lenses, have minimized neural damage and reduced the need for facet joint removal. Initially limited to Kambin's triangle, ESS now employs various approaches for lumbar, cervical, and thoracic conditions, offering results comparable to MISS. ESS is emerging as a widely applicable method for treating spinal ailments, with its benefits aligning well with the objectives of spinal surgery. Future research should focus on providing robust evidence to validate ESS as the premier minimally invasive approach for spinal conditions.

Conflict of Interest

The authors declare no conflict of interest.

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