Operative Techniques in
Orthopaedics

Endoscopic Diskectomy

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Spinal surgery is constantly progressing with the development of innovative treatment options and a shift toward minimally invasive options that improve outcomes and reduce morbidity. Minimally invasive diskectomy procedures are found in the literature as early at the 1950s followed by the development of chemonucleolysis, laser diskectomy, tubular microscopic diskectomy, and the currently available full-endoscopic techniques. As visualization of the disk and surrounding anatomy improved, unique approaches were designed to better access and treat the broad variety of lumbar disk pathologies. This chapter reviews the evolution of surgical treatment of lumbar diskectomy and outlines modern day treatment options with a focus on endoscopic techniques.
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Introduction

Disk herniation is the most common diagnosis of the lumbar spine in the modern era whereby displaced disk nuclear material protrudes beyond the vertebral osseous border in a focal pattern that can cause axial and neurologic symptoms.[1] Caused by various factors including trauma and age-related degeneration, disk herniations have been classified as a worldwide health problem due to their high incidence and frequently debilitating manifestation, including radicular pain and neurological deficits.[1,2] Neurologic symptoms and deficits are influenced by direct pressure and nerve root ischemia caused by physical compression of the neural structures and the associated inflammatory responses stimulated by immunoreactive molecules and enzymes released from the nuclear material; several inflammatory factors including COX-2, follistatin-like protein 1 (FSTL1) and tumor necrosis factor alpha (TNF-α) have found to be elevated in patients with herniated disks.[3] The pain and symptoms associated with discal herniation can be treated in various manners depending on the severity and extent of the protrusion.

Though conservative nonoperative management is attempted in most cases, some patients ultimately require surgery. The earliest report of surgical intervention was described as a lumbar discal hernia ablation, performed in 1934 by Mixter and Barr using a wide posterior trandural approach.[4,5] Mixter and Barr's findings were the first to clinically demonstrate radicular pain was the result of disk herniations, as symptoms of radiculopathy improved significantly in their patients postoperatively.[5] Today, diskectomy to treat disk herniation is the most commonly performed spinal surgery.[1,4] The procedure involves the removal of the protruding disk material in order to decompress the nerve or spinal cord to treat radiculopathic or myelopathic symptoms respectively. Since 1934, the procedure has evolved to utilize newly developed technologies and improve patient outcomes. As with other surgical fields, spinal surgery has shifted toward minimally invasive options that reduce incision size and improve recovery with less associated pain, morbidity, and recovery time.

History of Endoscopy

Medical technology and instrumentation have rapidly evolved over the last couple decades in parallel with the development of innovative surgical practices which have markedly reduced the invasiveness of spine surgery.[6] As technology becomes increasingly sophisticated, the need for large incisions, as required in open surgeries, has declined in favor of minimally invasive options. Minimally invasive surgical techniques utilize modern technological advances,

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including the miniaturization of the camera and the creation of the Hopkins rod lens, to allow for comparable optics despite the limited incision size. This approach is in many ways superior to traditional techniques as it is able to produce comparable outcomes while limiting damage to surrounding tissue, therefore, reducing patient recovery time, blood loss and postoperative pain while improving cosmetic outcomes.[7]

Endoscopic technology can be traced back as early as the civilization of Pompei; in the ruins, researchers found speculums used to examine cavities, including the cervix and rectum, that bore resemblance to modern instrumentation.[6] Limited by technology, these procedures relied on the use of ambient light to illuminate deeper body cavities.[6] In 1805, German obstetrician Phillipe Bozzini created a primitive endoscope that used candle light and mirrors to better visualize the bladder and rectum.[6,8] Throughout the nineteenth and beginning of the twentieth century, numerous scientists attempted to create more advanced endoscopic instrumentation that utilized other forms of artificial light, including electrical lighting.[6,8] However, the use of endoscopy was minimal due to 2 main limitations: Insufficient light and rigidity of instruments, the latter causing significant patient discomfort.[9] Rigidity was resolved in 1958 when gastroenterologist Basil Hirschowitz developed the fiber optic system which led to the creation of a flexible endoscope.[9]

In 2 different German cities during the 1960s and 1970s, endoscopic procedures became common practice for diagnostic purposes.[10,11] Doctors of the University of Erlagen were the first to successfully perform various endoscopic procedures including an endoscopic duodenoscopy and endoscopic retrograde cholangio-pancreaticography.[12] Furthermore, in 1973, 2 Erlagen physicians, Classen and Demling, created the Erlanger Papillotom and used it to perform the first endoscopic papillotomy; by 1977, over 1,500 endoscopic papillotomies had been performed with a 93.7% success rate and a mortality rate just over 1%, significantly lower than the 7.6%-12.3% reported for transduodenal papillotomy at the time.[12,13] At the same time, led by laparoscopic pioneer Kurt Semm, the gynecologists at the University Women's Clinic in Kiel were performing small endoscopic surgeries. While continuing to promote the need for "key-hole" surgery, Semm spearheaded the innovation of endoscopic instrumentation and the potential for endoscopic use outside the field of gynecology. In 1980, Semm performed the world's first laparoscopic appendectomy; this was the first time endoscopy was used on a closed cavity.[10] This historical achievement was met with significant criticism and resistance as the majority of surgeons still strongly supported the belief that large problems required large incisions; the opposition found it abhorrent that a gynecologist was attempting to teach surgical technique to actual surgeons.[10,11] Despite the contention, Semm continued to promote endoscopy. Five years later, general surgeon Erich Mühe performed the first laparoscopic cholecystectomy using Semm's instrumentation.[10] When Mühe presented his findings in 1986, he received the same reaction as Semm did years earlier. Many surgeons still believed that the small incision associated with what they termed "Mickey Mouse surgery" was dangerous and went further to criticize Mühe saying "small brain - small incision".[12] By March of 1987, Mühe had performed almost 100 endoscopic cholecystectomies which he found to have comparable long-term outcomes to open cholecystectomy while proving superior cosmetically and reducing hospital stay.[12,14] In 1990, German surgeon, Hans Troidl published a paper in which he admonished the surgical community for their refusal to test endoscopic practice.[9] Troidl goes further to deem their neglect as "irresponsibl[e] towards patients and the art of surgery".[9]

The Evolution of Minimally Invasive Approaches to Intervertebral Disk Surgery

Endoscopic techniques have been developing for over 200 years and gained popularity in orthopedic spine surgery in the past 50 years. It was first introduced by Burman in 1931 who developed a myeloscopy for direct visualization of the spinal cord and its pathologies.[15] As instrumentation improved, its use in spine and the variety of procedures increased rapidly. Hult was among the earliest surgeons to develop a technique for the treatment of herniated disks. In 1951, he attempted a partial diskectomy through an anterolateral fenestration in the disk by a left-sided appendectomy incision. Although results of the operations were good, complete recovery was delayed by symptoms of vertebral insufficiency and adverse effects of the anterolateral approach.[16] Regardless of the delay in recovery, Hult showed that decompression of intradiscal pressure could be achieved percutaneously.[17] Valls, Ottolenghi, and Craig designed instruments and described a safer posterolateral access to the lumbar and lower thoracic spine in order to obtain tissue for pathologic examination.[18] This basic approach that was developed in the 1950s is still being used today to enter the lumbar and thoracic spine for a variety of procedures. The posterolateral approach was further defined by Kambin when he identified a triangular working zone, known today as Kambin's triangle. This contains a safe zone for proper positioning of inserted instruments for diskectomies, minimizing risk of injury to surrounding nerves.[18] The zone is a right triangle with the base being the superior end plate of the caudal vertebral body, the hypotenuse is the exiting nerve, and the height is the traversing nerve.[19-21] Once a safe approach to the intervertebral disks was established, endoscopic and minimally invasive treatment to herniated disks closely followed.

In 1963, Smith found that injecting chymopapain into the intervertebral disk of rabbits caused dissolution of the disk without apparent effect on the surrounding tissues. He then progressed his studies to dogs with paralysis of the hind legs believed to be due to herniation of the intervertebral disks. His research found similar effects on the disks in dogs as some of them regained the ability to stand or walk. Autopsy confirmed that once again no harm to surrounding tissue was found. With these promising results he was the first to provide an injection with what is termed chemonucleolysis for the treatment of disk herniations in humans.[22] Chemonucleolysis works by altering the characteristics of the nucleus pulposus through digestion of proteoglycan core proteins resulting in a decrease of pressure in the disk. However, further studies showed mixed results with possible secondary anaphylactic shock and fatal outcomes. Therefore, chemonucleolysis was not adapted into common practice for orthopedic or neurological surgeons.[15,23,24] The transition from chemonucleolysis to a more manual debulking of the nucleus began in 1975 when Hijikata produced an intradiscal arthroscopic technique for percutaneous nucleotomy using the posterolateral approach. Hijikata performed a discography using Evans blue dye and then inserted specifically designed instruments through a 5 mm cannula to the lateral annulus. After an incision was made into the annulus, the blue-stained nucleus pulposus could be removed by pituitary forceps.[15,17] Following 1983, many authors described their own instrumentation and techniques for percutaneous nucleotomy, expounding on the technique of Hijikata. These authors included Schreiber and Suezawa, Kambin, and Monterio. The term "nucleotomy" was now used interchangeably with diskectomy because of the recently found significance of the fenestration in the annulus to decompress the disk. A sufficient window in the annulus allowed for expulsion of nuclear fragments and further decompression postoperatively.[17]

The next significant advancement in minimally invasive diskectomy came in 1985 with the invention of an aspiration probe by Onik et al. Previous diskectomy required large cannulas at risk of injuring nerve roots and use of a forcep to repeatedly remove material from the disk. Onik designed a 2 mm automated aspiration probe inserted in a 2.5 mm cannula which made removal of the nucleus pulposus quicker and easier. The only concern the authors had was arriving at a standard endpoint for the procedure. They describe removal of disk material using visual cues and stopping after disk is no longer accessible, and they question whether resolution of patient's symptoms or reduction in herniation on CT could be used as indicators for termination of the operation.[24] Around the same time, Ascher and Heppner used carbon dioxide (CO_2) lasers in neurosurgical procedures. In their writings lasers were used to remove lesions from the central and peripheral nervous system with little damage to surrounding tissue. Due to their success, Ascher looked for other utilizations of the lasers.[25] The use of lasers for treating intervertebral disks in the spine was later described by Choy et al. Their work showed that a small decrease in volume of the nucleus pulposus removed by the laser created a more significant decrease in pressure of the disk.[26,27] Continuous alterations are being made to the types of lasers and different wavelengths used in this procedure to distinguish which is best suited. These minimally invasive diskectomy techniques were not typically suited for treatment of sequestrated or migrated extraligamentous herniations. In 1997, Foley and Smith first described the contemporary use of endoscopes in spinal diskectomies.[28-30]

Defining Terms for Endoscopic Diskectomy

During the early period of endoscope use for decompression, the terminology describing techniques differed from the modern day use and can create confusion when reviewing older literature. Therefore, the authors feel it is important to discuss this disparity for clarification. For example, Schreiber et al describe "percutaneous" endoscopic diskectomy in 1982 where one cannula 3-7.2 mm in diameter is used with the endoscope to visualize the spinal elements and another cannula is used to manipulate the underlying tissue.[31] Microendoscopic diskectomy is another term with multiple definitions that was used interchangeably in the past as a general term for diskectomy with a microscope and/or endoscope. Foley et al and Kulkarni et al use this term interchangeably making it difficult to assess the difference between the techniques. More recently, the term microendoscopic is only used when both visualization techniques are performed in the same procedure. Moreover, retraction technique is often specified today using "open" for a procedure with traditional self-retaining medial to lateral retractors versus a "tubular" diskectomy where a tubular retractor is used, as described by Foley et al.[30] One could describe a procedure as an open microscopic diskectomy or a tubular endoscopic diskectomy, for example. This modern terminology is important to define for multiple reasons including understanding outcomes and future treatment decision making. Billing codes and surgical descriptions are used by major health entities and providers to determine steps of care and cost models.

Webster's dictionary defines percutaneous as "effected, occurring, or performed through the skin." In a medical dictionary, the term is defined further as "denoting the passage of substances through unbroken skin, as in absorption by inunction; also passage through the skin by needle puncture, including introduction of wires and catheters."[32] Presently, we most commonly define percutaneous procedures as those techniques that do not use a scalpel or make a formal incision. Some authors would denote a procedure as "percutaneous" when it is done without direct visualization of the underlying surgical field structures despite making a small incision to introduce working channels. Recent consensus of authors use the term, "full-endoscopic diskectomy" (FED) when the operator is directly visualizing the tissues during manipulation using a working channel.[33] An example of a true percutaneous diskectomy is the needle-based diskectomy, which will be further discussed later. Though it has not clearly been described in recent literature, it is logical to define procedures performed with direct visualization of surgical targets during their manipulation by the operator as "nonblinded" or "full-endoscopic" FED procedures, while procedures performed using only fluoroscopy during manipulation of underlying structures could be described as "blinded" procedures. Due to opacity of literature defining the wide variety of techniques utilized in the modern day, it is understandably challenging to group outcomes data and have a true understanding of the effectiveness of some of the newer techniques. That being said, some techniques have been published and will be evaluated in the coming sections of this chapter.

Current Techniques of Endoscopic Diskectomy

With the well-established success of the diskectomy procedure, refinement of surgical techniques has occurred over the last several decades. Large open incisions have reduced in size due to the use of microscopes and intraoperative fluoroscopy, which has made it much more convenient and conducive to precise location of incisions. Improvement in retractor technology in the 1990s further reduced incision sizes and introduced the concept of muscle and tissue dilation rather than muscle stripping from midline elements. Further visualization aides such as early endoscopes may have improved visualization early on, but subsequently enabled dramatic reduction in retractor and incision sizes whereby operators can operate through a working channel using specially designed microsurgical instruments. Currently, in endoscopic diskectomy there are 4 broad categories in which all procedures and techniques fall under as previously hinted. The first category is blind endoscopic surgery where the endoscope is utilized before and after intervention, but cannot directly visualize the working tools during the intervention itself. Therefore, tissues would be manipulated blindly using fluoroscopic guidance and palpation by the operator. Secondly, nonblind or full-endoscopic surgery describes procedures performed using the endoscope with working channels. This enables the operator to directly visualize structures aided only by the endoscopic camera while manipulating and modifying the underlying structures. In a biportal system, there are 2 working channels. One channel contains the endoscope while the second channel is the working port which introduces instruments and performs the direct tissue manipulation. Next, the third category of endoscopic diskectomy is a mixed use of direct unaided visualization with the addition of a scope as an adjuvant. Tubular microsurgical diskectomy, for example, gives the operator direct visualization of the underlying tissue with the option of using a microscope or endoscope to assist in magnifying or increasing the visual field. Lastly, the fourth category is included only because authors in the past used the term percutaneous endoscopic diskectomy PED. The modern term FED has replaced the term, PED, and the modern use of the term "percutaneous" refers to the true percutaneous needle-based diskectomy that does not include any endoscope.

Microendoscopic Diskectomy Technique

The early tubular technique referred to as microendoscopic diskectomy falls under the category of mixed. Surgeons used the posterolateral approach to initially insert a 20-gauge spinal needle to locate the lateral disk. Then, an incision was made the size of the tubular retractor system being used (either 16 mm or 18 mm) and a guidewire was inserted and directed toward the inferior aspect of the superior lamina and medial facet junction under lateral fluoroscopic guidance. Once satisfied with the position, a series of dilators and the final tubular retraction system were inserted over the wire while maintaining visualization of the position by fluoroscopy. The endoscope could then be inserted for improved visualization and the approach would be complete. Specialized bayonet instruments developed for use in tubular cases would then be used for the hemilaminotomy, medial facetectomy and approach of the safe triangular zone in which to work. This approach and technique is very similar to the traditional minimally invasive tubular microscopic diskectomy. The microscope may be used at any point during the decompression process and is sometimes preferred for a more three-dimensional viewing of sensitive structures.[28-30] The use of the modern, high resolution 30° endoscope allows visualization laterally, beyond the footprint of the tubular retractor to identify structures and ensure a safe working zone that is broader in scope and perspective to the microscope. Many surgeons still prefer this procedure over the full-endoscopic technique because the approach is similar to open diskectomy and has less of a learning curve. It also enables surgeons to treat various lumbar disk diseases including far lateral disk herniations, concomitant lateral recess stenosis, and noncontained disk herniations that other minimally invasive techniques may not address with a midline approach.[28]

Needle-based Percutaneous Diskectomy Techniques

Needle-based percutaneous procedures have been utilized in an experimental fashion using only fluoroscopy without direct or aided visualization of the underlying tissue at any time. Decompression is purely hypothetical and based off of needle localization to the intervertebral disk on fluoroscopic imaging. Decompression is performed either by manual debulking of the nucleus or with the use of thermocoagulation by conduction or radiofrequency. Few articles have been written about the effectiveness of true percutaneous needle-based decompression and for that reason there is only limited evidence for short-term and long-term relief. Amoretti et al did a retrospective review in 2004 of 10 case reports using the Dekompressor probe by Stryker, a type of manual debulking device that showed an 80% satisfactory rate in a small patient cohort without controls. The authors then followed up in 2006 with a prospective study of fifty patients describing similar results.[23,34] The theory behind using thermocoagulation for the treatment of contained herniations and discogenic back pain comes from the idea that outer tears of the annulus stimulate neovascularization and nociceptors. The heat produced by conduction or radiofrequency causes denaturation of the collagen fibers, cauterization of granulation tissue, and coagulation of nerve fibers.[35] Intradiscal electrothermal therapy (IDET) uses conductive heat delivered by placing a catheter across the posterior annulus. Percutaneous intradiscal radiofrequency therapy (PIRFT) uses radiofrequency with similar placement of a catheter to heat up the surrounding tissue. Several variations to the devices by multiple companies have been introduced to increase the size of the lesion and improve technique. These include a bipolar radiofrequency device and a radiofrequency probe augmented by cooling technology to prevent breakdown of the probe. IDET and PIRFT have been evaluated by a few randomized controlled studies, but the results were contradictory. Certain studies showed improvement with treatment of IDET or PIRFT compared to placebo, while other studies demonstrated no significant difference.[36] In a study by Helm et al, biacuplasty, which uses a bipolar cooled radiofrequency probe, was the only device with strong evidence from randomized controlled trials supporting its use to improve pain and function.[36] Even so, these have been termed thermal intradiscal procedures (TIPs) by healthcare systems and labeled as experimental and investigational for the treatment of low back pain. The Center for Medicare and Medicaid services along with other major healthcare insurances have issued national noncoverage determination for these types of procedures due to lack of evidence demonstrating improved health outcomes.

Full Endoscopic "Non-Blind" Diskectomy Techniques

Full-endoscopic techniques offer many advantages over other minimally invasive techniques including less postoperative pain, less adhering and scarring, reduced risk of infection, and reduced risk of spinal destabilization when compared to microsurgical techniques. In cases of cauda equina syndrome, unstable spine deformities, and large herniations, endoscopic surgery is not recommended and a microsurgical technique must still be utilized.[37] Full-endoscopic "non-blinded" techniques can be categorized further by surgical approach. The 2 fundamental approaches to arrive at the disk are transforaminal and interlaminar. A third approach called the transiliac is possible for L5-S1 disk herniations in patients with high iliac crest. However, due to difficulties penetrating the iliac bone, maneuverability once inside, and an increased risk of vascular injury, the procedure has struggled to gain popularity.[38] Each approach is unique and has its own advantages and disadvantages, which are highly dependent on the identified disk level and the individual patient anatomy.

The traditional FED uses the transforaminal or extraforaminal endoscopic lumbar diskectomy (FELD) approach performed from an angled trajectory where the endoscope targets the extraforaminal space and can work medially, through the foramen into the lateral recess and central area of the disk. The flatter the trajectory of the approach, the more medial the surgeon's instruments can reach through the foramen. Figure 1. demonstrates the difference in trajectory between each approach. It is possible to perform contralateral diskectomy using this approach when the contralateral herniation is contained within the annulus without extrusion or migration. When the working space is limited or additional epidural access is required, foraminoplasty with trephine, Kerrison punch or drill can be performed to create additional space.[39] Two different principle techniques are used in FELD that are widely taught and discussed in the

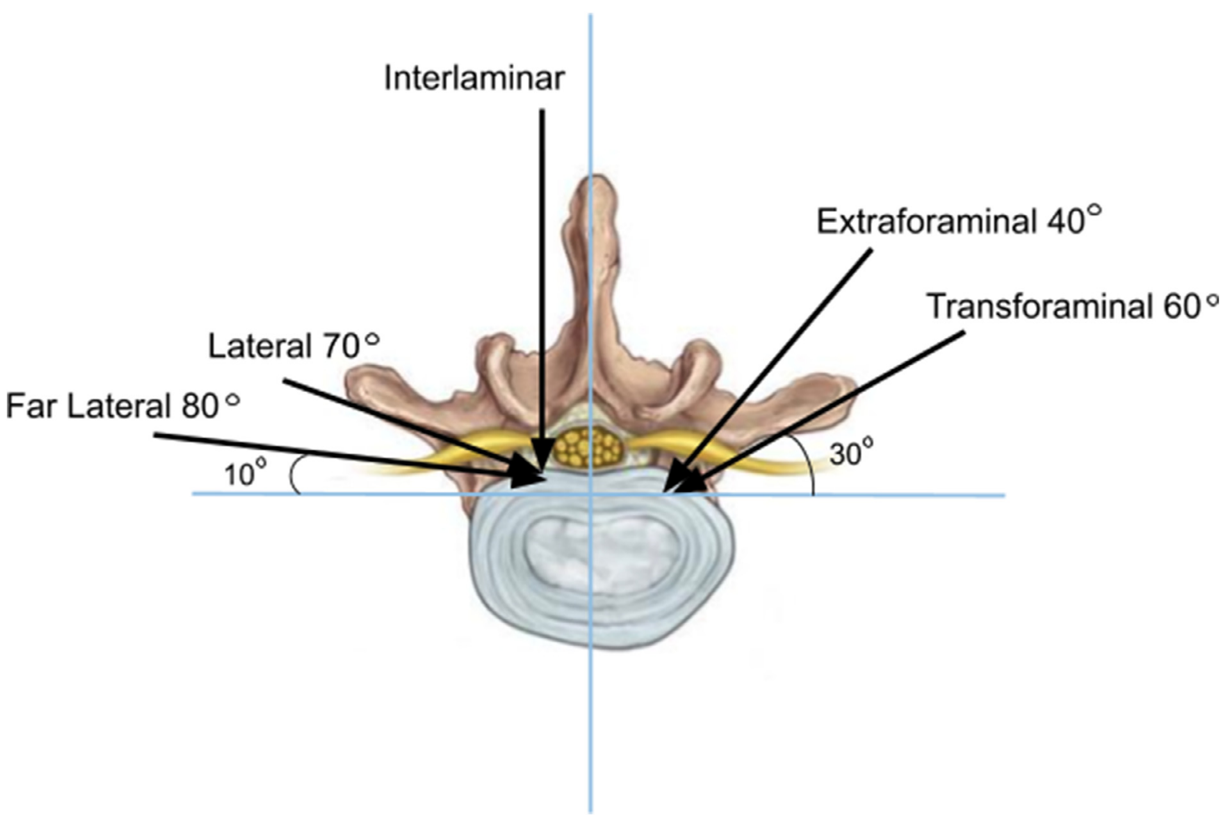

Figure 1 Shows the variety of surgical approaches to endoscopic diskectomy. Each approach has a unique trajectory angle and entry point in relation to midline.

literature. The "inside out" technique and "outside in" techniques are discussed in the next section titled, Extraforaminal Endoscopic Diskectomy Techniques for the Advanced Surgeon.

The midline, interlaminar endoscopic lumbar diskectomy (IELD) approach is similar in trajectory to the traditional microdiskectomy approach and is preferred by some surgeons due the familiar landmarks utilizing the natural posterior space between vertebrae. The directly upright positioned fluoroscope is used to localize the interlaminar window in the midline where local anesthetic is injected and incision is made. The dilator is inserted to penetrate the fascia and dock on the inferior edge of the lamina near the midline immediately adjacent to the softer landing of the ligamentum flavum. Caution is used to confirm one is not penetrating the ligamentum flavum with the dilator. Dural tears can occur if penetration occurs and is prevented by attaining a lateral fluoroscopic image if depth is uncertain. The endoscope is inserted through the midline to view the ligamentum flavum which is then penetrated under direct visualization in the midline preferably distant from the site of stenosis to minimize risk of dural tear and neurologic injury. Once the ligament is penetrated, endoscopic fluid pressure pushes the dura and epidural fat away from the ligament to allow safe resection of the ligament toward the lateral edge of the interlaminar window and facet joint.[40] Epidural fat is resected if necessary but minimized to reduce bleeding. If the lateral edge of the dural sac is not readily seen and adequate space for the cannula cannot be confirmed, then the approach is broadened laterally with kerrison rongeur followed by drill as needed. When facet hypertrophy is encountered or anticipated, spinal flexion over bolsters or bed frame should be emphasized preoperatively and appropriate decompression instrumentation should be confirmed. Kerrison punch and drill equipment are essential instruments when confronted with overgrown facets during this approach. This approach is primarily used at the L5-S1 level where the EF approach is often impeded by narrow, high iliac crest pelvic anatomy.

The advantages to the transforaminal approach are that it can be applied to all lumbar spinal levels, has relatively few complications that are uncommon, and can be performed with local anesthesia. Unfortunately, patient anatomy and herniation location can sometimes prevent access through the foramen and complete resection of the herniation. Patients with a combination of high iliac crest and lower lumbar disk herniations may not be able to have a transforaminal diskectomy. Additionally, this approach has limited cephalocaudal extension when resecting herniations that have migrated within the spinal canal.

When the transforaminal approach is not possible due to anatomy or position of the disk herniation, the interlaminar approach is an excellent alternative. However, this approach is most often limited to the lower lumbar L4-S1 disk levels where the interlaminar gap and epidural space are wide enough to safely accommodate the endoscope. Therefore, patients with high iliac crest and L5-S1 herniations, especially those with migrated herniations are typically better candidates for the interlaminar approach.[41] Huang et al did a recent meta-analysis to evaluate the effectiveness of each approach and to determine indications for each case. The results showed that the interlaminar approach had less estimated blood loss, shorter operation times, lower fluoroscopy times, but a higher complication rate. The complications were mainly postoperative dysesthesia and nerve root injury. They noted the angle of the interlaminar approach makes it difficult and unsafe to remove shoulder, extreme lateral, or central disk herniations because of the increased risk of cauda equina compression and nerve root stretch. Furthermore, the interlaminar approach is not an appropriate treatment for herniations in patients with spinal stenosis or segments with instability. The 2 approaches reported no difference in hospital stay, recurrence rate, or reoperation rate, and had similar outcomes based on the modified MacNab, Visual Analog Scale (VAS), Oswestry Disability Index (ODI), and Japanese Orthopedic Association (JOA) evaluations.[41] Some authors place more emphasis on the decreased fluoroscopy times and simplicity of the technique suggesting that the interlaminar approach may be a better choice for L5-S1 lumbar disk herniations.[42] Other authors believe the safety, use of local anesthesia, and multi-level application of the transforaminal approach makes it superior for all levels, and the interlaminar approach should only be used when the transforaminal is not possible.[33,41] In summary of these studies, both transforaminal and interlaminar approaches are highly successful in the treatment of herniated disks in the lumbar spine. Selection for which approach to use should be based off of the patient's anatomy, the level of the disk to be operated on, and the surgeon's experience and skill.

Extraforaminal Endoscopic Diskectomy Techniques for the Advanced Surgeon

Though lumbar diskectomy is largely regarded as one of the more technically challenging procedures in spinal surgery, the learning curve for endoscopic spinal surgery is very challenging and likely fraught with more complications during the learning phases. Serious complications of lumbar endoscopic diskectomies include neurologic injury and neuritis, hematoma, dural headaches, recurrent herniation, failure to improve and accelerated degeneration. In this context a stepwise approach to encorporating endoscopic techniques has been adopted using variations in approach.

During the early phases of FED adoption some surgeons have utilized the "inside-out" technique where the surgeon introduces the dilator through the soft tissues and directly through the annulus into the nucleus having created a new defect in the disk. The basis of this technique is to treat the pathological disk from the inside initially, and then move outwards into the epidural space to remove any part of the disk that have migrated.[43] This method was all made possible by the development of the Yeung Endoscopic Surgical System (YESS), which contained an endoscope with a larger working channel that allowed the use of basket forceps, kerrisons, and articulated pituitary rongeurs to work in the disk under direct vision.[44] A discography is performed and the problematic disk identified, the endoscope is introduced while the patient is lying prone in a posterolateral fashion toward the center of the disk through Kambin's triangle. The angle of trajectory can be changed based off of the location of herniation and the technique or approach being used. Yeung et al used a 25-35° angle of trajectory. A less common extreme lateral angle of 10-20° may also be used specifically to gain better access to intracanal herniations, but may be associated with higher complication rates.[37] With inside-out, a cavity must be created in the disk for viewing and manipulation, which may already be naturally present due to displacement of disk fragments.[43] The blind insertion of the endoscope creates the risk of possibly penetrating through an intact annulus rather than the torn lesion, and why some would argue the outside-in technique is superior.[39] Once the annular tears are identified they are treated with intradiscal thermal modulation from the inside-out. The endoscope is then withdrawn from the disk to explore the foramen, the exiting nerve, and the epidural space. In these areas, extruded disk fragments can be removed after performing a foraminotomy under direct visualization. If inadequate decompression is suspected, then the ventral facet and roof of the upper foramen could be opened up further.[43]

The "outside-in" technique is more technically challenging for the advanced user. This approach targets the damaged portion of disk or extruded herniated fragments initially before entering the disk. In this technique, the endoscope is docked just outside the foramen for the starting position with a slightly steeper approach angle of 45-60°. A foraminotomy can be performed if necessary using a reamer, Kerrison punch, or high-speed burr for safer insertion of the endoscope into the spinal canal in order to visualize the surface of the annulus and any pathological areas. Annular tears can then be identified for access by means of blue-stained nucleus pulposus leaking out from the initial discography. As a result, the healthy part of the annulus is undisturbed and only diseased portions of the disk are removed. Thereafter, a thermal annuloplasty using a radiofrequency probe is often performed to denervate and shrink fibers within the annulus to reduce the disk into its native preinjury position. Some authors use annuloplasty techniques that attempt to repair the hole and prevent reherniation.[39] The outside-in technique was made popular in 2006 with the introduction of the transforaminal endoscopic surgical system (TESSYS) created by Hoogland et al.[45] A recent retrospective study by He et al was done to evaluate the effectiveness of the combined use of the YESS inside-out and the TESSYS outside-in techniques on patients with multilevel lumbar disk herniations. The YESS technique was used to treat central and paracentral hernias while the TESSYS was used to treat migrated or sequestered herniations. Results from the study of 52 patients with combined YESS and TESSYS showed a 98% satisfaction rate compared to a previously reported 89.2% satisfactory when YESS was used alone. The JOA and ODI scoring systems supported this claim showing superior scores to the use of combined techniques compared to YESS and TESSYS alone.[46] The study findings indicate that herniations with unique morphology may benefit from different techniques of approach.

The final category includes blinded endoscopic techniques that were frequently used in the past, but have fallen out of favor due to the advancements in endoscopes and instruments allowing the surgeon to directly visualize a working field throughout the procedure. Visualization may decrease the risk of nerve injury and complications following these procedures. One example of a blinded technique in use today is the Disc-FX system by Elliquence. A cannula is placed into the center of the disk using fluoroscopic guidance in similar fashion as the inside-out technique. However, the cannula has a small diameter of a few millimeters that cannot support a modern endoscope with internal working channel. The "inside out" technique is typically used with this size system because foramenal material cannot be safely manipulated or removed without the opportunity for direct visualization. After breaching the disk annulus and fluoroscopic confirmation of the cannula position, instruments are inserted through the cannula to blindly remove disk material, manually debulking the nucleus. Thermocoagulation of the annulus is then performed using a radiofrequency probe, and an endoscope can be inserted to visualize the disk anatomy on the way out of the disk and confirm successful decompression of the nerve. The goal is to decompress the nerve through disk shrinkage and modulation of the nucleus, while the annuloplasty denervates the nerve fibers in the annulus to reduce pain signals.[47] Few studies have been done to evaluate the efficacy of this procedure, but one small study by Kumar et al and another by Hellinger et al showed significant improvements in VAS, ODI, ad MacNab scores up to 4 years after treatment with Disc-FX in selected patients.[48] Currently, Medicare, Medicaid, and several other major insurance companies do not provide coverage for this procedure due to lack of evidence establishing effectiveness.

Discussion

Endoscopic diskectomy surgery has evolved rapidly over the past 50 years, and new techniques and treatment options are continuously being developed to improve the success of treatment. There are a number of endoscopic procedures designed to treat disk herniations which have been categorized into blinded, nonblinded, mixed, and percutaneous needle-based procedures. Each procedure has unique indications based on disk anatomy, radiological imaging, and patient symptomatic criteria. In 2017, Feng et al performed a meta-analysis to compare success rate, complication rate, and reoperation rate between surgical interventions for lumbar herniations. The procedures observed included percutaneous endoscopic lumbar diskectomy (now called full-endoscopic lumbar diskectomy or FELD), standard open diskectomy, standard open microsurgical diskectomy (SOMD), chemonucleolysis, microendoscopic diskectomy (MED, specifically tubular), percutaneous laser diskectomy and decompression, and automated percutaneous lumbar diskectomy (APLD). The meta-analysis reviewed randomized control studies for each procedure and determined that in the current literature FELD has higher success rates and decreased complication rates, while SOMD has lower reoperation rates. Additionally, APLD has the lowest success rate and highest complication and reoperation rate.[49] Another meta-analysis in 2018 found that open and microdiskectomy had significantly worse ODI scores, longer length of stay, increased blood loss, and lower incidence of revision surgery when compared to tubular and full-endoscopic diskectomy. Tubular diskectomy was associated with a greater rate of overall complications including dural tears and recurrent herniations.[50]

In summary, full-endoscopic diskectomy may be superior due to its minimally invasive approach that permits visualization of the working field during manipulation of underlying tissue. However, the use of open or microdiskectomy is still the most popular approach in both studies. This is possibly due to relatively recent advances in endoscopic equipment, challenges with the various approaches currently described, the relatively slow learning curve with substantial complication rates and skill required to perform the procedure, and the comfort level of each surgeon due to the relative paucity of training in fellowship programs. Regardless, the success of minimally invasive full-endoscopic diskectomy continues to be confirmed with additional studies and the use of this approach has been incorporated into other spine procedures.

Developing Endoscopic Spine Procedures

Spine surgery is an ever-evolving field where surgeons are constantly developing and adapting techniques to reduce complication rates and improve patient recovery. Minimally invasive endoscopic procedures have the advantage of more accurate tissue manipulation under direct visualization and less iatrogenic destruction. Theoretically, this translates into decreased postoperative pain, shorter stay in hospital, and increased patient satisfaction. The integration of minimally invasive procedures into spine surgery has never been as significant as with endoscopic diskectomy. Due to the success of endoscopic diskectomy, surgeons are attempting to translate endoscopes into other spine procedures with the aspiration of similar results.

Currently, multiple procedures are in the preliminary stages of full-endoscopic use including endoscopic transforaminal interbody lumbar fusion (ETLIF), cervical endoscopic decompression and foraminotomy, and endoscopic treatment of spine pathological lesions, infections, and traumatic fractures. Early reports present feasibility of the endoscopic to assist minimally invasive single-level TLIF using conscious sedation.[51] An advantage to using conscious sedation as opposed to general anesthesia is the ability of the patient to provide immediate feedback if the surgeon unintentionally comes into contact with a nerve or other sensitive structure. Furthermore, in the absence of general anesthesia and intubation, the associated risks and negative impacts are negated. In a series by Wang et al, 9 of 10 patients were discharged the following day after ETLIF, while 1 patient was kept for issues of social support, not related to operative success. At 1 year follow-up, ODI showed statistically significant reduction in comparison with preoperative scores. Radiological and clinical results confirmed the success of the fusion with no evidence of nonunion or perioperative complications. A more recent study in 2019 by Ahn et al evaluated the current minimally invasive techniques for TLIF including full-endoscopic, biportal endoscopic, and tubular microendoscopic. A comprehensive review of literature found no significant differences among the 3 techniques regarding clinical outcomes, fusion rate, or complication rate. However, the full-endoscopic technique was the only one to be performed under local anesthesia; a beneficial aspect for patients where anesthesia poses a higher risk such as in the elderly or those with higher comorbidity indexes.[52] Similarly, from 2014 to 2016, Dr. Wan of the Department of Pain at Zheijiang Provincial People's Hospital performed 25 single-level posterior percutaneous full-endoscopic cervical diskectomies on patients under local anesthetic to treat radiculopathy caused by soft-disk herniation; previously, this procedure was performed exclusively under general anesthesia.[53] There were no serious complications intra- or postoperatively and the procedure was successful in 96% of patients with only one requiring a subsequent ACDF. On average, patients experienced significant pain reduction and increased cervical function. The results in conjunction with those of Dr. Wang, while somewhat limited by small sample size, show a promising future for the reduction in general anesthesia use during minimally-invasive diskectomies and fusions.

The cervical spine remains a more challenging operative region due to limited working space, less mobility and proximity to the spinal cord. Thus, the development of minimally invasive cervical techniques has been stunted in comparison with those of the lumbar and thoracic spine, with fewer studies published assessing its efficacy and safety.

Conclusion

Lumbar diskectomy has evolved dramatically since the 1950s with rapid expansion of surgical techniques and options in the past twenty years. Improved instrumentation and consensus over terminology, indications and research protocols are needed to further refine the procedures and optimize treatment outcomes.

References

1. Vialle LR, Vialle EN, Suárez Henao JE, et al: Lumbar disc herniation. Rev Bras Ortop 45:17-22, 2010
2. Schoenfeld AJ, Weiner BK: Treatment of lumbar disc herniation: Evidence-based practice. Int J Gen Med 3:209-214, 2010
3. Amin RM, Andrade NS, Neuman BJ: Lumbar disc herniation. Curr Rev Musculoskelet Med 10:507-516, 2017
4. Blamoutier A, Guigui P, Charosky S, et al: Surgery of lumbar and thoracolumbar scoliosis in adults over 50. Morbidity and survival in a multicenter retrospective cohort of 180 patients with a mean follow-up of 4.5 years. Orthop Traumatol Surg Res 98:528-535, 2012

5. Mixter WJ, Barr JS: Rupture of the intervertebral disc with involvement of the spinal canal. N Engl J Med 211:210-215, 1934
6. Lau W, Leow C, Li A: History of endoscopic and laparoscopic surgery. World J Surg 21:444-453, 1997
7. Overdevest G, Peul WC, Brand R, et al: Tubular diskectomy versus conventional microdiskectomy for the treatment of lumbar disc herniation: Two year results of a double-blinded randomised trial. Acta Neurochir 152:747, 2010
8. Moran ME, Moll FH: History of cystoscopy. In: Patel SR, Moran ME, Nakada SY (eds): The History of Technologic Advancements in Urology, Springer International Publishing, 3-20, 2018
9. Troidl H: Surgical endoscopy and sonography: Surgery at the crossroads. Surg Endosc 4:41-46, 1990
10. Litynski GS: Endoscopic surgery: The history, the pioneers. World J Surg 23:745-753, 1999
11. Semm K: Endoscopic appendectomy. Endoscopy 15:59-64, 1983
12. Litynski GS: Erich Mühe and the rejection of laparoscopic cholecystectomy (1985): A surgeon ahead of his time. JSLS 2:341-346, 1998
13. Lux G: Endoscopic papillotomy. The development of a method. Endoscopy 10:206-208, 1978
14. Mühe E: Long-term follow-up after laparoscopic cholecystectomy. Endoscopy 24:754-758, 1992
15. Snyder LA, O'Toole J, Eichholz KM, et al: The technological development of minimally invasive spine surgery. BioMed Res Int: 1-9, 2014
16. Hult L: Retroperitoneal disc fenestration in low-back pain and sciatica: A preliminary report. Acta Orthop Scand 20:342-348, 1951
17. Hijikata S: Percutaneous nucleotomy. Clin Orthop Relat Res 238:9-23, 1988
18. Kambin P, Zhou L: History and current status of percutaneous arthroscopic disc surgery. Spine 21:57S-61S, 1996
19. Kambin P, Schaffer JL: Percutaneous lumbar diskectomy. Clin Orthop Relat Res 238:24-34, 1989
20. Kambin P, Brager MD: Percutaneous posterolateral diskectomy. Clin Orthop Relat Res 223:145-154, 1987
21. Kambin P, Sampson S: Posterolateral percutaneous suction-excision of herniated lumbar intervertebral discs. Clin Orthop Relat Res 207:37-43, 1986
22. Smith LW: Enzyme dissolution of the nucleus pulposus in humans. The Classic 206:4-9, 1986
23. Amoretti N, Huchot F, Flory P, et al: Percutaneous nucleotomy: Preliminary communication on a decompression probe (Dekompressor) in percutaneous diskectomy. J Clin Imaging 29:98-101, 2005
24. Onik G, Helms CA, Ginsburg L, et al: Percutaneous lumbar diskectomy using a new aspiration probe. Am J Roentgenol 144:1137-1140, 1985
25. Ascher PW, Heppner F: CO_2-laser in neurosurgery. Neurosurg Rev 7:123-133, 1984
26. Choy DSJ, Case RB, Fielding W, et al: Percutaneous laser nucleolysis of lumbar disks. NEJM 317:771-772, 1987
27. Hellinger J: Technical aspects of the percutaneous cervical and lumbar laser-disc-decompression and −nucleotomy. Neurol Res 21:99-102, 1999
28. Perez-Cruet MJ, Foley KT, Issacs RE, et al: Microendoscopic lumbar diskectomy: Technical note. Neurosurg 51(Suppl 2):129-136, 2002
29. Kulkarni AG, Bassi A, Dhruv A: Microendoscopic lumbar diskectomy: Technique and results of 188 cases. Indian J Orthop 48:81-87, 2014
30. Foley KT, Smith MM: Microendoscopic diskectomy. Tech Neurosurg 3:301-307, 1997
31. Schreiber A, Suezawa Y, Leu H: Does percutaneous nucleotomy with discoscopy replace conventional diskectomy? Clin Orthop Relat Res 238:35-42, 1989
32. "Percutaneous." *The Free Dictionary*, Farlex, www.thefreedictionary.com/percutaneous
33. Yoshinari H, Tezuka F, Yameshita K, et al: Transforaminal full-endoscopic lumbar diskectomy under local anesthesia in awake and aware conditions: the inside-out and outside-in techniques. Curr Rev Musculoskelet Med 24:311-317, 2019
34. Amoretti N, David P, Grimaud A, et al: Clinical follow-up of 50 patients treated by percutaneous lumbar diskectomy. Clin Imaging 30:242-244, 2006
35. Kircelli A, Coven I, Cansever T, et al: Patient selection and efficacy of intradiscal electrothermal therapy with respect to the Dallas Discogram Score. Turk Neurosurg 27:623-630, 2015
36. Helm S, Simopoulos TT, Stojanovic M, et al: Effectiveness of thermal annular procedures in treating discogenic low back pain. Pain Phys 20:447-470, 2017
37. Fiorenza V, Ascanio F: Percutaneous endoscopic transforaminal outside-in outside (TOIO) technique for foraminal and extraforaminal lumbar disc herniations — operative technique. World Neurosurg 130:244-253, 2019
38. Bai J, Zhang W, Wang Y, et al: Application of transiliac approach to intervertebral endoscopic diskectomy in L5/S1 intervertebral disc herniation. Europ J Med Res 22:1-10, 2017
39. Liu KC, Yang SK, Ou BR, et al: Using percutaneous endoscopic outside-in technique to treat selected patients with refractory discogenic low back pain. Pain Phys 22:187-198, 2019
40. Ruetten S, Komp M, Merk H, et al: Use of newly developed instruments and endoscopes: Full-endoscopic resection of lumbar disc herniations via the interlaminar and lateral transforaminal approach. J Neurosurg Spine 6:521-530, 2007
41. Huang Y, Yin J, Sun Z, et al: Percutaneous endoscopic lumbar diskectomy for LDH via a transforaminal approach versus an interlaminar approach: A meta-analysis. Der Orthopade: 1-12, 2019
42. Chen J, Jing X, Li C, et al: Percutaneous endoscopic lumbar diskectomy for L5S1 lumbar disc herniation using a transforaminal approach versus an interlaminar approach: A systematic review and meta-analysis. World Neurosurg 116:412-420, 2018
43. Gore S, Yeung A: The "inside out" transforaminal technique to treat lumbar spinal pain in an awake and aware patient under local anesthesia: results and a review of the literature. Int J Spine Surg 8:1-47, 2014
44. Yeung AT: The evolution and advancement of endoscopic foraminal surgery: One surgeon's experience incorporating adjunctive technologies. Int J Spine Surg 1:108-117, 2007
45. Hoogland T, Schubert M, Miklitz B, et al: Transforaminal posterolateral endoscopic diskectomy with or without the combination of a low-dose chymopapain: A prospective randomized study in 280 consecutive cases. Spine 31:E890-E897, 2006
46. He S, Sun Z, Wang Y, et al: Combining YESS and TESSYS techniques during percutaneous transforaminal endoscopic diskectomy for multilevel lumbar disc herniation. Medicine 97:28, 2018
47. "Disc-FX® System: Minimally Invasive diskectomy." *Elliquence*, www.elliquence.com/products/disc-fx-system/
48. Kumar Na, Zaw AS, Kumar Ni, et al: Annulo-nucleoplasty using Disc-FX in the management of degenerative lumbar disc pathology: How long can the effect last? Global Spine J 8:365-373, 2018
49. Feng F, Xu Q, Yan F, et al: Comparison of 7 surgical interventions for lumbar disc herniation: A network meta-analysis. Pain Phys 20:E863-E871, 2017
50. Alvi MA, Kerezoudis P, Wahood W, et al: Operative approaches for lumbar disc herniation: A systematic review and multiple treatment meta-analysis of conventional and minimally invasive surgeries. World Neurosurg 114:391-407, 2018
51. Wang MY, Grossman J: Endoscopic minimally invasive trasforaminla interbody fusion without general anesthesia: initial clinical experience with 1-year follow-up. Neurosurg Focus 40:1-5, 2016
52. Ahn Y, Youn MS, Heo DH: Endoscopic transforaminal lumbar interbody fusion: a comprehensive review. Expert Rev Med Devices 16:373-380, 2019
53. Wan Q, Zhang D, Li S: Posterior percutaneous full-endoscopic cervical diskectomy under local anesthesia for cervical radiculopathy due to soft-disc herniation: A preliminary clinical study. J Neurosurg Spine 29:351-357, 2018