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Development of an Endoscopic Spine Surgery Program

Overview and Basic Considerations for Implementation

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Abstract

Endoscopic spine surgery (ESS) is an innovative technique allowing for minimally invasive, direct visualization of spinal abnormalities. The growth of ESS in the United States has been stunted by high start-up costs, low reimbursement rates, and the steep learning curve associated with mastering endoscopic techniques. Here, we describe the current state and future direction of ESS and provide key action items for ESS program implementation.

Although endoscopic spine surgery (ESS) has become increasingly popular, as evidenced by a marked increase in published reports[1], ESS is still viewed as a niche field within orthopaedic surgery. The reasons for the sluggish adoption in the United States are multifactorial and include ambiguity around reimbursement and efficacy, the steep learning curve, and expenses associated with adopting the technology[2,3]. Previous review articles have characterized the current state of ESS and provided commentary on its history and utility[4,5]. However, literature describing the process for implementing an ESS program is lacking. This article offers a basic overview of ESS and sheds light on the challenges associated with implementation of ESS programs.

ESS Techniques, Indications, and Technology

ESS Techniques

ESS is categorized under the umbrella of minimally invasive spine (MIS) surgery. MIS surgery includes techniques such as micro, mini-open/percutaneous, and tubular[6]. In ESS, a tubular trocar is inserted via a small incision, and the endoscope with camera is threaded through the established portal to the target area. Although visualization through the endoscope is possible, a highly magnified version of the image is displayed on a high-definition screen in the operating room. Common techniques implemented by spine surgeons today include full endoscopy, biportal endoscopy, and microendoscopy (Table I). Full endoscopy (i.e., uniportal scope) utilizes a single portal through which the endoscope and a surgical instrument are inserted. In full endoscopy, the working channel has space for only the endoscope and 1 surgical instrument, which are manipulated in a colinear fashion. Biportal endoscopy uses 2 working channels, allowing for independent manipulation of the endoscope and the surgical instrument. In microendoscopy, a tubular retractor is used, similar to other minimally invasive tubular approaches to the spine, with the addition of a camera within the tube allowing for visualization. This technique uses a dry environment and is considered distinct from endoscopy in the classical sense[1].

ESS Approaches and Indications

ESS can be utilized in the cervical, thoracic, and lumbar spine. Spine surgeons implement 2 main approaches to access anatomical structures: the interlaminar (posterolateral) approach and the transforaminal (extraforaminal) approach[1]. As detailed in the article by Derman, the choice of approach is contingent on surgeon preference and anatomical constraints based on spinal level[7]. In general, surgeons make use of existing osseous windows to minimize osseous resection. When treating lumbar disease, the transforaminal approach is generally used for foraminal stenosis at any level, a foraminal or far lateral herniated nucleus pulposus (HNP) at any level, and a central or paracentral HNP above L4-L5. The transforaminal approach utilizes Kambin's triangle, a safe triangular working zone bordered by the exiting spinal nerve anteriorly, the superior plate of the

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TABLE I Endoscopic Spine Surgery Techniques

Endoscopy Technique	Approach Options	Benefits	Drawbacks
Full endoscopy (i.e., uniportal)	Transforaminal or interlaminar	Least amount of tissue damage	Less freedom with a single portal, working portal size limitations
Biportal endoscopy	Transforaminal or interlaminar	Greater freedom with independent scope and instrument control	Semi-blind introduction of instrument, greater tissue disruption due to multiple portals
Microendoscopy	Primarily interlaminar	Single tube large enough for multiple instruments	Greater tissue disruption due to larger portal size, required dry environment

lower lumbar segment inferiorly, and the proximal articular process of the inferior vertebra posteriorly[8]. Indications vary broadly, from highly migrated disc herniation to foraminal stenosis and lateral recess stenosis[9-11]. The interlaminar approach involves posterolateral access to the lamina and interlaminar space and is less viable at higher lumbar levels as the size of the interlaminar windows decreases. Instead, the transforaminal approach can be used at the higher lumbar levels, as the iliac crest is less likely to obstruct the surgical path. At the level of L5-S1, however, the interlaminar window is large, and the position of the iliac crest makes the transforaminal exposure difficult[12]. Therefore, the interlaminar approach can be utilized with minimal osseous resection. The interlaminar approach is indicated for the treatment of central and paracentral HNP at L5-S1 and is the preferred technique for central and lateral recess stenosis at any level[7,13,14].

At the level of the cervical spine, microendoscopic posterior cervical laminoforaminotomy has been utilized successfully despite concerns over elevated rates of surgery-related complications such as major neurovascular injury and cerebrospinal fluid fistulas[15,16]. More recently, full-endoscopic cervical spine surgery techniques including full-endoscopic posterior foraminotomy and anterior cervical discectomy for cervical radiculopathy have been performed, with positive outcomes[17,18].

ESS for the treatment of the thoracic spine is considered technically challenging. Endoscopic thoracic discectomy has been utilized via a transforaminal approach for the treatment of thoracic disc herniations[19]. ESS techniques for the thoracic spine are evolving globally. Recently, Quillo-Olvera and Kim described a novel oblique paraspinal decompression for thoracic disc herniation using a combination of a tubular retractor with transforaminal full endoscopy[20].

Current Technology for ESS

A number of manufacturers produce ESS systems that are available on the global market for uniportal and biportal endoscopy, including Wolf/RIWO Spine, joimax, Maxmore, and elliquence. Chen et al. provided a comprehensive overview of the technical specifications of the different endoscopic systems for spinal stenosis decompression[21]. All of the aforementioned vendors offer uniportal endoscopy systems for lumbar ESS. Maxmore is the only one of these vendors offering a biportal system in the United States.

Efficacy, Safety, and Other Benefits

Surgical Outcomes

Conventional microsurgical techniques, such as microdiscectomy, utilize a high-powered microscope to visualize anatomical structures through the surgical incision. Microdiscectomy has long been considered the gold standard for the surgical management of lumbar disc disease[22]. Randomized controlled trials have demonstrated comparable efficacy between ESS and conventional microsurgical techniques. Ruetten et al. examined 178 patients with lumbar disc herniations who underwent interlaminar and transforaminal lumbar discectomies that were performed via either a full-endoscopic technique or microsurgical technique[23]. The clinical results and recurrence rates were equivalent between the endoscopic and microsurgical techniques. The authors reported that the full-endoscopic technique decreased traumatization, with the patients in that group reporting significantly less postoperative pain, pain medication, and postoperative work disability. However, the authors neglected to report the raw data for postoperative pain and pain medication, and postoperative work disability was not clearly defined.

Komp et al. followed 135 patients with degenerative lumbar central spinal stenosis who underwent microsurgical laminotomy or full-endoscopic interlaminar spinal decompression for 2 years after surgery[24]. Clinical results at 2 years and revision rates were equivalent between the 2 surgical techniques. Postoperative pain over the first 5 days and postoperative pain medication were significantly reduced in the group that underwent full-endoscopic surgery. Full-endoscopic surgery also resulted in a shorter total length of postoperative hospitalization when compared with the microsurgical technique for spinal decompression. The authors did not include the mean or median periods of postoperative hospitalization. Earlier discharge in the endoscopic group was not due to increased analgesia but rather was due to frank improvements in pain, as 11% of patients in the full-endoscopic group requested analgesics on the second postoperative day compared with 48% of patients who were managed with the microsurgical technique.

Other randomized controlled trials[25,26] also have demonstrated that ESS has similar efficacy to traditional microsurgical methods and could serve as a viable alternative for spinal surgical procedures. Other benefits of ESS include treating degenerative spine disease in elderly patients, who often experience complications during or after invasive spine procedures[27-29].

A number of systematic reviews and meta-analyses have been performed to aggregate and examine ESS outcomes. Phan et al. found no difference between endoscopic and open approaches to lumbar discectomy in terms of complications[30]. Pairuchvej et al. observed significant decreases in back pain, leg pain, and the risk of complications in patients with spinal stenosis who underwent biportal or full-endoscopic surgery compared with microscopic lumbar decompressive laminectomy; the authors speculated that the reduction in complications such as a dural tear and root injury could be attributed to superior visual control[31]. Moreover, Pranata et al. showed comparable efficacy and safety when biportal endoscopic spinal surgery was compared with microscopic decompression for lumbar spinal stenosis[32].

With regard to the acceptance of ESS among professional societies, the North American Spine Society (NASS) endorsed endoscopic percutaneous discectomy in the treatment of lumbar disc herniation for carefully selected patients[33].

Risks and Complications of ESS

Risks and complications of ESS can in part be correlated with the steep learning curve associated with mastering the techniques, as discussed later in this article. Challenges include the lack of tactile sensation, limited surgical field, and unfamiliarity with the technology[34]. In the early phase of this learning curve, incomplete decompression is a potential complication, as inadequate preoperative planning or inadequate positioning of the working channel can lead to missed fragments. Additionally, iatrogenic nerve root injury can occur during positioning of the endoscope or during decompression[35].

Incidental durotomy is an intraoperative complication in both open spine surgery and ESS. If not treated appropriately, an incidental durotomy can lead to persistent leakage of cerebrospinal fluid, pseudomeningocele, infection, or meningitis[36]. One limitation of ESS is the management of dural tears without converting to open surgery. In open spine surgery, primary repair of the dural tear is the conventional method of treating an incidental durotomy[11]. Endoscopic techniques for treating a dural tear include using collagen inlay grafts and/or sealant; however, there is no established standard technique for repairing an incidental durotomy in ESS. Because of the unfamiliarity with and associated learning curve of endoscopic durotomy repair methods, surgeons may choose to convert to the open surgery protocol. Nevertheless, many experienced spine surgeons have had success when treating incidental durotomies with inlay grafts and sealants without converting to open surgery. Further advancements in ESS equipment may one day allow for endoscopic primary repair[37]. An additional rare complication associated with ESS is increased cerebrospinal fluid pressure, which can be caused by an imbalance in the inflow and outflow of irrigation fluid and subsequent accumulation of fluid in the spinal canal[38]. This can cause symptoms such as neck pain, seizure, and pseudohypoxic brain swelling[39]. To prevent this issue, flow rates are carefully monitored, and water pressure is generally maintained between 2.41 and 22.83 mm Hg during biportal endoscopy[40].

Spinal epidural hematomas can occur after ESS as well. Kim et al., in a study of 310 patients who had undergone biportal ESS, reported a 23.6% rate of asymptomatic postoperative hematoma and a 1.9% rate of symptomatic postoperative hematoma[41]. In comparison, Sokolowski et al., in a study of 50 patients who had undergone conventional open surgery for

TABLE II Action Items for the Implementation of an ESS Program in an Orthopaedic Practice

1. Attend an industry-sponsored ESS cadaver workshop
2. Assess role for ESS in one's own practice
3. Meet with hospital administration/vendor to assess the feasibility of performing ESS in your facility
   - Vendor may provide trial equipment for first ESS. Subsequent surgeries will require investment in equipment (capital acquisition, per-case fee, lease-to-own)
4. Identify appropriate first surgery
   - Appropriate: Select a less technically demanding first surgery
     - Paracentral disc herniation at L5-S1, best when herniation deflects traversing nerve root medially
     - Foraminal disc herniation at L4-L5 and above
   - Not appropriate: Surgeries involving migrated fragments, L5-S1 foraminal or far lateral abnormality, and central and/or osseous stenosis are **not** recommended as a first surgery
5. Perform proctored first surgery
6. Debrief first ESS
7. Perform additional surgeries, slowly increasing ESS variety and complexity
8. Track learning curve by measuring operating room time, complications, and patient-reported outcomes
9. Once comfortable with lumbar endoscopic discectomy, can advance to endoscopic decompression for lumbar stenosis. Consider advancing to thoracic/cervical endoscopy and/or endoscopic lumbar fusion. Industry-sponsored courses are available for more advanced techniques

lumbar decompression, reported a 58% rate of asymptomatic postoperative epidural hematoma and a 0% rate of symptomatic postoperative epidural hematoma[42].

Implementation

Learning Curve and Training Considerations

The predominant challenges to the implementation of ESS practices pertain to the learning curve associated with the adoption of novel technology and techniques by traditionally trained spine surgeons. Morgenstern et al., in a study of 144 patients who underwent transforaminal endoscopic lumbar discectomy, reported a learning curve of 72 cases for the spine surgeon to reach 90% excellent proficiency[43]. Ransom et al. described an apprentice-style program in which 2 established spine surgeons learned from an endoscopic master spine surgeon; clinical outcomes improved after 15 lumbar decompression cases[2]. The majority of initial endoscopic skill acquisition comes from courses that are industry-sponsored, and it is important to note that much of the learning curve pertains to operative time rather than serious complications. For example, Wang et al. reported that operative time associated with an endoscopic interlaminar technique decreased from 107.9 minutes for the initial 10 patients to 68.5 and 43.2 minutes for subsequent 10-patient series[44]. With respect to complications in the initial stages of learning, Choi et al. reported a 10.3% complication rate, which often decreases as the surgeon becomes familiar with the surgical technique[45].

Institutional Support

Unique institutional support for ESS implementation includes financial support for equipment acquisition and anesthetic expertise.

Anesthetic expertise in particular is crucial to developing a successful ESS program, as awake ESS procedures can be offered to patients who have difficulty tolerating general anesthesia and require MIS surgery with a shorter operative time. Endoscopic laminectomies and discectomies (including transforaminal endoscopic discectomies and fusions), anterior discectomies and fusions (ACDFs), lumbar fusions, and dorsal column stimulator placements have been performed while the patient is awake[46-48]. In the treatment of the lumbar spine, utilizing local spinal anesthesia rather than general anesthesia is

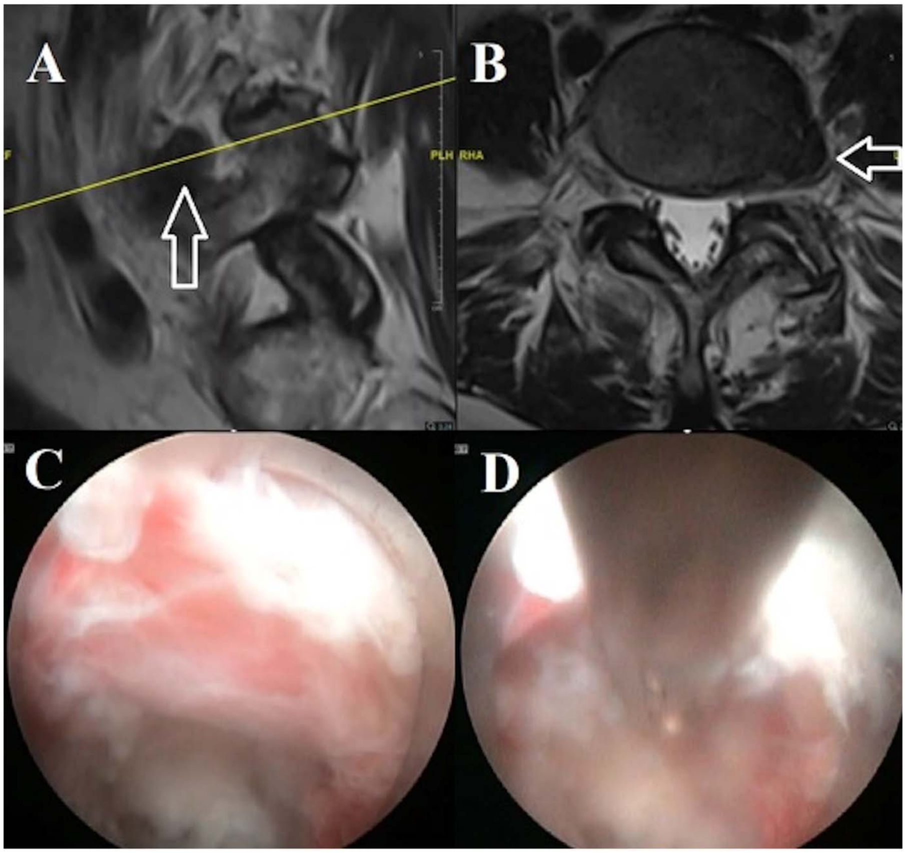

Fig. 1

Figs. 1-A through 1-D Case 1, a 36-year-old woman with a far lateral/extraforaminal herniated disc. **Figs. 1-A and 1-B** T2-weighted sagittal (**Fig. 1-A**) and axial (**Fig. 1-B**) magnetic resonance imaging (MRI) scans demonstrating a left L4 to L5 far lateral/extraforaminal disc herniation (open arrows). **Fig. 1-C** Endoscopic camera view of the left L4 nerve and the disc below, taken through a transforaminal approach 11 cm off the midline. **Fig. 1-D** Endoscopic camera view of the semibendable grasper displacing the left L4 nerve and removing the disc herniation.

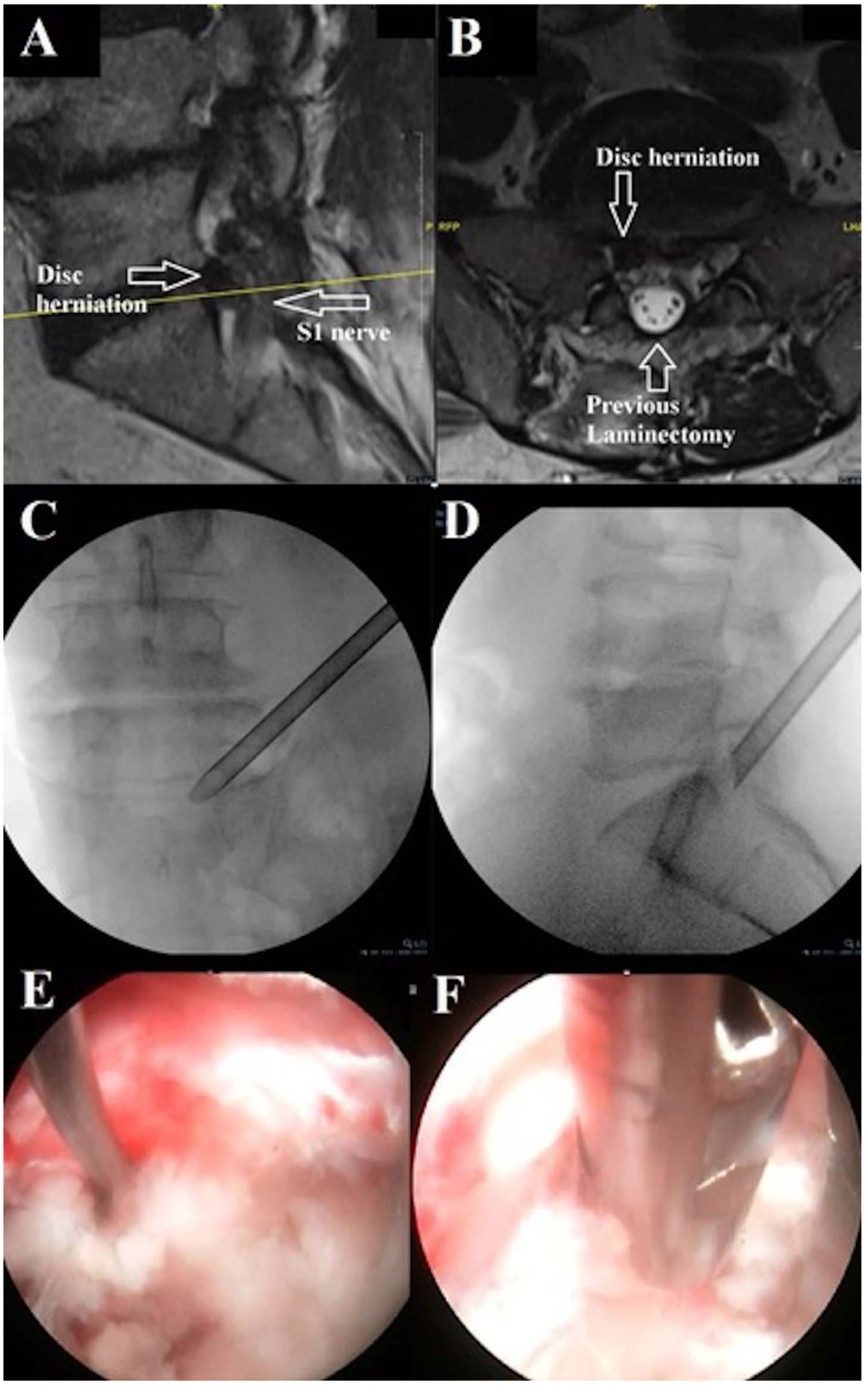

Fig. 2

Figs. 2-A through 2-F Case 2, a 65-year-old man with a post-laminectomy herniated disc. **Figs. 2-A and 2-B** T2-weighted sagittal (**Fig. 2-A**) and axial (**Fig. 2-B**) magnetic resonance imaging (MRI) scans demonstrating a right L5-S1 herniated disc (open arrows) and an L5-S1 laminectomy defect. **Figs. 2-C and 2-D** Anteroposterior (**Fig. 2-C**) and lateral (**Fig. 2-D**) fluoroscopic images demonstrating the position of the 7-mm tubular retractor placed in the right L5-S1 foramen through a transforaminal approach. **Fig. 2-E** Endoscopic camera-view of the right S1 nerve and an endoscopic ball probe dissector used to free the herniated disc from the S1 nerve. **Fig. 2-F** Endoscopic camera view of the endoscopic grasper used to remove the disc herniation.

associated with decreased operative time, shorter hospital stays, and decreased total procedure cost[49].

Costs and Reimbursement

High initial set-up costs also have contributed to the slow adoption of ESS in the United States. A typical endoscopic system includes an endoscopic camera, a light source, an irrigation fluid pump, a radiofrequency ablator, and a video-recording system with a monitor. There are several methods through which ESS systems can be placed into institutions, including outright purchase, lease-to-own, or a per-case fee. Some systems have more reusable equipment or have compatibility with existing endoscopy or arthroscopy components, which can also drive down costs. Altogether, the cost of purchasing endoscopic equipment outright is estimated to be approximately $350,000[50]. Low reimbursements for ESS procedures also have slowed the growth of ESS in the United States. The endoscopic discectomy Current Procedural Terminology (CPT) code 62380 is reimbursed more poorly than the microdiscectomy CPT code 63030 (approximately 20% less based on work relative value units) and may not be covered at all, as some insurance carriers consider ESS to be investigational. Chung et al. assessed reimbursement costs with use of the PearlDiver online health-care database and showed that open discectomies are reimbursed significantly more than minimally invasive discectomies[51]. In addition to start-up expenses, other costs to consider include maintenance fees, updating of system hardware and software, and investments in novel accessory technologies[52].

Despite the high start-up costs, endoscopic procedures may be cost-saving for ESS providers by shortening the lengths of hospital stays, decreasing complication rates, and expediting return to work for patients[53]. Choi et al., in 2019, compared endoscopic techniques versus microdiscectomy for lumbar disc herniation and found a significantly lower cost burden associated with endoscopy[59]. Moreover, biportal endoscopy equipment often can be used for endoscopic orthopaedic procedures other than those involving the spine, which can be cost-saving for orthopaedic groups as well[54]. Additionally, the availability of endoscopy has the potential to increase procedural volume and ultimately compensate for the higher disposable costs. Telfeian et al. found that the average distance traveled in the United States for ESS was 91 miles (146 km). As patients are willing to travel for these minimally invasive procedures, the increased volume at a regional center offering ESS may offset the startup costs[55].

Steps for Implementation

As highlighted above, implementing an ESS program requires training and resource investment. We have included a number

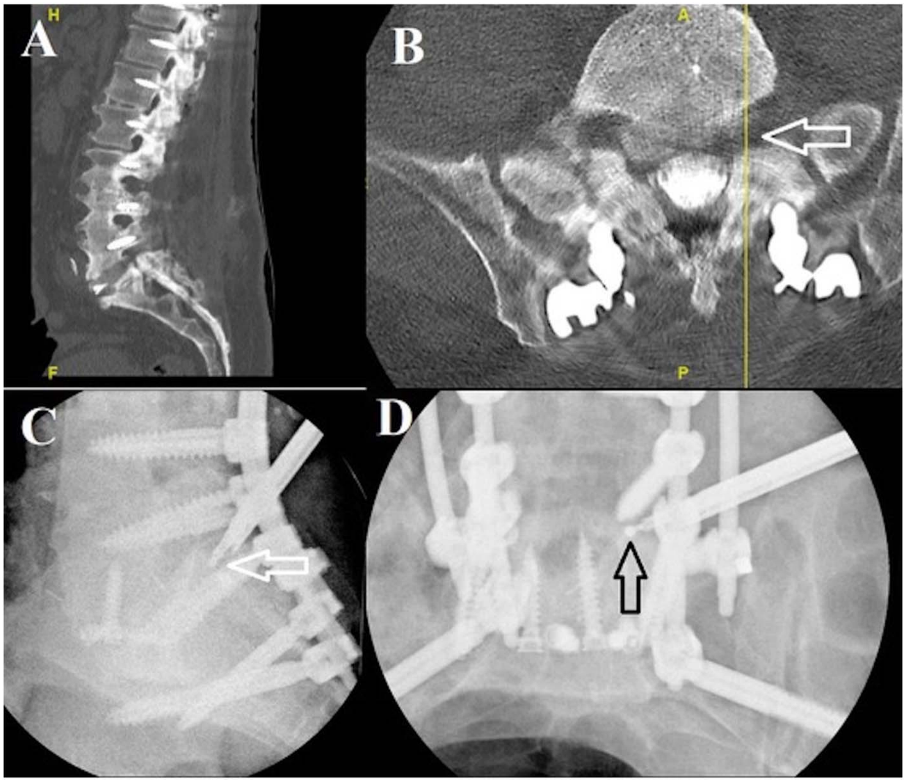

Fig. 3

Figs. 3-A through 3-D A 58-year-old man with post-fusion hyperostosis. **Figs. 3-A and 3-B** Sagittal CT reconstruction (**Fig. 3-A**) and axial CT myelogram (**Fig. 3-B**) demonstrating the compression in the left L5-S1 foramen (white open arrow). **Figs. 3-C and 3-D** Lateral (**Fig. 3-C**) and anteroposterior (**Fig. 3-D**) fluoroscopic images demonstrating the endoscopic drill (white and black open arrows) used to perform the foraminotomy and fusion exploration.

of action items to guide orthopaedic surgeons through implementing their own programs (Table II).

Illustrative Cases

We have discussed the barriers to performing ESS, including the equipment costs and learning curve. Three illustrative cases are presented here to demonstrate the utility of ESS and to highlight the potential for reduced postoperative pain and decreased hospital stays. All procedures were performed in awake patients in an outpatient setting. All patients were informed that information regarding their case would be submitted for publication, and they consented.

Case 1. Far lateral/extraforaminal disc herniation (Fig. 1). A 36-year-old woman presented with severe debilitating thigh pain that was refractory to nonoperative treatment. An awake, transforaminal endoscopic discectomy was performed, and the patient was able to fly back to her home state on the same day as the procedure.

Case 2. A post-laminectomy herniated disc (Fig. 2). A 65-year-old man presented with a severe right S1 radiculopathy and a right L5-S1 herniated disc with a history of a previous L5-S1 laminectomy that had been performed by another surgeon 6 months previously. An awake, transforaminal endoscopic discectomy was performed, and the patient was able to return to work on the day after surgery.

Case 3. Post-fusion hyperostosis (Fig. 3). A 58-year-old man presented 6 months after the most recent revision fusion procedure with the onset of a new left foot drop. A computed tomography (CT) myelogram indicated possible osseous compression in the left L5-S1 foramen. An awake, transforaminal endoscopic foraminotomy and fusion exploration was performed, and the foot dorsiflexion strength improved immediately from 1/5 to 4+/5.

The cases presented here were selected to demonstrate the utility of ESS. The indications for ESS are beyond those for straightforward discectomies and foraminotomies. Endoscopic techniques provide an opportunity for making some of the most challenging spine abnormalities easier for the surgeon and the patient.

Future Directions

ESS has the potential to decrease tissue damage, postoperative pain, the length of hospital stay, medical costs, and the risk of complications[5]. Interest in the ESS field is compounded by the growing elderly population, the expansion of outpatient spine surgery, and the short-term morbidity associated with open approaches[1]. At its inception, ESS was utilized primarily for discectomies. However, novel developments in ESS equipment and customizable instruments are paving the way for techniques such as endoscopic lumbar interbody fusion and endoscopic dural repair[5].

Other future advancements in ESS include developing artificial intelligence and robotics to aid in accurate and consistent cannula placement with use of image recognition[56]. This technology has the potential to reduce the steep learning curve associated with ESS and to improve the quality and consistency of ESS procedures[57]. In addition, enhancements in 3D navigation technology along with the implementation of ESS training models are predicted to aid surgeons in overcoming the learning curve associated with achieving ESS proficiency[34]. Moreover, augmented reality has the potential to drive ESS advancement further through the use of head-mounted optical see-through displays, which allow surgeons to remain focused on the surgical site rather than look up at the monitor[56]. In the future, artificial intelligence may be used to perform real-time structure recognition to guide surgeons during procedures[58].

Conclusions

ESS programs are expected to grow in the U.S. and globally as indications for ESS expand and technology advances further. Challenges to ESS expansion include increasing training opportunities, overcoming the learning curve, navigating low reimbursement rates, and overcoming the high initial costs. However, clinical studies have demonstrated benefits of ESS, and there are various financial options to support placement of equipment. Initial costs can be offset by increased procedure volume from patients willing to travel to the limited number of centers that offer ESS. In order to scale up the utilization of this technology, more fellowship programs should teach ESS to graduating spine surgeons so that these surgeons can incorporate the technology into their own practices.

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