In-vivo Endoscopic Visualization of Patho-anatomy in Symptomatic Degenerative Conditions of the Lumbar Spine II: Intradiscal, Foraminal, and Central Canal Decompression

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ABSTRACT

The patho-anatomy in an aging spine is partly defined by Rauschning's anatomic cryosections. Theories of pain generation and principles of minimally invasive spine surgery are suggested by close examination of these specimens. If the visualized patho-anatomy can be studied *in vivo* in a partially sedated patient by spinal probing, spinal pain can be better understood, and rational endoscopic treatment options may then evolve.[1]

A 1997 IRB-approved study provided evidence that endoscopic transforaminal surgery was feasible for the treatment of a wide spectrum of degenerative conditions in the lumbar spine. The technique incorporated evocative chromo-discography to correlate reproduction of pain with *in-vivo* probing of patho-anatomy. Laser and radiofrequency ablation augmented mechanical decompression to obtain pain relief.[1-3]

Endoscopic visualization of patho-anatomy ranging from annular tears to spondylolisthesis and stenosis provided clinical evidence that foraminal decompression, ablation, and irrigation could effectively treat these visualized painful conditions with minimal morbidity. This resulted in a better understanding of the pain generators in the lumbar spine, opening up options for surgical pain management.[1-5]

The procedure does not burn any bridges for more traditional surgical techniques. The learning curve may be steep for some and long for others, but results are very good, concomitant with each individual surgeon overcoming his personal learning curve.[6]

INTRODUCTION

Clinical assessment and routine imaging studies are not enough for determining the source of chronic back pain and sciatica for surgical planning.[7] Imaging should be supplemented by diagnostic and therapeutic injections to help elucidate the source of pain. Current imaging creates both false positive and false negative clinical conclusions of up to 30%.[8] Well-executed foraminal diagnostic and therapeutic blocks provide valuable prognostic information in understanding the transforaminal surgical approach to treating lumbar pain.[8–14]

In transforaminal endoscopic procedures, the ability to visualize and palpate patho-anatomy in the degenerative spine in an awake patient adds greatly to the treatment of painful degenerative conditions. To elucidate theories of pain generation by probing the patho-anatomy in a conscious patient, and treat the pain generator by decompressing, ablating, and irrigating the source of pain, is the goal of this article. Much like the development of arthroscopic joint surgery, the ability to visualize patho-anatomy and correlate it with surgical results creates a better understanding of the pain generators in the lumbar spine. The findings also serve to advance and evolve the minimally invasive endoscopic techniques for treatment of the symptomatic degenerative spine (Figs. 1a, 1b, & 2).

The endoscopic foraminal approach to the spine and disc is a technique that allows access to degenerative patho-anatomy without injuring and altering normal anatomy. The learning curve may be long for some surgeons not familiar with the technique, but once mastered, results are also good, concomitant with the surgeon overcoming his personal learning curve, opening his mind to new concepts and patho-anatomy not seen in traditional surgery. In medicine, it is uniformly more difficult for seasoned practitioners to discard old concepts than to adopt new ones. Those understanding and accepting new concepts will find this article valuable for their role in treating patients with acute and chronic back pain and sciatica.

THE AGING SPINE

The disc is avascular and cannot heal from injuries. Nutrition is by diffusion through the end plate. The end plate is porous and permeable to nutrients. This permeability and the ability to transport nutrients normally decrease during growth and aging, from diminished blood supply to the intervertebral disc. This occurrence in the second decade appears to initiate tissue breakdown. A Volvo award-winning paper in 2002 delineates these changes.[15] Permeability also decreases when there is disease due to disc degeneration and end plate pathology. Nerve fibers normally only penetrate the outer area of the annulus; however, in degenerative disc disease, the nerves progress to the inner annulus and toward the nucleus. Inflammatory and granulation tissue forms in and outside the disc, producing pain.[16]

The pain can present as:

- ◆Leg pain along nerve dermatomes and dynatomes from disc herniation or annular tears
- ◆Back pain from disc protrusions
- ◆Backache due to facet changes felt along the paraspinal area
- ◆Claudication-like leg pain due to unilateral single-level or multilevel lateral canal stenosis
- ◆Bilateral claudication due to central soft tissue or bony canal stenosis
- ◆A combination of back pain and sciatica from multiple pain generators (confusing basic standard clinical guidelines)

Five of these symptom groups can be distinguished clinically, but because their patho-anatomies usually overlap, it may be necessary to consider new diagnostic and therapeutic methods of evaluation, such as chromo-discography, endoscopic probing, and endoscopic evaluation. Symptoms are due to disc and facet changes as components of a functional spinal unit, and both usually cause pain as degeneration progresses.[17–22] The cryosections of Rauschning made our understanding deeper. Sacroiliac and piriformis syndromes and related symptoms also contribute to back and leg

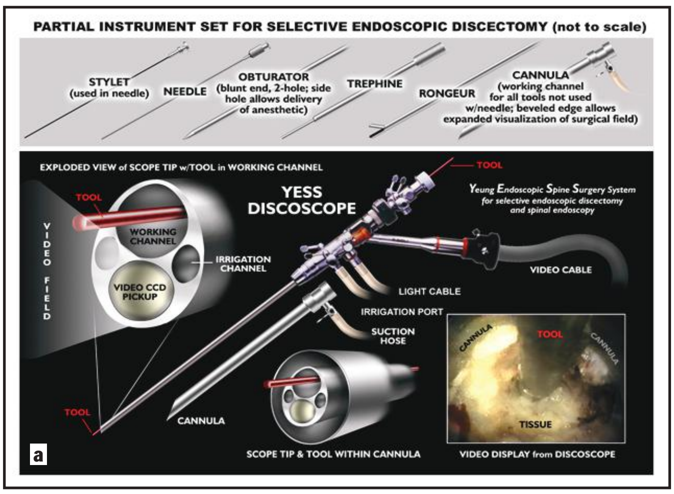


Figure 1a. The Richard Wolf YESS™endoscope facilitates endoscopic documentation of pathoanatomy. The uniqueness of the YESS™ scope is the 2.8mm working channel with integrated distal irrigation ports that keep the lens clear of blood that may otherwise obscure intradiscal and epidural visualization.

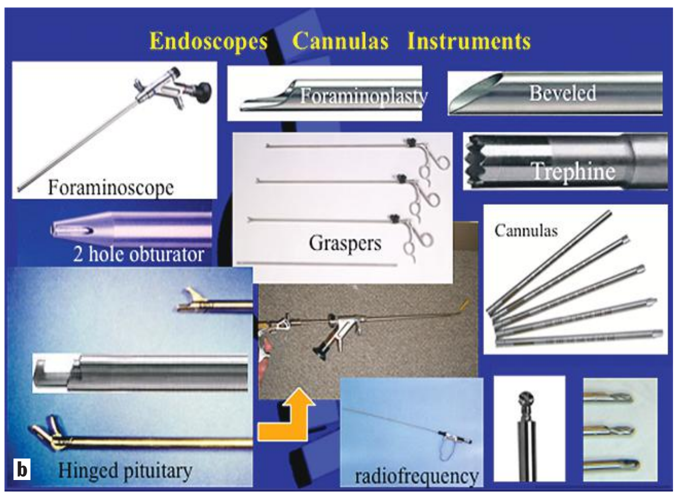


Figure 1b. In addition to custom instruments used by the senior author, Wolf has a full complement scopes and instrumentation designed for disc inspection, disc excision, foraminal decompression, and ablation. An additional complement of scopes with working channels and instruments offer operating ports of 2.2, 2.8, 3.1, and 4.2mm are used for discectomy, rhizotomy, foraminoplasty and for the trans foraminal and translaminar approach to the lumbar spine.

Figure 2. KARL STORZ: GORE SET of instruments for lumbar spine endoscopy and surgery. This set includes bipolar cautery probe, kerrison style roungeurs, angled articulated instruments, and trephines. In addition it has a drill, burr, and shaverset. The set has a 3.5 mm working channel, and instruments specially configured for shorter statured Asian morphometry. It has a hook, which helps with probing, nerve mobilization and manipulation of annular tears. The basic set has only 7 instruments needed for simplicity, but adequate for routine surgery.

pain, and are gaining more attention, but are not addressed in this paper.

The patho-anatomy and degenerative processes in an aging spine are elegantly defined by Wolfgang Rauschning's anatomic cryosections of cadaveric specimens.[23] Theories of pain generation are suggested by close examination of these specimens. The patho-anatomy of spinal pain can be better understood by probing painful tissue and structures *in vivo* in a conscious, alert, or partially sedated patient, and rational treatment options evolve following this endoscopic technique.

An IRB-approved study commenced in 1997 and continued to the present time has provided evidence that endoscopic transforaminal surgery was feasible for the diagnosis and treatment of a wide spectrum of degenerative conditions. We can make clear distinctions from the changes visualized in the disc, facets, foramen, lateral, and central canal. As a result, new endoscopic treatment options develop.

Minimally invasive diagnostic and surgical techniques that are demonstrated to effectively treat certain painful conditions with minimal morbidity include:

- ◆Identification of morphological changes for intradiscal therapy: Chromo-discography is a critical tool to help correlate pain production with the patho-anatomy visualized. This includes *in-vivo* probing, evoking pain from the disc and annulus.
- ◆Lateral canal volume expansion by endoscopic mechanical and laser-assisted foraminoplasty, also effective in selective cases of olisthesis, stable or minimally mobile.
- ◆Facet-related changes treated with denervation of the facet (and possible adjacent musculature responsible for spasm) under endoscopic visualization.
- ◆Central canal transforaminal or sublaminar decompression by unilateral and contralateral entry with endoscopic visualization.

In his presentations at MIS international spine meetings, Rauschning further discusses the significance of these patho-anatomic findings as pain generators and as a guide to endoscopic minimally invasive spine surgery. Rauschning's theories of pain generation are now supported endoscopically *in vivo*, offering supporting evidence that bridges theory to *in-vivo* surgical evidence. Endoscopic treatment of these pain generators will ultimately bring more cost-effective treatment earlier in the disease process. A better understanding of spinal pain through endoscopic means is the result.[1–5,24–28]

PHILOSOPHY, METHODOLOGIES, AND THEIR EVOLUTION

In 1997, an IRB study was approved at St Luke's Medical Center, Phoenix, Arizona, to evaluate Selective Endoscopic Discectomy™ and thermal annuloplasty for the treatment of painful lumbar discs presenting with back and leg pain. Inclusion criteria were herniated nucleus pulposus diagnosed by MRI and correlated with evocative discography, the Yeung Endoscopic Spine System (YESS™ technique).[1–5,29,30] The study was supported by Oratec, Inc. (Mountain View, CA) a company about to go public with its electro thermal catheter (IDET) to treat painful annular tears. Oratec also had a temperature-controlled unipolar, flexible, endoscopically guided, flexible thermal probe for endoscopic use that was to complement the IDET catheter.

Patient selection centered on positive "provocative" discography as an indication for intradiscal thermal therapy and as an adjunct to mechanical decompression, regardless of the stage of degeneration in this pilot study. A concordant positive response was considered an indication for disc decompression (discectomy) and thermal annuloplasty. This study of painful lumbar discs included one patient with isthmic spondylolisthesis and one with minimal degenerative spondylolisthesis who also had a disc bulge and concomitant discogenic pain diagnosed by evocative discography.

All 50 patients had improvement of their discogenic back pain. Two patients, however, developed severe dysesthesia with the unipolar temperature-controlled flex probe, but only one

Table I
Symptomatic degenerative conditions of the lumbar spine identified by *in-vivo* patho-anatomy treatable by endoscopic transforaminal surgery

1.	Annular tears associated with discogenic lumbar pain as determined by evocative discography™, both positive and false negative
2.	All disc herniations and protrusions accessible through the foramen whether contained, extruded, or sequestered
3.	FBSS from foraminal fibrosis, recurrent HNP, and subarticular lateral recess stenosis
4.	Mild central spinal stenosis
5.	Foraminal and extraforaminal stenosis
6.	Foraminal osteophytosis
7.	Juxtafacet and pedunculated synovial cysts
8.	Spondylolisthesis, degenerative or isthmic, with a painful bulging or protruding disc

patient ended up with a permanent residual, a partial 3/5 neuropraxia that worsened to 0/5 neuropraxia due to comorbidities and an ill-advised subsequent two-level fusion by a competitor surgeon. The second surgeon did not recognize the patient's comorbidities, (positive babinski, peripheral neuropathy, epilepsy, and what the patient reported as stroke-like symptoms). The company withdrew the temperature-controlled probe after the complication, which resulted in a malpractice lawsuit, fueled by the rogue, vehement criticisms of the second surgeon in response to an ultimately bad surgical result. Oratec aborted support for the study, retrieving their temperature-controlled probes. This occurred in the same time frame in which Oratec launched the IDET catheter for clinical use in an IPO. It was later determined that the thermal couple had difficulty keeping the power and temperature from fluctuating, as the thermal couple was required to constantly adjust its power in order to maintain the temperature at a constant setting in the face of the cold irrigation fluid used for endoscopy. The concept is still worthy of further investigation, however, as there was no visual evidence of tissue damage, carbonization, or necrosis with the Oratec probe, but as desired, a better and greater shrinkage of collagen as visualized endoscopically.

After the first 50 patients, the technique evolved further by substituting a proprietary low-temperature, steerable, bipolar radiofrequency probe for the Oratec probe. Under endoscopic visualization, the bipolar probe was used in patients with a wider spectrum of painful degenerative conditions ranging from discogenic pain to lumbar spondylosis, stenosis, and "stable" spondylolisthesis. Stability was defined as having less than 2 mm excursion on flexion/extension x-rays. There were no further thermal injuries with the bipolar probe. The probe was later evaluated by Stephan Hellinger of Munich, Germany, for safety and efficacy. His study showed that the probe, when activated, only raised the temperature in the epidural space to 41 degrees Celsius and no thermal injuries have been recorded in more than 4,000 subsequent cases. Because of the good/excellent results in the study, the endoscopic treatment of visualized patho-anatomy by disc decompression, annulus thermal modulation, and disc irrigation continued, substituting the Oratec probe with a bipolar 1.7-4.0 MHz low-temperature radiofrequency probe (Elliquence LLC, Baldwin, NY).

Based on Yeung's experience with intradiscal therapy treatment in all stages of discogenic pain together with the thermal study conducted by Hellinger, the Disc FX system was developed by Elliquence, LLC. As an integral part of the procedure, evocative chromo discography, (mixing isovue-300 9 cc with indigo carmine dye 1 cc) was used in performing intraoperative discography to stain and label the fissured and degenerative acidic nucleus pulposus along with any structural collagen tissue in contact with the indigo carmine dye.[31] Selective Endoscopic Discectomy™ of the degenerative nucleus pulposus followed. To differentiate this visualized endoscopic procedure from other endoscopic procedures in the literature, the technique was trademarked, as the "YESS™" technique, and taught worldwide.[32–39] The IRB patients were followed at one month, 3 months, 6 months, and one year. After the end of the study, the study database was continued and maintained on an Excel spreadsheet, with an ongoing collection of images in each operative report correlating the clinical presentation, MRI, intraoperative chromo-discogram, and surgical patho-anatomy images collected, stored, organized, and maintained on SVHS tape and DVD. The collection of images made this paper possible, with added contributions from the second author, who has also dedicated his spine career to endoscopic surgery. Most patients with good results stopped follow-up after 2 years, but many would re-establish contact years later, and often times with friends who they referred. Many patients remain greatly satisfied even after 14 years (see voluntary unsolicited testimonials www.sciatica.com). Evaluation was with modified MacNab criteria, Oswestry Disability Index, pain visual analog scale (VAS), SF 12, and a patient satisfaction questionnaire. As a result of 20 years of experience with intradiscal therapy, Table I illustrates the senior author's experience with degenerative conditions treated successfully with the foraminal endoscopic approach to the spine.[32–52] One caveat we learned from this longitudinal study is: Earlier intervention in a degenerative condition with a technique that does not cause collateral damage, but helps preserve normal conditions, is extremely successful and may become the desired method of surgical pain management.

INNERVATION OF THE SPINAL SEGMENT

Another important concept that is important for surgeons to recognize is that the innervation of the spinal segment is complex, and axial back pain cannot always be divided into anterior and posterior column pathology because the innervation of the spinal segment has nerves communicating the dorsal ramus (responsible for facet and posterior column pain) with the ventral ramus (responsible for discogenic pain and sciatica). Therefore, discogenic pain can also produce chronic back pain without sciatica. Decompression and ablation techniques may have to address both sources of pain.

CLINICAL APPLICATIONS

Although all these basic anatomical studies and observations have not found their way to the peer-reviewed literature, there are sufficient numbers in our endoscopic database, containing surgical images that include intraoperative evocative discography patterns with surgical images on each operative report, that independent reviewers can analyze. They can then help write and publish articles on the patient selection criteria for each endoscopic treatment of this wide spectrum of degenerative conditions. Multiple retrospective case series reports are now being mined from a database of over 3,500 surgical cases containing the digital images being scanned in electronic health records, including storage of SVHS tapes and DVDs of each endoscopic procedure. While results are being reported at podium and poster presentations at international spine and minimally invasive specialty meetings, independently reviewed studies are just now making their way into the literature. With this database, indications are being refined for the endoscopic diagnosis and treatment of pain generators in the lumbar spine that have eluded diagnosis and visualization by conventional means. The goal of each substudy is to obtain a 90% success rate for each stratified condition treatable by foraminal endoscopic surgery, with minimum surgical morbidity and complication rates. The fair/poor results will make the list of "relative" contraindications.

As endoscopic foraminal surgery evolves, extension of the initial 50-patient study in 1997 now encompasses a wide spectrum of painful degenerative conditions of the lumbar spine. Favorable results have been obtained for multi-level discogenic pain, synovial cysts, failed back surgery syndrome, spinal stenosis, degenerative and isthmic spondylolisthesis, and, in the future, results will even include neoplasms. The technique, even if not ideal, has helped many patients with severe comorbidities who would otherwise be excluded from any surgical consideration. The approach will have potential for endoscopic implants and as a means of delivering biologics. We will continue to build on the positive outcomes and list the failures as relative or suggested contraindications. Development of new instrumentation, currently custom-made and proprietary, will make the procedure easier for the spine surgeon who adopts the transforaminal endoscopic technique.

In the face of pain, inflammatory tissue in the disc and annulus is the common denominator. Inflammation is correlated with the presence of grade IV and V annular tears to the annulus. Inflammation affecting the exiting nerve is associated with chemical irritation of the DRG and lateral recess stenosis. The literature does not address the cause of failure in fluoroscopically guided intradiscal procedures. With visualization, it is now known that at least one of the major causes of failure is the failure to remove the offending embedded nuclear material in the annular layers that prevents tears from healing. Temporary post-op dysesthesia is partially associated with the thermal removal of the inflammatory membrane and furcal nerves in the foramen. Delayed dysesthesia days to weeks post-op is still incompletely explained. Neo-angiogenesis and neurogenesis are findings not previously reported in surgical clinical studies. These "anomalous" nerves in the "hidden zone" of MacNab are a source of pain from the foramen that has not been previously reported in the literature. These "anomalous" nerves make foraminal endoscopic surgery a risk for unexplained dysesthesia, and it is currently not possible to completely eliminate it.

SCOPES AND INSTRUMENTS

Two scope designs and complementary instruments for the YESS technique are available for commercial sale. The original YESS scope designed for intradiscal surgery has integrated distal irrigation ports to provide constant irrigation inflow and outflow through the distal end of the scope. This allows for clear visualization of the disc cavity, but has smaller instruments for intradiscal therapy. Second- and third-generation systems with larger working channels (Vertebris) and instruments are available for complementary and translaminar use. For intradiscal therapy in collapsed discs, there is also a smaller 2.2-mm working channel endoscope designed by Martin Knight that can be used only with pituitary rongeurs (5 French) and laser fibers smaller than 2.2mm. The Knight scope was manufactured by Richard Wolf GMBH (Kinittlingen, Germany) but is no longer available. A custom-designed 70-degree scope without working channel is utilized to look at dorsal annular tears (Fig. 1).

More recently, Gore modified the Yeung design with a set by Storz that is specially configured for shorter-statured Asian patients. It contains basic instruments that augment the YESS system by Richard Wolf with some additions, like a hook (Fig. 2). The hook helps to create a plane between annulus and nucleus, and facilitates removal of the fragment, especially if up or down migrated. Other brands (e.g., Joimax Karlsruhe, Germany) are designed for an outside-in endoscopic approach, targeting the pathology directly with serial dilators and trephines.

DISC-RELATED SYNDROMES

Annular Tears and Discography

Up to 30% of tears are identified with discography when no HIZ is present. The annular defect or condition is confirmed endoscopically. Grade V tears may be painful or non-painful with

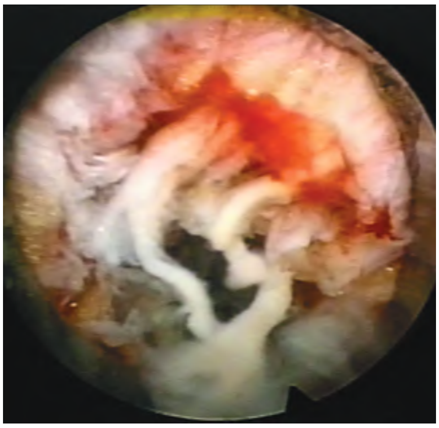


Figure 3. An inflammatory membrane is identified in the epidural space containing multiple nerves entering the disc through a grade V annular defect

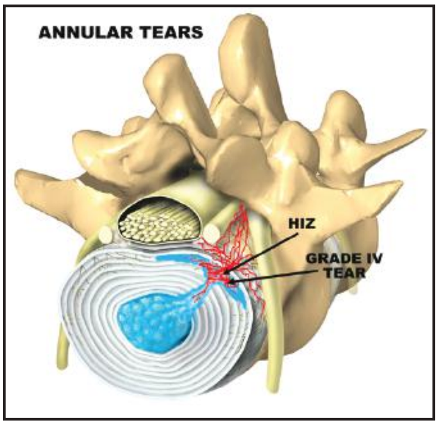


Figure 4. Illustration of a Grade IV Annular tear. Annular tears can be graded according to Adam's Classification. It can be visualized intradiscally and treated with tools utilizing bipolar flextip Radiofrequency, laser, tissue sealants, and biologics that enhance tissue healing.

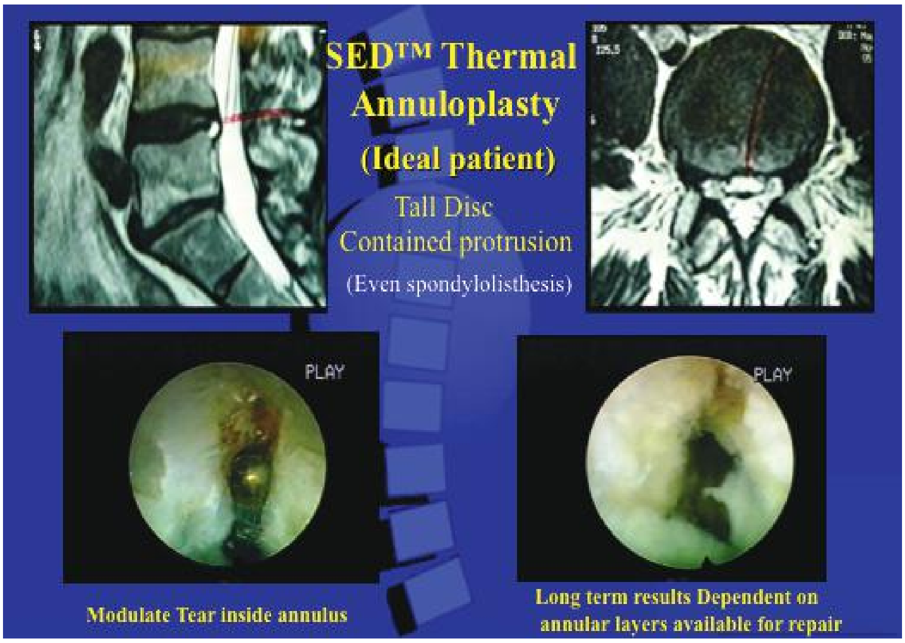


Figure 5. Radiofrequency Thermal Modulation of a Grade IV annular tear in a tall disc

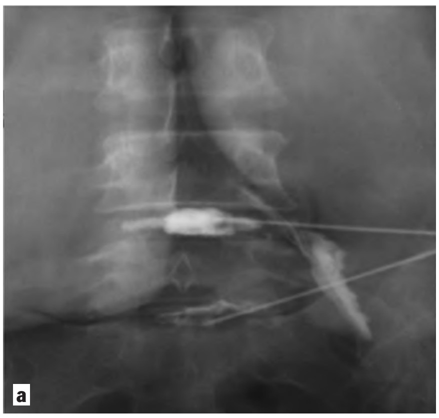


Figure 6a. Discography showing contrast leaking to the L4 nerve.

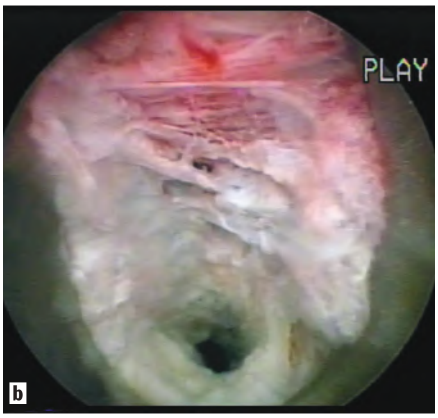


Figure 6b. Foraminal view of the annular tear in figure 6a.

evocative discography because the larger tears cannot be pressurized. Granulation tissue and neo-neurogenesis occur in inflammatory membranes identified around the sensitized annulus (Fig. 3). The inflammation sensitizes the pain nociceptors in the annulus. Neo-angiogenesis and neurogenesis may be part of the physiologic healing response to annular tears, and its presence is associated with pain production. Tears with no inflammation around it may show leakage of contrast, but no pain is evoked. In all patients with painful annular tears where the surgeon is able to reach the tear, decompression, ablation, and irrigation bring relief of pain over 90% of the time. The duration of relief, however, varies and is dependent on the severity of the initial condition and on patient selection.

If the annulus does not heal, an inflammatory membrane will cause axial and neuropathic pain out of proportion to a similar tear without inflammation, especially if the tear communicates with the dorsal root ganglion. Besides discography, only by endoscopic probing in a conscious patient can pain be confirmed. The difference between a sensitized tear (low-pressure positive discography) and a non-sensitized tear (mildly painful or non-painful abnormal discogram) is the presence or absence of inflammation. Pressure on a nerve will only cause numbness unless accompanied by inflammation when it causes pain.

False negative evocative discography can occur in patients with grade V lateral and posterior tears that cannot be pressurized by evocative discography. Grade IV tears, however, usually produce pain at varying degrees because the annulus can be pressurized. False negative discography does not negate surgical success in treating annular tears. The literature utilizing pressure manometers is of very little value for endoscopic surgery and is not needed for endoscopic surgery because the surgeon can very closely and accurately estimate the opening pressure of 30 psi (low pressure) and maximum pressure of 90 psi (high pressure) standardized with a 22-gauge needle on a 10-cc syringe. The pressure is then correlated with the volume accepted by the disc in relation to the discogram pattern. Medium pressure (60 psi) will usually generate concordant pain with an abnormal degenerative pattern.

Evocative Discography™ and Annular Tears

High pressure needed in evocative discography signifies a good annulus with many intact layers. This is likely to heal faster and fuller. When there is a chronic tear that has not healed due to nuclear material in the tear, it induces inflammation and pain. Inflammation is due to basic chemical sensitization. In evocative discography, in addition to assessing this chemical sensitization, we are doing morphologic change analysis of annular tear patterns and the layers left to heal (Fig. 4). Grade IV and V tears that are highly sensitive have inflammatory granulation tissue in the annulus layers and inside the nucleus. Tears producing pain at higher pressures actually do better with disc decompression because more annular layers are still intact and functional. Successful long-term results require removal of trapped nucleus within the annular tears to allow the tears to heal. The pain persists due to embedded nuclear material in the tear that is a barrier to healing. The annular tear may then have the ability to heal after its removal.

The ideal patient for intradiscal therapy has a tall disc (Fig. 5). Evocative discography produces the best prognosis for thermal modulation in patients who have positive discography with medium or high pressure because this signifies a relatively intact annulus. Prognosis is even better when the tear is visualized endoscopically and then closed with thermal annuloplasty. Prognosis is also good when there are multiple intact annular layers left to heal as determined by high-pressure concordant pain. Here, L5-S1 shows a degenerated disc that was not painful. At L4-5, on injection, dye was leaked to the L4 nerve, eliciting severe radicular pain (Fig. 6a). In this patient we found granulation tissue and an inflammatory membrane on the site of leakage (Fig. 6b).

Illustrative Case

Mr. B. is a 30-year-old male with sciatica and numbness. This patient requested endoscopic decompression for a contained disc protrusion causing only mild sciatica, with persistent numbness in the L5 distribution (Figs 7a & 7b). He was worse with physical therapy and temporarily improved with epidural blocks. He elected to have endoscopic surgery because of his dissatisfaction with non-surgical management.

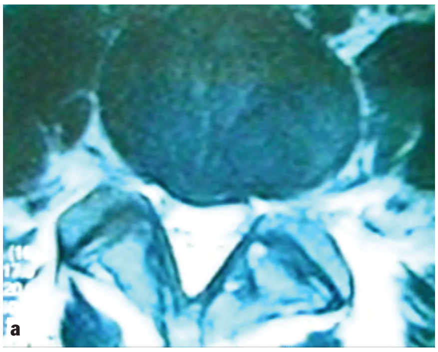


Figure 7a. Axial MRI.

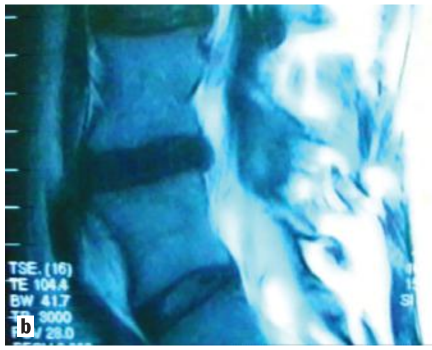
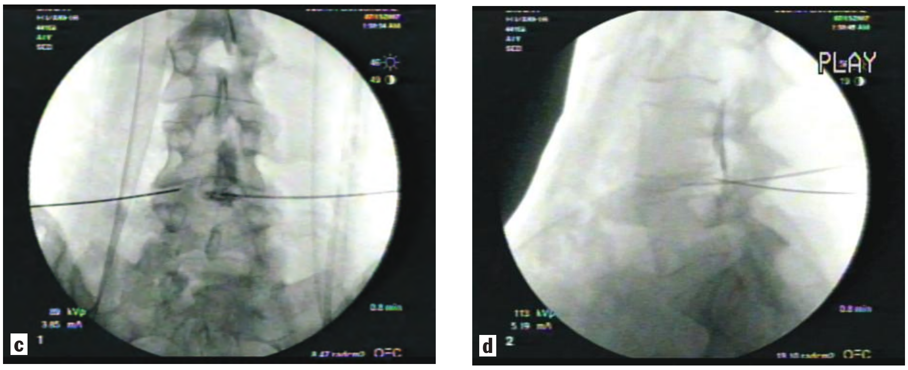


Figure 7b. Saggital MRI.



Figures 7c, 7d. Intraoperative PA and lateral discogram demonstrating a grade V annular tear.

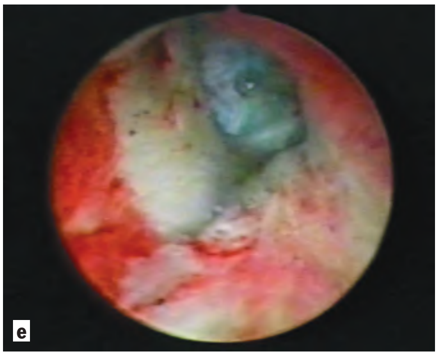


Figure 7e. Annular defect identified after removing the degenerative nucleus. The defect was visualized with a 70-degree scope. The nerve and dura was protected by an intact PLL between the annular defect and epidural space, shielding the nerve from chemical irritation. The tear would open and close with the patient's breathing. The nerve and epidural space was shielded by the PLL. Note mildly inflamed disc annulus and blue stained nucleus material.

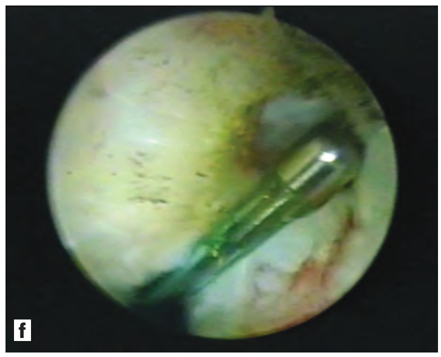


Figure 7f. Thermal modulation with a bipolar flex probe (using a biportal technique) ablated the inflammatory and disc tissue and partially contracted the hole in the annulus.

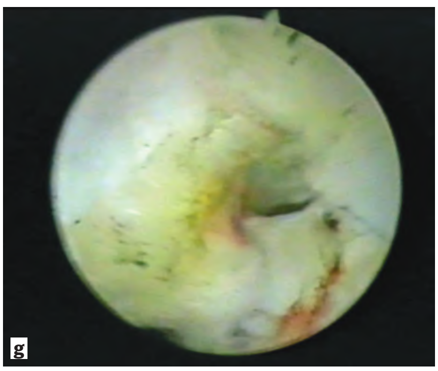


Figure 7g. After thermal modulation, a valve-like flap would open and close the hole.

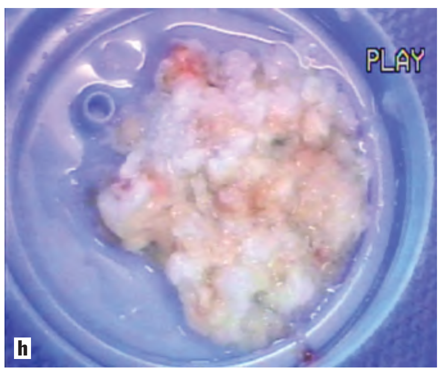


Figure 7h. Discectomy specimen contained 4 grams of soft, degenerative nucleuspulposus.

Figure 8a. This saggital MRI demonstrates two dark discs on T2 imaging, but does not show significant disc protrusion or the presence of an HIZ. It could be interpreted as "normal." Positive evocative discography identified a painful grade IV annular tear.

Figure 8b. The annular tear is identified endoscopically and successfully treated with foraminal discectomy and thermal annuloplasty.

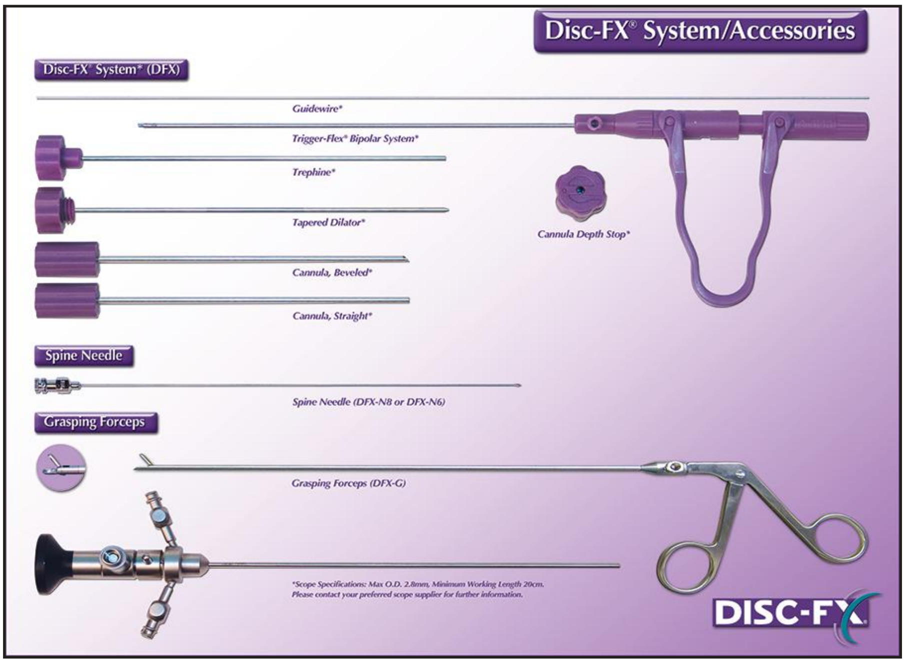


Figure 9. Disc FX Disposable Surgical System with Assessories.

No pain was elicited by evocative discography. False negative discography was diagnosed (Fig. 7c). The patient demonstrated extravasation of contrast with low opening pressure. The disc could not be pressurized. We elected to decompress the disc to inspect the annular tear.

The defect was visualized with a 70-degree scope (Fig. 7d). The nerve and dura were protected by an intact PLL between the annular defect and epidural space, shielding the nerve from chemical irritation. The tear would open and close with the patient's breathing. Note mildly inflamed disc annulus and blue stained nucleus material (Fig. 7e). The tear was treated intradiscally with the Elliquence bipolar flexible radiofrequency probe (Figs. 7f & 7g). The surgical specimen (Fig. 7h), 3.0 grams by weight, represents the average amount of disc material removed from degenerated discs with annular tears.

Mr. B's preoperative symptoms resolved completely post-op and remained much improved at one-year follow-up. He has not returned for follow-up care in the subsequent four years since his surgery. This is typical for patients who get better and have no residual symptoms. Many write years later to express their appreciation and send friends with similar symptoms who provide us with follow-up information. Most patients with annular tears and disc herniations receive significant pain relief in the first few days post-op, then continue improvement over the next 1 to 3 months. This may depend on the duration of their HNP. The best results are obtained when the HNP is present for less than 3 months.

Painful Annular Tear in Disc with a "Normal" MRI

A patient with severe sciatica is often identified by the presence of a small, high-intensity zone on the saggital or axial cut (Figs. 8a & 8b). An HIZ is seen on MRI only when large enough or if the MRI cut is directly over the HIZ or it may be missed. In this patient, the axial MRI identified the presence of an HIZ, and the pressure-sensitive annular tear was identified by evocative discography, then confirmed endoscopically. Although the annular tear was not associated with any disc protrusion, the pain was intense with medium-pressure, low-volume evocative discography. Here, the patho-anatomy of the tear is clearly visualized, with resolution of sciatica following SED and thermal annuloplasty. Five years later, this patient is still pain free. Tall discs with most of their annular layers intact exhibit excellent results. Some are 14 years out. Former patients often write to provide an update of their condition, expressing their satisfaction and appreciation (see testimonials at www.sciatica.com).

For small tears like this patient had (Fig. 8a & 8b), an even less-invasive three-in-one disposable surgical kit is designed for surgeons and non-surgeon pain management physicians without access to an endoscope who also want to use the least-invasive technique they can choose. "Disc FX" is designed for such a patient as a fluoroscopically guided Selective Endoscopic Discectomy™ and thermal annuloplasty procedure, using cannulas less than half the size of the YESS endoscopic system.

Disc FX

With a smaller disposable kit, more patients can be treated with minuscule surgical morbidity without the endoscope (Fig. 9). It will bridge the gap between non-surgical treatment and surgical discectomy for discogenic pain that may be the prodromal cause of an eventual herniation. The Disc FX system is designed to mimic SED™ and its results on small, contained disc protrusions and discogenic pain from annular tears (Fig. 10a). The technique emphasizes mechanical and electro thermal disc decompression, thermal modulation, and intradiscal irrigation, called

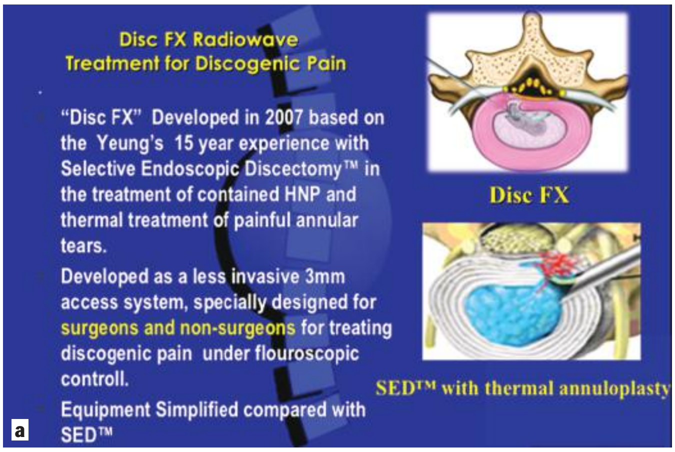


Figure 10a. Disc FX radio wave treatment for small, contained disc herniations and discogenic pain.

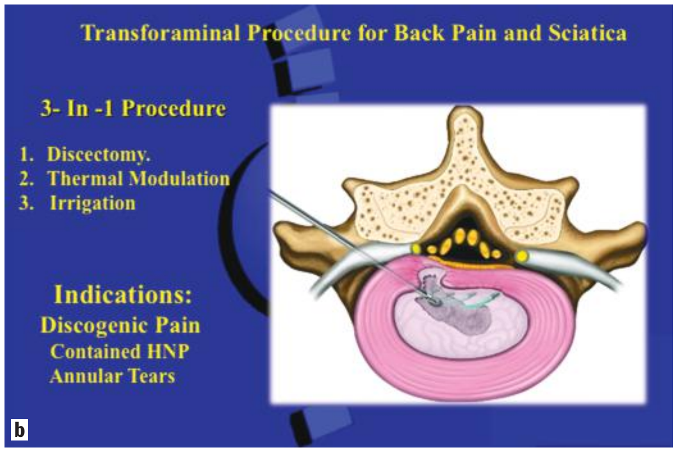


Figure 10b. Transforaminal 3 in 1 Procedure Illustration.

the three-in-one procedure (Fig. 10b).

In a validation study that evaluated the effect of Disc FX on annular tears and small, contained disc herniations, a small endoscope was inserted to visualize the herniation site following Disc FX decompression and thermal annuloplasty (Fig. 11). We were able to examine the effect of mechanical and electro-thermal discectomy on the annular tear by Disc FX instrumentation, and whether it could expose the tear and respond to the thermal modulation of the annular tear. Meticulous placement of the flex probe to the inner dorsal annular wall with a far lateral trajectory is required and necessary to reach the annular tear. Meticulous surgical technique and needle placement are very important, although the average amount of disc material (0.8 to 2 grams) removed was less than in endoscopically visualized selective endoscopical discectomy (average 3 to 4 grams). The less-invasive instrumentation designed to be used with a fluoroscopically guided disposable system offers less-invasive and potentially more effective results over other fluoroscopically guided endoscopic procedures available, such as Stryker's Decompressor (Stryker Spine, Allendale, NJ) and Arthrocare's Coblation (Austin, TX).

The emphasis on endoscopic treatment of annular tears in this article is to allow the reader to consider endoscopic annuloplasty as a potential cost-effective means of treating annular tears that affect patient quality of life and productivity due to ongoing recurrent pain that is not resolved by nonsurgical means. Because of the interpositional nuclear material embedded in the annular tear, these tears don't heal naturally. This article will de-emphasize extruded and sequestered disc herniations that can be treated efficiently and safely by traditional open means, but we also want to demonstrate the advantages that the foraminal approach offers over traditional surgery. It allows for the treatment of a painful condition that can start as an annular tear, but eventually progresses to an extruded HNP. This patient suffered from back pain and sciatica for years. He was managed with physical therapy and epidural blocks with transient relief that eventually resulted in no relief (Figs. 12a & 12b). He eventually required surgical intervention when the herniated disc extruded and radiculopathy developed. The emphasis on endoscopic treatment of annular tears in this article is to allow the reader to consider endoscopic discectomy and annuloplasty as a cost-effective means of treating annular tears that affect patient quality of life and productivity from disabling pain not resolved by "conservative" means. This article will not emphasize disc herniations that can be treated efficiently and safely by traditional open means, but to illustrate the potential advantages that the foraminal approach offers over traditional surgery.

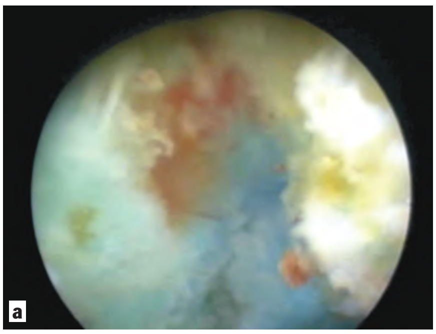


Figure 11. Annular tear exposed by mechanical debridement of nucleus pulposus using disc FX. Bipolar annuloplasty to follow. Note bleeding from annular tear and removal of blue stained degenerative nucleus. It is desirable to mechanically remove the disc herniation first, before annuloplasty, but the bipolar flex probe can aide nucleus ablation as a mechanical/electrothermal procedure.

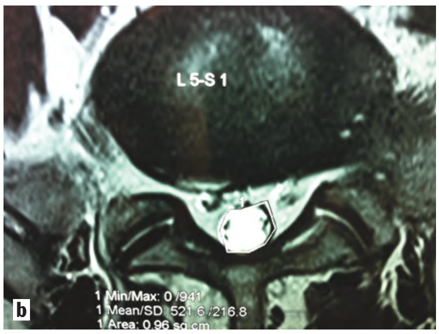


Figure 12a. This MRI demonstrates a bulging disc with an annular tear that progressed to in an eventual herniation. The patient had intermittent, but debilitating pain at this stage. Earlier definitive treatment of this condition with Disc FX or selective endoscopic discectomy would have mitigated the years of prolonged and debilitating symptoms.

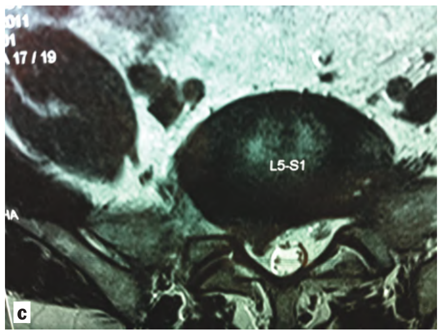


Figure 12b. The patient progressed to herniation without radiculopathy. Back pain and sciatica was now constant. An extruded free fragment was found at surgery.

Figure 13a. Large annular defect in a large central HNP.

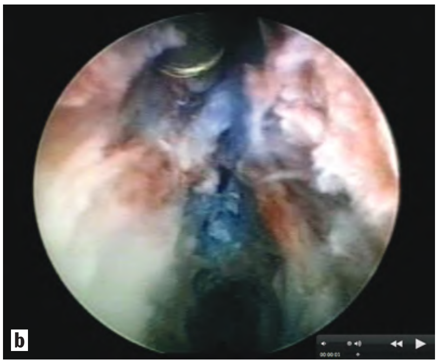


Figure 13b. Thermal modulation of the posterior tear defect containing embedded disc material.

Central Disc Herniations

In contrast to traditional posterior discectomy, central disc herniation is one such herniation that benefits greatly from the transforaminal approach. Moderate to large central disc herniations are more successfully treated with endoscopic transforaminal discectomy than the posterior approach.[52] The musculature is not disturbed and the weakened annulus is not further compromised by the surgical approach, but preserved. Prognosis is better than the posterior approach for transforaminal endoscopic discectomy. A biportal transforaminal approach will decompress the disc even more without disturbing the integrity of the dorsally stretched annulus. Intraoperative visualization of the dorsal annular wall illustrates how the transforaminal approach can preserve and treat the posterior annulus after nucleus decompression.

This intradiscal view of a large painful tear was seen after removing a large central disc herniation (Figs. 13a & 13b). Note the inflammation around the tear. Nuclectomy not only decompressed the protrusion, but also removed degenerative inflammetogenic nucleus and exposed the tear for visualized thermal treatment. Visualization is important because sometimes the tear is too large to contract and heal, but the integrity of the dorsal annulus is preserved. Recurrence rate therefore will be lower, and thermal modulation of the annulus actually helps relieve back pain from central herniations. Annuloplasty with radiofrequency ablates the granulation tissue, closes some fissures, and can ablate pain nociceptors in the annulus. In this case, the patient still had excellent relief of back pain at last follow-up 2 years later. She is now 5 years post-op.

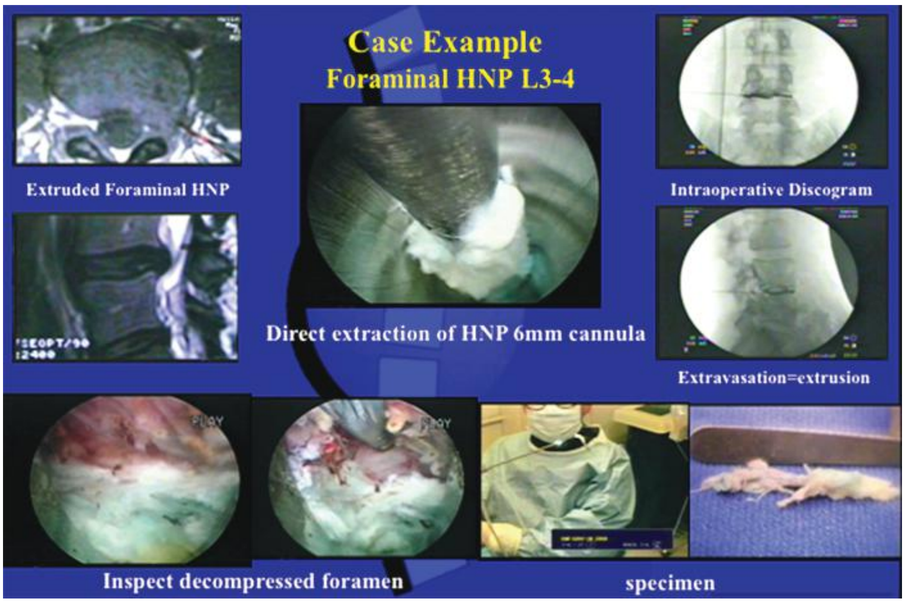


Figure 14. Foraminal HNP at L3-4. Foraminal and extraforaminal HNP is ideal for the transforaminal approach. The disc herniation is encountered in the path of the cannula for extraction with endoscopic pituitary forceps (center image) and the decompressed nerve is easily visualized in the foramen.

The Patho-anatomy of Disc Herniations (HNP)

The ideal herniation for the foraminal endoscopic approach is a foraminal or extraforaminal herniation. The herniation is in the direct path of the surgical cannula and instruments. The herniation can be removed with minimal surgical morbidity because the instruments do not interrupt normal anatomy and access the disc through natural tissue planes (Fig. 14).

Figure 14 demonstrates what is visualized in a uni-portal endoscopic extraction of an extraforaminal herniated nucleus pulposus (HNP) at L3-4. Foraminal and extraforaminal HNP are ideal for transforaminal endoscopic discectomy. The disc herniation is encountered directly in the path of the cannula with endoscopic pituitary forceps (center image) and the decompressed nerve is visualized immediately after removal of the herniation.

As the surgeon becomes more skilled, he can take on most of the herniations encountered transforaminally by using different trajectories and performing foraminoplasty (using the inside-out or outside-in technique) to gain access to the epidural space to reach the extruded and/or sequestered fragment. Utilizing the foraminal approach is very surgeon dependent, with the very skilled and experienced using the foraminal approach 80% to 90% of the time, while the skilled endoscopic surgeon who also performs micro-lumbar discectomy (MLD) may choose to go transforaminally only about 30% to 40% of the time. It is appropriate to use the posterior microlumbar (MLD) approach, especially when the surgeon is more comfortable and experienced with the MLD approach that offers him better access and visualization in accordance with his experience. As the surgeon becomes more skilled and comfortable with the transforaminal approach, he may gradually take on more difficult cases because surgical morbidity is less, even if the clinical result is the same.

Complete decompression of the nerve roots by herniations in the epidural space is facilitated by proper trajectory and positioning of the working cannula, with or without foraminoplasty. Foraminoplasty is performed not just to decompress the foramen, but also to remove any bony obstruction in the way of the cannula and endoscopic instruments. To accomplish this, different uniportal and biportal trajectories may be required to accomplish desired decompression due to the anatomic variations in the patient's anatomy. The illustrations (Figs. 15a–15k) show how a sequestered disc fragment migrating cephalad behind the vertebral body at L4-5 (Figs. 15a & 15b) is extracted.

We demonstrate the transforaminal approach for a sequestered fragment using the inside-out technique targeting an extruded, sequestered HNP fragment at behind the vertebral body of L4- (Figs. 15a & 15b). The cannula may be angled from the cephalad aspect of the foramen using a blunt obturator or serial dilators to target the sequestered fragment (Fig. 15c). The senior author, however, prefers to access the disc by entering the disc ventral to the extruded fragment, then performing a visualized foraminoplasty by positioning the cannula against the pedicle and ventral facet (Fig. 15d). Trephines, kerrisons, or high-speed diamond burrs (Fig. 15e) may be used to gain access to the fragment in the epidural space (Fig. 15f). The extruded fragment is then removed through the cannula (Fig 5g & 15h). The epidural space behind the vertebral body is probed for remaining fragments (Figs. 15i & 15j), followed by confirmation of decompression by visualizing the freed nerve (Fig. 15k). Finally, the sequestered disc and bone specimen provides confirmation of foraminal decompression of disc and bone (Fig. 15l).

The Foramen: Cadaveric Anatomy Comparing Interlaminar Access with Foraminal Access

The blue hubbed needles are positioned into the disc through the annulus (Fig. 16).

A cannula with a bevel or a penfield-like extension is placed in the foramen at the base of the herniation. One half of the bevel is in the disc and the dorsal one half of the cannula is positioned to view the epidural space in the plane of the traversing nerve (Fig. 17). The cannula is rotated to expose facet or patho-anatomy to be decompressed, or to protect the exiting nerve and DRG. Multiple cannula configurations are designed to accommodate the surgeon's needs.

The subarticular recess, epidural space, and pedicles of the spinal segment are also reachable through the foraminal approach using various needle trajectories and access cannulas. Once inside the disc, the entire intradiscal space and inner annulus are accessible. The axilla of the spinal segment and the epidural space containing the traversing nerve are usually hidden from the surgeon. They can be accessed and explored by simply partially resecting the ventral portion of the superior articular process to expose both the exiting and traversing nerve. This foraminoplasty technique is used to

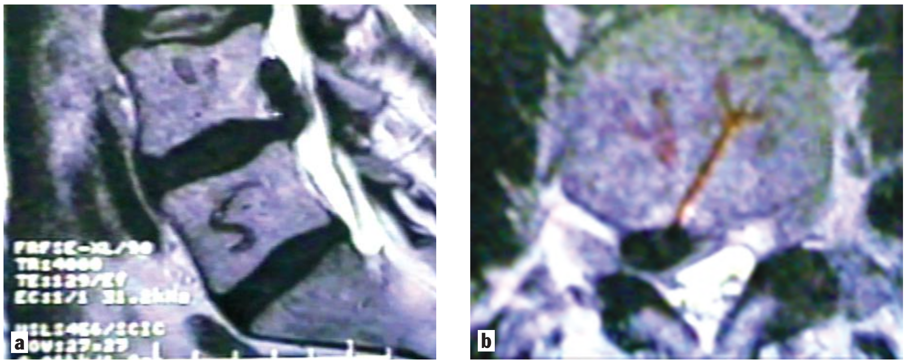


Figure 15a and 15b. Lateral and axial MRI of an extruded, sequestered HNP L4-5 left.

Figure 15c. Thecannulamay enterthe foramen cephalad where it has the most space. Once in the foramen, the cannula can be directed parallel into the disc space by levering against the ventral facet and bluntly directing the obturator into the disc space. This technique is in contrast to the direct outside-in serial dilation foraminoplasty technique described by Joimax and Hoogland.

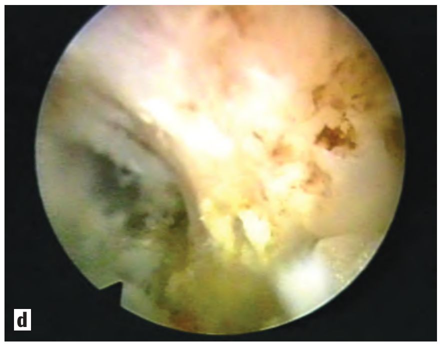


Figure 15d. Base of ventral facet at the pedicle. The facet and pedicle can be decompressed by shielding the exiting nerve and using the trephine or burr to remove enough bone to reach behind the vertebral body to reach a caudally migrated fragment.

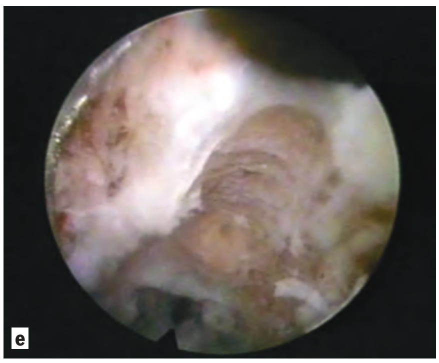


Figure 15e. Decompression of the superior articular process. The SAP decompression can be followed cephalad to remove the tip of the SAP to reach the axilla and a cephalad migrated HNP as shown in figure 15 a, b. The axilla between the traversing and exiting nerve is the "hidden zone" that contains many obstructions , including the superior foraminal ligament responsible for axillary impingement missed by traditional surgeons. Excising the ligament "opens the door" to the axilla and allows visualization of both traversing and exiting nerves in the same view.

Figure 15f. Following decompression of the axilla, the hidden zone of MacNab reveals both exiting and traversing nerves

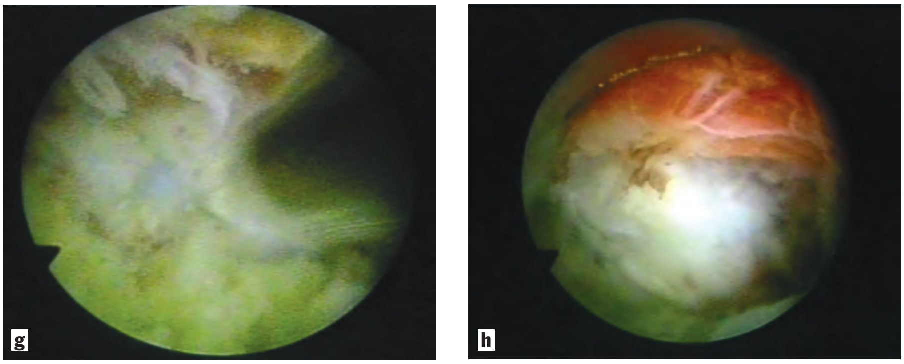


Figure 15g,h. Acephalad or caudally migrated extruded fragment can be pulled into mouth of cannula at the disc level by using the inside-out YESS technique

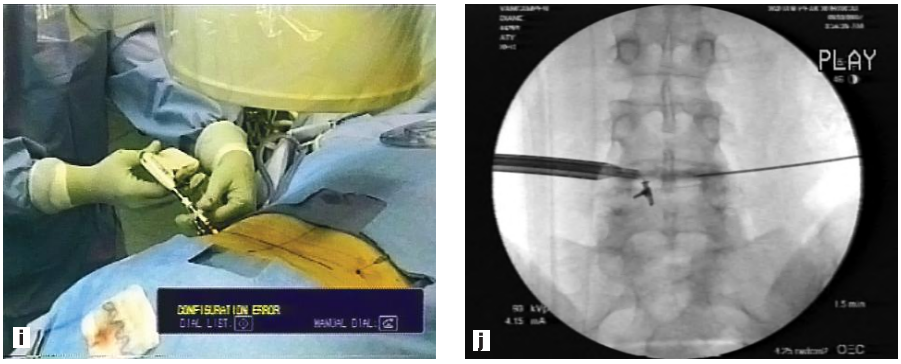


Figure 15i, j. Flexible pituitary (Endius) pulling sequestered HNP into foramen for a caudally migrated fragment

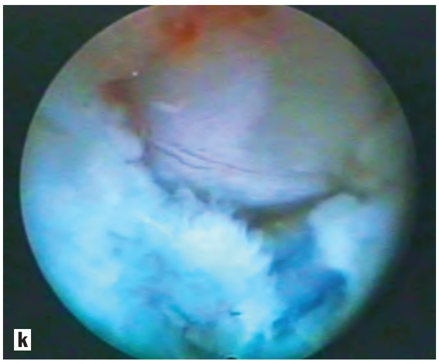


Figure 15k. Decompressed nerve and thecal sac confirmed endoscopically.

Figure 15l. Disc and bone specimen.

access sequestered fragments. We do this with the inside-out technique, while other endoscopic surgeons find the outside-in technique using trephines outside the dilator more intuitive for them. There may be more dysesthesias and potential nerve injuries with the outside-in technique because the surgeon may not be able to visualize and account for anatomic variations and anomalous anatomy. Anomalous anatomy such as furcal nerves can be identified and avoided, but not always. If over 2 mm, resection should be avoided if possible, but it is usually safe to resect or ablate a nerve that is 1 mm or smaller. It is therefore desirable to study patho-anatomy when the transforaminal endoscopic approach is utilized.[36,44,48,49,53]

A cannula with a bevel or penfield-like extension is placed in the foramen at the base of the herniation (Fig. 18). One half of the bevel is in the disc and the dorsal one half of the cannula is positioned to view the epidural space lateral to the traversing nerve. The cannula is rotated to expose patho-anatomy or protect nerves. Multiple cannula configurations are designed to accommodate the surgeon's needs.

Foraminoplasty

A bulging disc or hardened (calcified) annulus may protrude into the anterior epidural space. A trefoil canal may accentuate radicular symptoms. As the disc space narrows, the facets converge and also invaginate the ligamentum flavum against the traversing nerve and axilla of the exiting nerve, including the DRG. The contents of the cauda equina are constricted. Endoscopic ventral decompression is done through the foramen by removing the ventral surface of the facet and continuing with removal of the tip of the superior articular process, then resecting the dorsal annulus. This can provide relief from central and lateral recess stenosis. Foraminoplasty in this manner can also be utilized to access the axilla between the traversing and exiting nerves and to reach the epidural space. Foraminal disc fragments and foraminal stenosis from osteophytes often contribute to sciatica that is underestimated on MRI. It is a leading cause of failed back surgery syndrome (FBSS). It is more evident when the axilla is examined endoscopically. Transforaminal decompression will not produce instability, especially when the disc is already collapsed.

The annulus can also be resected in a severely collapsed disc without creating instability. In selected patients who get good/excellent relief with transforaminal therapeutic blocks, a foraminal decompressive procedure may provide enough relief that the patient may avoid decompression and fusion. The technique is especially helpful in cases of failed back surgery syndrome from residual lateral recess stenosis.[54–59]

The foramen can be decompressed by stripping of the facet capsule with a laser, trephining the ventral facet, then following that by sculpting the ventral facet with endoscopic kerrisons and/or a high-speed diamond burr (Figs. 19a–19f). Here, the diamond burr is shown sculpting the inferior surface of the superior articular process (Figs. 19c & 19d). The decompression will continue toward the exiting nerve. The cannula will retract and protect the nerve as the burr removes bone and follows the exiting nerve into the foramen. The superior foraminal ligament serves to obstruct the exiting nerve. It should be resected, and osteophytes seen impinging nerves in the foramen can be removed in a similar manner.

As the facet decompression moves toward the exiting nerve, the cannula is advanced to protect and retract the nerve from the burr, laser, or other bone-cutting instruments. Note the lateral edge of the exiting nerve at 7 o'clock (Fig. 19d).

The ligamentum flavum is contiguous with the ventral facet capsule (Fig. 19f). It is often released during foraminoplasty, especially if the medial ventral facet is resected. When the flavum is released from the facet, it will shield the nerve. It is easiest to use the straight firing laser, guided by a curved nitinol sheath to remove the flavum. If the flavum is removed, the lateral aspect of the traversing nerve is visualized, and confirmation of decompression for central stenosis is accomplished.

Other Foraminal Anatomy: Nerves and Ligament

The foramen contains anomalous branches of the spinal nerves called "furcal" or "forked" nerves (Figs. 20a–20c). Most of these branches come off the exiting nerve outside the foramen, but many reside in the area of the foraminal ligament obstructing the entrance to the epidural space. Furcal nerves in the foramen can contribute to discogenic pain.[36,44,48,49,59] The nerve is not safe from injury even with "perfect" instrument placement. Endoscopic cannulas and instruments can work around the furcal nerve, but resection or ablation is not always avoidable. The surgeon must make a conscious effort to determine when it is safe to remove these nerves that may be contributing to the pain syndrome or to avoid removing them, taking the chance that the endoscopic decompression is not complete. Ablation or resection of large furcal nerves may cause dysesthesia, numbness, and sometimes, weakness.

Sympathetic nerves (Figs 21a–21c) are also present, but rare (documented by H and E sections). Endoscopic identification may demonstrate that there is a sympathetic component to severe sciatica, especially dysesthesia that contributes a condition similar to regional sympathetic dystrophy. Combining a sympathetic therapeutic block with a foraminal epidural block gives the best clinical relief of severe sciatica and pre- or post-op dysesthesia. Partly due to these anomalous nerves, dysesthesia cannot be completely eliminated in transforaminal endoscopic surgery.

The Biportal Technique

The biportal technique (Figs. 22a–22c) allows for a more completely visualized approach intradiscally, especially for extruded and/or sequestered fragments that may require probing the nerve and removal of the sequestered disc fragment with the inside-out technique through the annular defect.

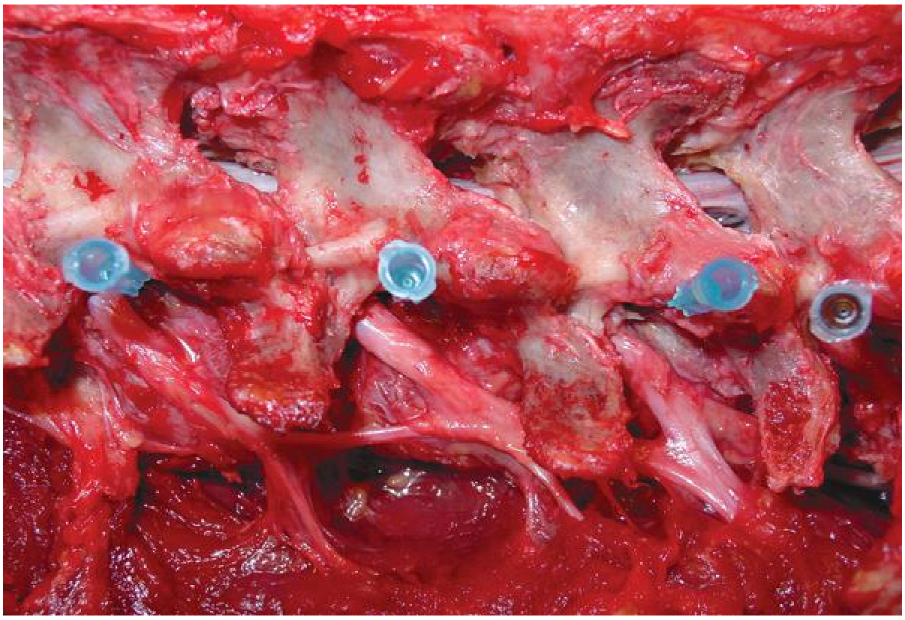


Figure 16. Cadaver dissection of Foraminal Anatomy.The blue hubbed needles are positioned into the disc through the annulus. Note furcal nerve at L4=5 foramen.

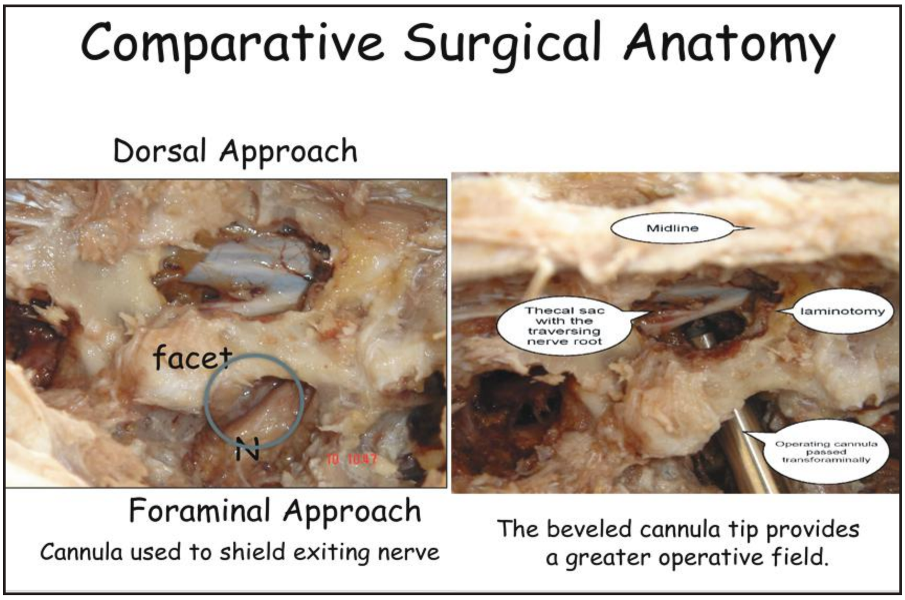


Figure 17. Endoscopic transforaminal technique: Cadaver Illustration showing cannula position protecting the exiting nerve and exposing the traversing nerve.

The Painful Disc "Bulge"

Epidurography outlines the bulging disc (Fig. 23a), accentuated by extension. Discography and epidurography may identify a bulging disc causing discogenic pain. A therapeutic foraminal epidural block may give good temporary relief. If there is a painful bulging disc, even in degenerative spondylolisthesis, patients have experienced satisfactory relief and avoided fusion. If there is also lateral stenosis, patients can improve enough with Selec-

Figure 18. Classic view of foramen, scope position periscopic, upper half shows epidural tissue, mid 9-3 line is PLL Post Annulus complex, below is disc tissue, white fragment for removal.

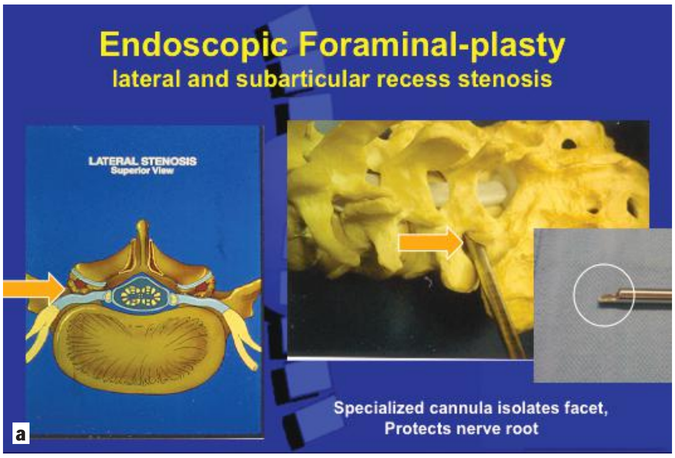


Figure 19a. Cannula placement for foraminalplasty.

Figure 19b. Kerrison foraminoplasty.

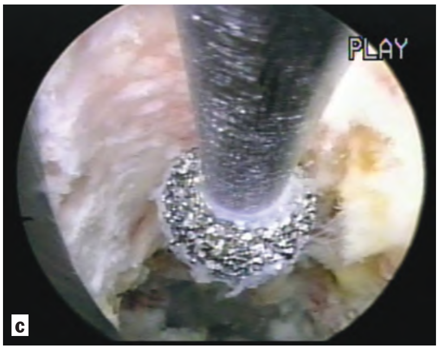


Figure 19c. Diamond burr decompressing ventral aspect of the SAP.

Figure 19d. Relationship of the exiting nerve with the SAP.

Figure 19e. Bony specimen and foraminal disc fragment removed following foraminoplasty

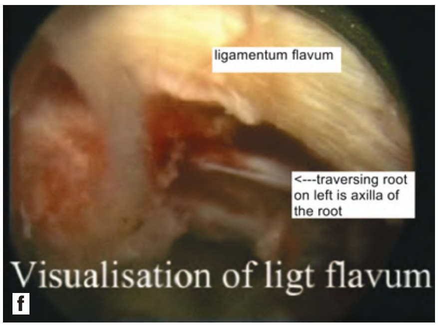


Figure 19f. The ligamentumFlavum

tive Endoscopic Discectomy (SED™) and thermal annuloplasty plus foraminal endoscopic decompression to avoid fusion. Back extension will accentuate the effect of the bulging disc and the stenosis causing increased leg pain. Contrary to traditional thinking, these patients can improve for an extended period of time with endoscopic foraminal decompression. It will not burn options for fusion when the spinal segment ages and deteriorates further. This technique does not challenge fusion, but provides an alternative for those patients who want to avoid fusion, opting for a non-fusion approach to their pain while waiting for "natural spinal stabilization."

Degenerative Spondylolisthesis

When a patient with spondylolisthesis presents with back pain and sciatica, non-operative treatment is still the first line of care. After failure of non-surgical treatment, surgical options are numerous. Fusion does not have to be the gold standard.[1] Decompression without fusion is championed by Epstein.[60] In her series of 290 patients, only 2.7% required stabilization. There are patho-anatomical conditions that will respond to endoscopic decompression without fusion, especially if the patient's sciatica is worse than their back pain, and the pain is coming from the disc. Most patients are able to tolerate the back pain of spondylolisthesis, but not leg pain. Degenerative spondylolisthesis may be asymptomatic or it may cause low back pain with or without moderate radicular pain.[1,61] When radicular pain is present and poorly tolerated, endoscopic surgical decompression without fusion may provide pain relief without the need for surgical stabilization. It is possible to correct and obtain relief from spondylitic, stable, or minimally unstable segments, especially if there is a concomitant bulging disc or painful foraminal HNP.[1,61] Discectomy (Figs. 23a–23c) can be successful without further destabilizing the spondylolisthesis when the decompression is performed transforaminally. This is because the facet joint is usually not destabilized with foraminal decompression if there are no predisposing factors such as a vertical alignment of the facet.[62] No subsequent surgical instability has occurred, even if the degenerative progression occurred over time in patients who opted for endoscopic treatment over a fusion. In other words, no treatment bridges were burned.[1,60] When back pain is more dominant, dorsal endoscopic rhizotomy will help relieve back pain. In Yeung's series of patients with no instability or minimal instability, over two-thirds received good results and avoided fusion or further surgical treatment.[63] When flexion/extension x-rays show no instability, these patients may avoid fusion. The patho-mechanism of slippage is not entirely known, but abnormal sagittal orientation of the facet joints, disc degeneration, and hyper laxity of the spinal ligamentous structures all play a role. In patients with favorable results following foraminal decompression in the minority of patients who eventually require fusion, their results are uniform-

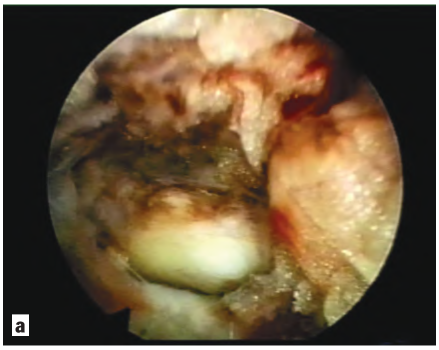


Figure 20a. This 2-mm myelinated furcal nerve is identified in the annular fat in the middle of "Kambin's triangle."

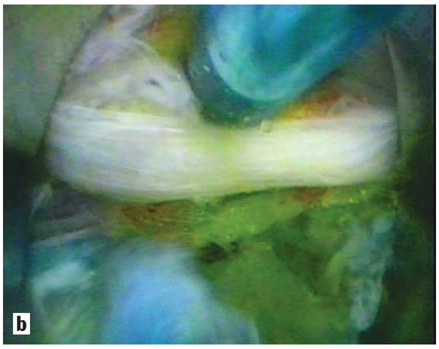


Figure 20b. Smaller furcal nerves, such as the nerve above, usually seen in the area of the foraminal ligament, are less vulnerable to dysesthesia, but should be avoided if the disc can be decompressed without removing it.

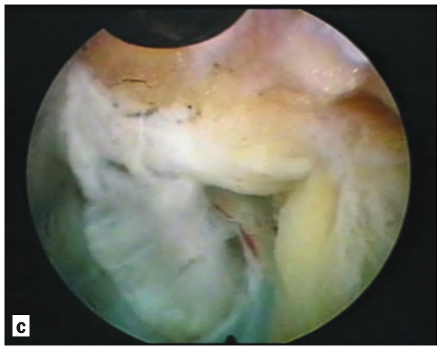


Figure 20c. This large furcal nerve, obviously part of the exiting nerve, should not be transected or a neuropraxia can be expected, as it appears to be an integral part of the exiting nerve.

Figure 21a. Sympathetic nerve in foramen.

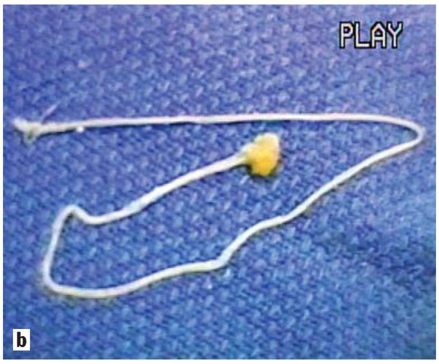


Figure 21b. Excisional biopsy of sympathetic nerve.

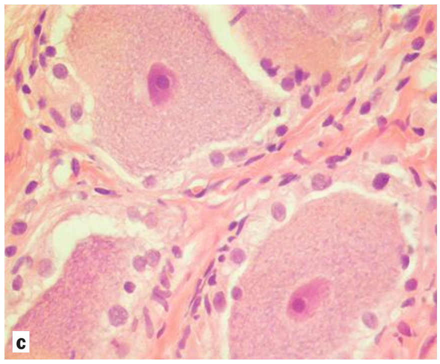


Figure 21c. H and E slide of the nerve in 22b.

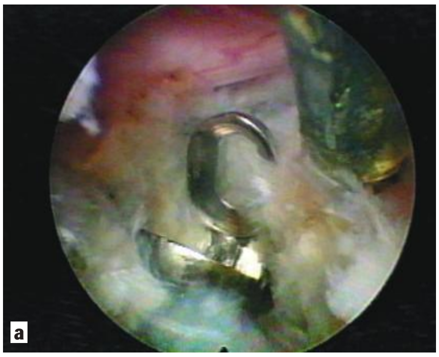


Figure 22a. Biportal manipulation technique with a flexible pituitary forceps and the Elliquence Bipolar Triggerflex® probe. Confirmation that the traversing nerve is completely free is by direct visualization.

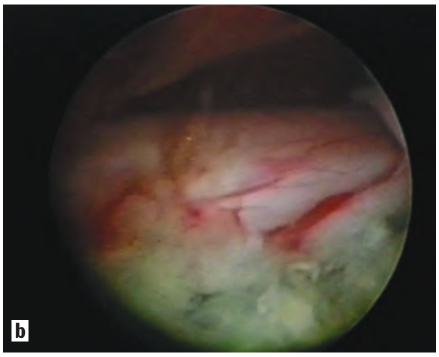


Figure 22b. This endoscopic documentation confirms the complete decompression of the traversing nerve. The nerve pulsates freely in the epidural space.

Figure 22c. Pathology specimen of extracted disc fragments. The white disc fragments represent the extruded HNP and the pink fragments represent inflamed disc material lying inside the annulus adjacent to the traversing nerve.

ly good because the lateral recess is already decompressed, and FBSS from lateral recess stenosis is mitigated.

In mild instability, the tip of the superior facet of the inferior vertebra is shown impinging on the exiting nerve (Fig. 23b). The posterior annulus and ligamentum flavum can also impinge on the thecal sac, especially in extension, in degenerative spondylolisthesis. Thermal modulation of the disc, mechanical and laser foraminoplasty, resection of the tip of the SAP, and sculpting the ventral facet with endoscopic kerrison roungeurs and diamond burrs can decompress the exiting nerve and the foramen and provide relief of back pain and sciatica in a degenerating disc with or without spondylolisthesis.

The patient in Figure 23c presented with a bulging degenerative disc as well as foraminal stenosis. She refused fusion even though all her surgeons recommended it. She opted for endoscopic decompression and was satisfied with endoscopic decompression of her disc and foramen. Later, dorsal endoscopic rhizotomy relieved her back pain. The combination of disc, foraminal decompression, and dorsal endoscopic rhizotomy offers an endoscopic technique that can provide favorable results short of decompressing and fusing the spinal segment. Because this is the best indication for fusion, that is still the first recommended surgical intervention for traditional surgeons, but less-invasive alternatives are feasible for those patients who absolutely refuse fusion or want to delay fusion, but need relief.

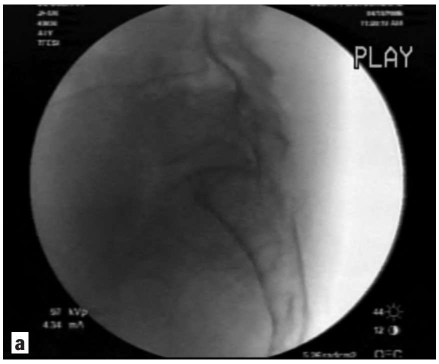


Figure 23a. Painful bulging disc can be present even in the face of degenerative spondylolisthesis. Lumbar Extension accentuates the bulge, and the patient is more comfortable in the flexed position.

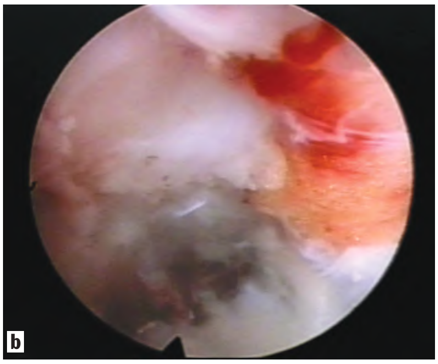


Figure 23b. This patient has grade I degenerative spondylolisthesis and predominant leg pain. She got relief in the flexed position, but had pain standing erect. At surgery, the tip of the SAP was found impinging on the exiting nerve.This explains her pain during extension. Resection of this impingement resolved her leg pain.

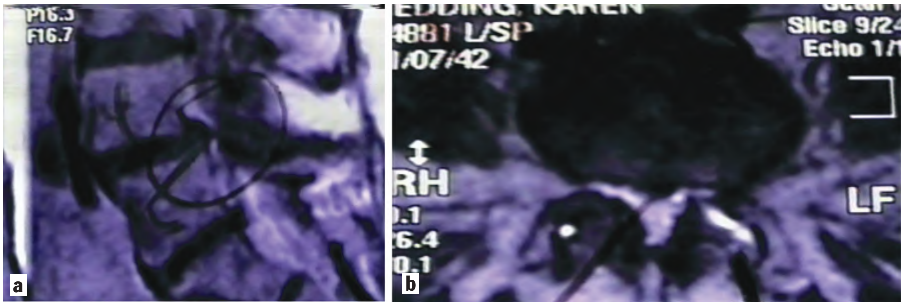


Figure 23c. Example of degenerative spondylolisthesis, lumbar spondylosis, and spinal stenosis, all present in this patient, who was successfully treated endoscopically.

Isthmic Spondylolisthesis

It is possible to treat isthmic spondylolisthesis endoscopically without fusion in highly selected patients with predominant sciatica and little back pain. The source of pain may be from impingement of the exiting nerve by an osteophyte from the superior articular process and a prominent osteocartilaginous mass from the pars defect. The case example in Figures 24a to 24g demonstrates the patho-anatomy and surgical decompression of the exiting nerve causing sciatica in isthmic spondylolisthesis.

Facet Juxta-articular and Pedunculated Cysts

Facet cysts are very elusive if they have a pedunculated stalk.[1,63] Large sessile synovial cysts, however, are readily seen on MRI (Fig. 25a). Pedunculated cysts are usually an incidental finding that does not always show up on an MRI. Many such cysts are discovered during foraminal exploration (Fig. 25b) and are demonstrated to be a cause of sciatica not seen by imaging. Both may bring good temporary results with epidural steroid therapeutic injections.

BACKACHE: DORSAL ENDOSCOPIC RHIZOTOMY FOR AXIAL BACK PAIN

Although a transforaminal decompression of the disc by the YESS™ selective endoscopic discectomy technique clearly demonstrated relief of back pain when combined with thermal annuloplasty,[1–5,26,27,33,34] axial back pain is thought of as a condition of lumbar spondylosis and facet arthrosis. Most causes of chronic axial back pain, however, actually arise from both pain generators.[3–5,49,50]

In 2006, in a prospective case study of 50 patients, Yeung evaluated the results of dorsal endoscopic rhizotomy for the treatment of axial back pain, targeting the medial branch of the dorsal ramus that innervates the facet joint at the level of, and caudal to, each spinal level.[64] Cadaver dissections of the dorsal ramus identified variations in medial branch anatomy when compared with Bogduk's illustration and the literature. It was hypothesized that endoscopic ablation of the medial branch at the base of the transverse process, because it could visually target the nerve, would deliver results superior to the fluoroscopic technique. Using the endoscopic technique, Yeung found that he could convert patients who failed to improve after undergoing pulsed radiofrequency ablation using fluoroscopically guided methods by interventional pain management physicians. In patients who had good relief with medial branch blocks, Yeung could also target the intermediate and lateral branch of the dorsal ramus and get immediate resolution of muscle spasm and the involuntary list sometimes associated with axial back pain. Due to this observation, the original technique evolved to look for the medial branch and the intermediate and lateral branches as well. In addition, Yeung has encountered the dorsal ramus itself ventral to the intertransverse ligament. The dorsal ramus is larger than its branches, and it is not known whether ablation of the dorsal ramus, while more aggressively removing the source of back pain, may produce a greater risk of a neuroma forming after ablation or transection. For this reason dorsal ramus lesioning was avoided, because ablation of the medial branch was sufficient to relieve axial back pain. Clinical success in converting failed pulsed radiofrequency to successful results with dorsal endoscopic rhizotomy provided additional evidence that the endoscopic results were better than the current literature. Cadaver dissections brought the discovery of anomalous nerves in the foramen identified either as furcal nerves or autonomic nerves. Probing the nerves in the awake state may help identify these as normal vs. anomalous nerves. In endoscopic rhizotomy, the patient can sometimes feel discomfort and the muscles may twitch as the nerve is ablated.

Success rate in the pilot study obtained over 90% good/excellent results using the degree of pain relief by medial branch block and by patient satisfaction. VAS decreased from 6.2 to 2.5, and Oswestry from 48 to 28.[64] Each year, about 10% had partial recurrence of their pain, but to a lesser level. Repeat endoscopic rhizotomy or rhizotomy at the upper levels of L1, L2, and L3 in severe degenerative scoliosis or multi-level spondylosis brought additional relief, as afferent nerves may collect at L2, according to the literature. The best results were in patients with only moderate spondylosis. This procedure was also partially effective in adjacent level disease, but pain from hardware at the fusion site may persist. We found that even if we could not visualize the medial branch, ablation of the periosteum and fibrous tissue at the osseous tunnel located at the transverse process and lateral facet wall was sufficient to ablate nerves innervating the facet. The dorsal ramus ventral to the intertransverse ligament is currently avoided, because the nerve is large and close to the DRG. Even this caution does not limit exploration of the dorsal ramus because this nerve is also in the vicinity of the foraminal ligament, furcal nerves, and autonomic nerves. Further study is needed. The results of dorsal endoscopic rhizotomy, however, are better than the published literature on blind pulsed radiofrequency ablation because of more accurate targeting of the branches of the dorsal ramus contributing to axial back pain.[50,64]

Ventral to the inter-transverse ligament, the Dorsal ramus gives off a medial, intermediate, and lateral branch. Bogduk's published anatomical drawings (Fig 26a) are followed by pain management physicians as standard anatomy for flouroscopically guided pulsed radiofrequency ablation. In our multiple cadaver dissections, however, the branches of the dorsal ramus are variable, do not always cross the transverse process, and are not always as depicted as published in the literature. Variations occur more frequently cephalad to L3. The medial branch usually crosses the transverse process just lateral to the facet, with the intermediate and lateral branch coursing laterally, to innervate the dorsal column musculature and possibly the facet (Fig. 26b). The medial branch can exit to innervate the facet without crossing the transverse

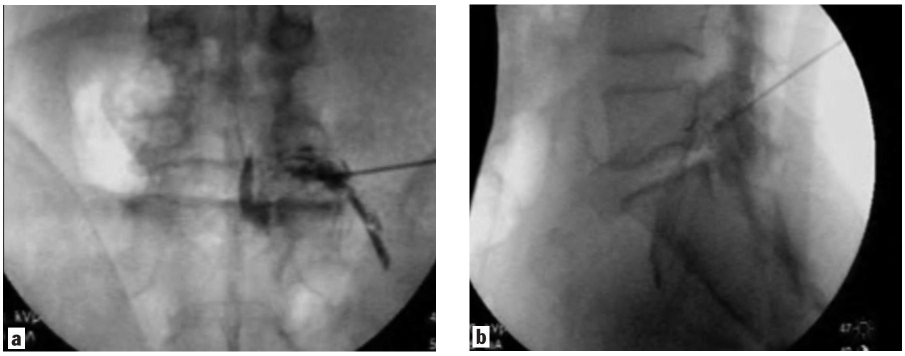


Figure 24a, b. This epidurogram targeting the pars defect in isthmic spondylolisthesis outlines the exiting nerve in the foramen. A therapeutic injection provided great relief of sciatica. The lateral view demonstrates needle position and dye in the pars defect, foramen, and exiting nerve sheath.

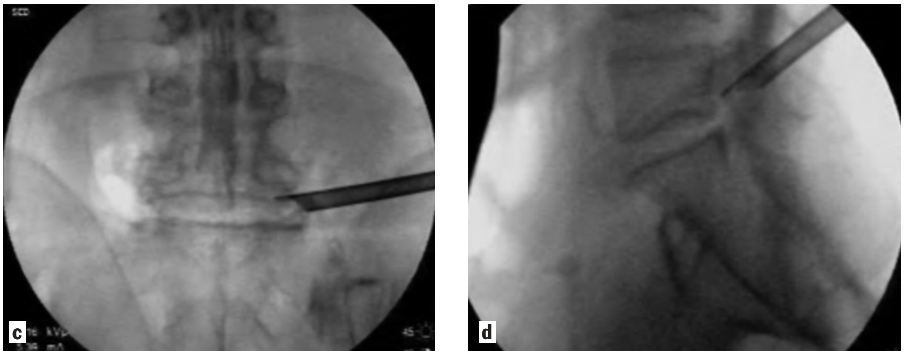


Figure 24c and 24d. Cannula placement on the isthmic, spondylitic pars defect.

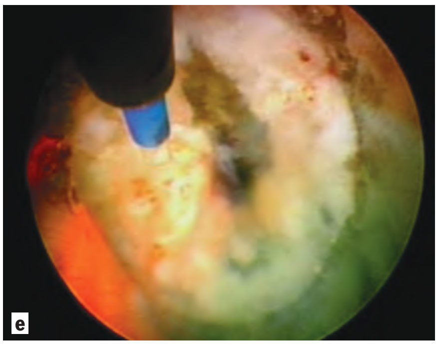


Figure 24e. An Ho YAG laser is used to ablate the osseous cartilaginous prominence impinging against the exiting nerve. The cannula has retracted and protects the exiting nerve located at 5 o'clock.

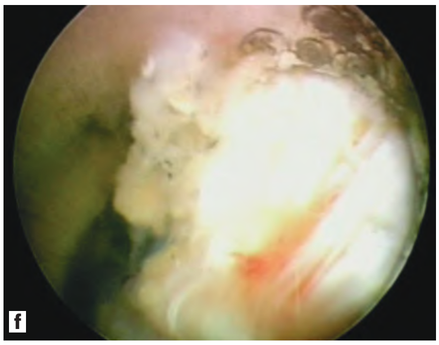


Figure 24f. Rotating the window of the cannula to the 5'oclock position exposes the exiting nerve. The nerve is seen with a fibrotic sheath, but it still has perineural fat around it, a good sign that decompression will provide a good result in relieving the patient's sciatica.

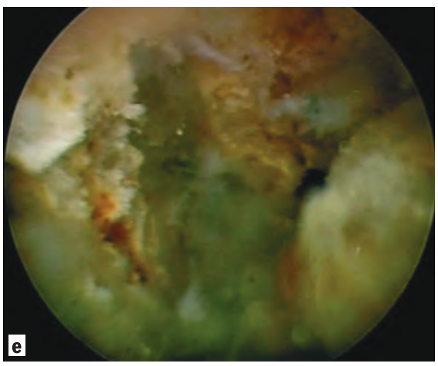


Figure 24g. The pseudoarthrosis defect is clearly identified after decompressing the exiting nerve (at 5 o'clock).

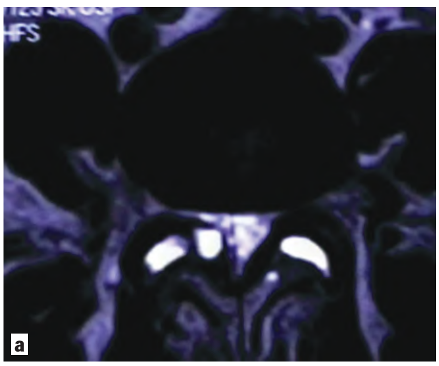


Figure 25a. This MRI clearly demonstrates a juxta-articular cyst compressing the thecal sac. These cysts can be decompressed endoscopically if large enough to be visualized and accessible by foraminoplasty.

Figure 25b. This indigo-carmine stained cyst wall next to the exiting nerve is removed, and the stalk ablated with lasers or bipolar radiofrequency. The patient can feel the cyst being removed and can report pain relief following the cyst removal.

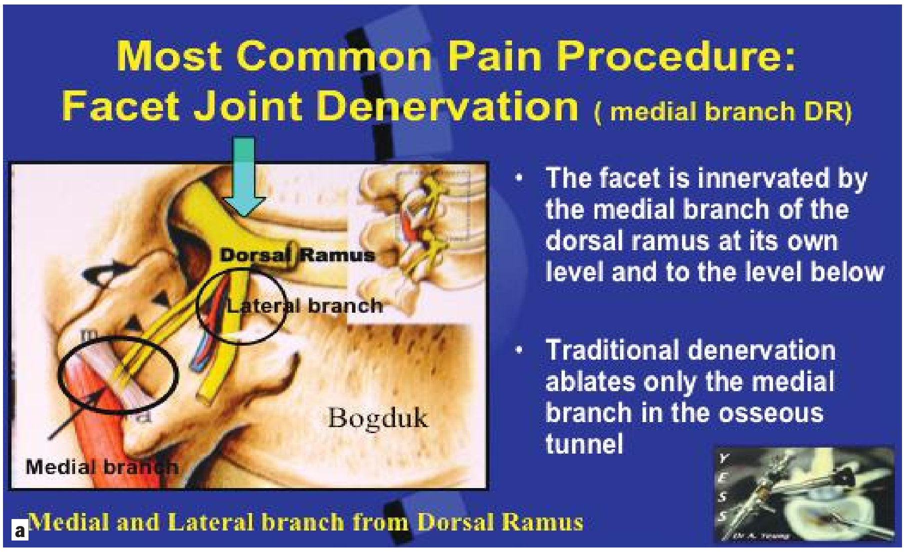


Figure 26a. Illustrated anatomy of the dorsal ramus and its branches.

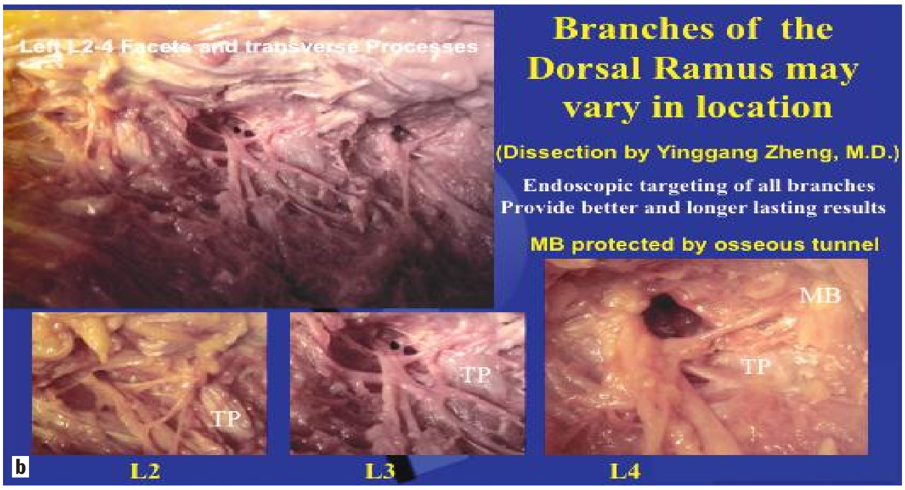


Figure 26b. Cadaver Dissection demonstrating variations in the Anatomy of the Dorsal Ramus and its branches. Cephalad to L3, the medial branch may branch off to the facet without crossing the transverse process. The variations explain the inconsistency of techniques dependent on fluoroscopic placement of radiofrequency electrodes and the need for endoscopic visualization.

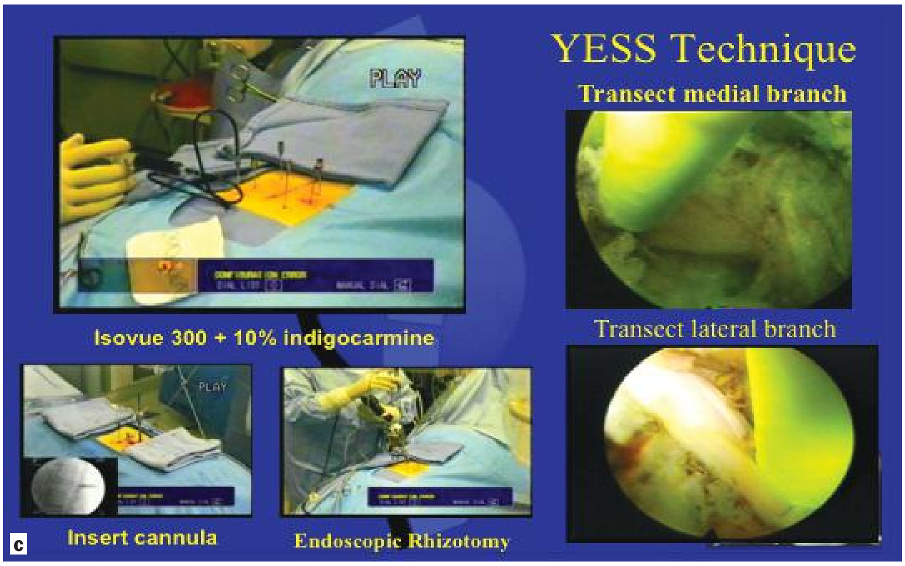


Figure 26c. Dorsal Endoscopic Rhizotomy Technique and visualized transection of the medial and lateral branch.

process cephalad to L3, but it is more consistent from L3-S1. Dorsal endoscopic rhizotomy targets these branches with endoscopic visualization in a plane dorsal to and on the transverse process (Fig. 26c). It can cauterize the facet and pedicle wall to ensure more thorough ablation.

Endoscopic Foraminal and Dorsal Central Canal Decompression

Claudication symptoms in patients with lumbar spinal degeneration are due to stenosis and changes in canal configuration.[65] Evaluation of canal size and configuration is by CT scan, by CT myelography, or by MRI. The spinal canal varies in diameter, affected by the thickness of the ligmentum as much as the bony canal.[66,67] It was found to be 10% tighter with MRI sequences, in comparison with CT myelogram, and foraminal diameters were found to be 19.7% tighter in MRI. A CT myelogram is better suited only for bony canal assessment. It does not take into account soft tissue compression. Direct visualization of the involved nerves looking for perinerual fat and pulsation is the best available method to access the presence or absence of stenosis.[39,44,49]

Claudication in both lower limbs is usually due to central canal-related changes. Dorsally, stenosis is often due to thickening or buckling of the ligamentum flavum. Indirect decompression in these patients can also be achieved by use of interspinous distracters.

Direct central canal decompression can be accomplished transforaminally and percutaneously by:

- Biportal foraminal approach by resecting or decompressing the bulging annulus and releasing the ligamentum attachment to the medial facet capsule
- Accessing the interlaminar canal from the ipsilateral and contralateral side
- Foraminal decompression of the annulus and ventral facet

Bulging of the ligamentum flavum contributes to between 50% and 85% of the spinal canal narrowing. The ligamentum flavum, not the disc, had a dominating role for load-induced narrowing of the lumbar spinal canal.[68] It is attached inferiorly to the superior edge and the postero-superior surface of the

Figure 27a. Surgifile™ (Surgitech Inc.) automated rasp for central decompression.

Figure 27b. Surgifile™ (Surgitech Inc) rasp for Foraminal decompression

lamina below. It is attached superiorly to the inferior edge and the antero-inferior surface of the lamina above. Its thickness ranges from 3.5 mm to 6 mm.

Schema of Central Access

Access to the sublaminar area is through the interlaminar space starting about 3 cm from the contralateral side at an angle of 25%. The point of entry is easily decided by taking a pointer away from the pedicle medial wall in a cross section and going sublaminar and coming up to skin. The point of touching skin from inside out will be ideal for entry for this sublaminar access. Use of burr and graspers is done to excise the ligamentum from the interlaminar area under direct endoscopic vision.

The dura is non-adherent in the midline area and with fat in that plane and the gap in the midline of the ligamentum flavum makes it feasible to separate the ligamentum flavum from the attachments to lamina. Special knives, burrs,

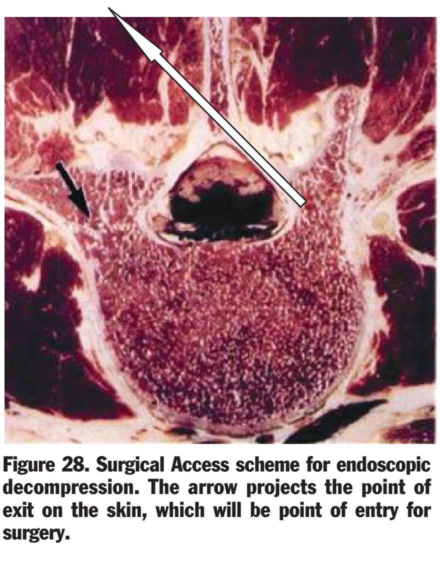


Figure 28. Surgical Access scheme for endoscopic decompression. The arrow projects the point of exit on the skin, which will be point of entry for surgery.

or rasps are used to detach it from the edges of the laminae. In severe cases, both the central and foraminal decompression may be needed, as a frequent cause of failed decompression is the inability to reach both areas surgically.

The surgical tool Surgifile™ (Figs. 27a & 27b; Surgitech Inc, Charlotte, NC) consisting of an automated file has been developed, tested, and validated in cadavers.[69] This tool will help surgeons decompress stenosis minimally invasively. It will soon find its way to clinical use following sale to a spinal company that recognizes its value and role in MIS decompression.

The rasp can be used for ipsilateral or contralateral decompression using different trajectories. It is capable of subarticular and lateral recess decompression, a common cause of failed surgery for central stenosis with residual lateral recess impingement. In the laboratory, it is demonstrated to be more effective and less invasive than standard tools such as curettes, kerrisons, and burrs.

This automated file (Surgitech Inc, Charlotte, NC) is currently designed for an open access approach for central and subarticular decompression. Modifications of this automated tool for transforaminal and endoscopic use will help the endoscopic procedure evolve even faster.

Considering the average thickness of the ligamentum small curettes and graspers are currently used for its removal. Surgifile is an instrument with a lower profile. Entry in the interlaminar area is from the opposite side, and the tip is directed toward the facet on the other side. A blunt dilator helps in creating this surgical plane.

Work in Progress: Endoscopic Central Decompression

Chopko et al. have described a unilateral same-sided approach to the central sublaminar area. The sublaminar space is highlighted by use of radio-opaque dye. Our approach in development is entry on the contralateral side (Fig. 28). This uses c arm in reverse oblique projection at 50 degrees on side of entry (side of entry is opposite side of pathology). Work on this approach is still under development but is supported by the previous publication.[70]

CONCLUSION

The endoscopic foraminal approach through MacNab's "hidden zone" to the disc, epidural space, and facet is a technique that spares denervating and destabilizing the important multifidus and sacral spinalis muscles, yet allows access to patho-anatomy in the lumbar spine through a physiological plane at the intertransverse area. Interventional diagnostic techniques such as evocative discography™, foraminal epidural-grams, and therapeutic injections best performed by the surgeon help with patient selection for surgical intervention. Visualization of normal and patho-anatomy in the conscious patient provides valuable information in the continued study of discogenic pain. It is recommended for surgeons to do their own diagnostic and therapeutic injections. This exercise will improve needle placement skills and help the surgeon's patient selection process because the surgeon must still make the surgical decision based on the patient's response or lack of response to the procedures in the patient selection process. The more favorable surgical results from patient selection allow for continued improvement of the surgeon's endoscopic skills, concomitant with the continued evolution of endoscopic spinal surgery.

Some endoscopic surgeons are demonstrating that it is feasible to make endoscopic spinal surgery a "full" endoscopic approach. Although we are aware of this possibility for discectomy and stenosis, we should consider this caveat: If there are effective open methods to handle the patho-anatomy, the surgeon factor has to be the ultimate consideration for your patient. Do what is most comfortable in each surgeon's hands and do what is best for your patient, as this technique has a long learning curve, and those surgeons who adopt and master the technique will make a major contribution to their patients and to the cost-effective treatment of back pain and sciatica.

Once endoscopic skills are mastered, the surgical skills acquired will likely open the doors to exciting new developing technology that may provide the missing links to current techniques and concepts. Work is already under way with projects such as an intradiscal annular reinforcement intradiscal containment device (Ouroborous Medical, Pleasanton, CA), nucleus hydration and augmentation with implantable nylon shunts (Aleeva Medical, San Jose, CA), or hydrogel implants Gelstik and Neudisc (Replication Medical, Cranbury, NJ), and ablation of nerves with radiofrequency, ablating the nerve innervating the vertebral body and end plate (Relievant, Redwood City, CA). The upside potential for the transforaminal approach to the painful degenerating spine is encouraging. Endoscopic fusion through the foramen with an FDA-approved PEEK implant (Amendia, Marietta, GA) is now available as a less-invasive O-Lif (oblique) foraminal approach through Kambin's triangle that spares removing the facet joint.

When all surgical solutions for spinal pain are exhausted, wireless electrodes (Stimwave, Scottsdale, Arizona) implanted through the foramen with a needle or endoscope adjacent to the dorsal root ganglion or ventral epidural space is being investigated and compared with current spinal column techniques for failed back surgery syndrome. STI

AUTHORS' DISCLOSURES

Anthony Yeung, developer of the Yeung Endoscopic Spine System (YESS™) and Dorsal Endoscopic Rhizotomy System (Richard Wolf, GmBh), is a consultant, a member of the speakers bureau, and receives royalties from Richard Wolf, Elliquence, Int. (Disc FX).

Satish Gore, a consultant to Karl Storz, has modified and refined the YESS™ system.

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