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THE SURGICAL RISKS AND EFFICACY OF FORAMINAL ENDOSCOPIC SPINE SURGERY: AS DEFINED BY VISUALIZATION OF PAINFUL PATHO-ANATOMY

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1. Introduction to Tissue Sparing Surgery

One of the first truly minimally invasive techniques, chemonucleolysis by injection of chymopapain into the disc space, was the procedure of choice for young patients under 20 years of age with a contained herniation. As well, large prospective double-blind series and numerous cohort studies validated the method by Level I Evidenced Based Medicine in a wide spectrum of age groups. In spite of this level of scientific validation, Chymopapain is no longer available due to few serious complications of anaphylaxis and transverse myelitis. This simple, valuable, and cost effective technique, introduced by Lyman Smith [1] in 1955, caused drug companies to suspend production. Litigation adverse practitioners also began to shy away from enzymatic denaturalization of the nucleus pulposus [2] , especiallly when large numbers of poorly trained surgeons unfamiliar with needle technique was responsible for most of the complications.

2. Minimally Invasive Approach by Keyhole Incision

The minimally invasive approach to the spine, by its nature, already limits the incidence and level of serious operative complications. Most surgeons equate minimalism with smaller incisions through traditional approaches where they are familiar with the anatomy. Foraminal keyhole incisions approach the target surgical zone through fascial or muscle planes. There is limited, if any, dissection through normal anatomic structures. Conscious sedation with local anesthetics avoids the sequelae of general anesthesia. Micro-instrumentation produces little irritation of tissues. Blood loss is minimal, and insufficient to require monitoring or transfusion. Constant irrigation with saline thoroughly removes chemical irritants and most pathogens. A single suture or adhesive dressings are adequate for wound healing. The medication requirement is much lower compared to open surgery. Mobilization, recovery, and return to work are all shorter. Patient satisfaction averages over 90% [3]. The results are equivalent to open surgery with less morbidity in experienced hands. Why then, is foraminal endoscopic surgery slow to become accepted?

The steep or lengthened learning curve is the most daunting reason that prevents many surgeons from embracing foraminal endoscopic surgery, where surgical anatomy, approach, and anatomic relationships are different from the traditional approach. Most academic training centers do not offer relevant training, and interested surgeons had to learn the technique after they became established and comfortable with traditional approaches. Early in the learning curve, the success rate can be less than with the traditional approach and the complication rate can increase due to unfamiliarity with endoscopic anatomy. The surgical success rate, however, soon increases if the surgeon conquers the learning curve. If a surgeon experiences his first complication or surgical failure in the early phase of his learning curve, there is a strong dis-incentive for the surgeon to continue, causing him to revert to old ways or perhaps to even argue against the techniques. The surgeon may also conclude that, in his hands, the traditional approach is more efficacious. Unfortunately, instead of determining that it is more difficult for that individual surgeon, the technique is condemned by some surgeons who cannot master the technique. Minimally Invasive surgery can also be discouraging to surgeons who are more comfortable with larger incisions and more generous exposure for visualization and exploration purposes. Once the learning curve is overcome, however, the advantages of minimally invasive spine surgery is very evident, and the accomplished and experienced minimally invasive surgeon soon learns to include minimally invasive techniques in his surgical armamentarium.

3. The Posterolateral (Foraminal) Approach

This approach was originally described by Kambin to access the lumbar spinal segment through the triangular zone between the traversing and exiting nerves. (Figure 1) The starting point for needle entry was estimated, but techniques for more accurately identifying the skin window has served to improve instrument placement. For more accurate instrument placement, standardization of the approach through topographic landmarks measured by intraoperative fluoroscopy created the concept of a skin window, annular window and disc anatomic disc center. (Figure 2) Drawing lines on the patient's skin for reference (Figure 3) also created a reference line for adjusting the needle trajectory, thus decreasing the chance of inadvertent puncture of the exiting nerve by repeated needle passes to the annulus, especially at L5-S1 where the triangular zone is very small. The development of a two hole obturator (Figure 4) allowed the surgeon to bluntly enter the foramen, using the side hole to anesthetize the instrument tract and annulus, pushing the exiting nerve aside if needed. Special cannulas with bevels and side openings (Figure 5) helped the surgeon protect vital structures and provided an opening, targeting the pathology with the surgical instruments. Clear visualization was imperative, and became consistent with a multi-channel endoscope (Figure 6) utilizing pressure and volume controlled irrigation. A working channel in the endoscope made it possible to operate on pathology in the path of the cannula,

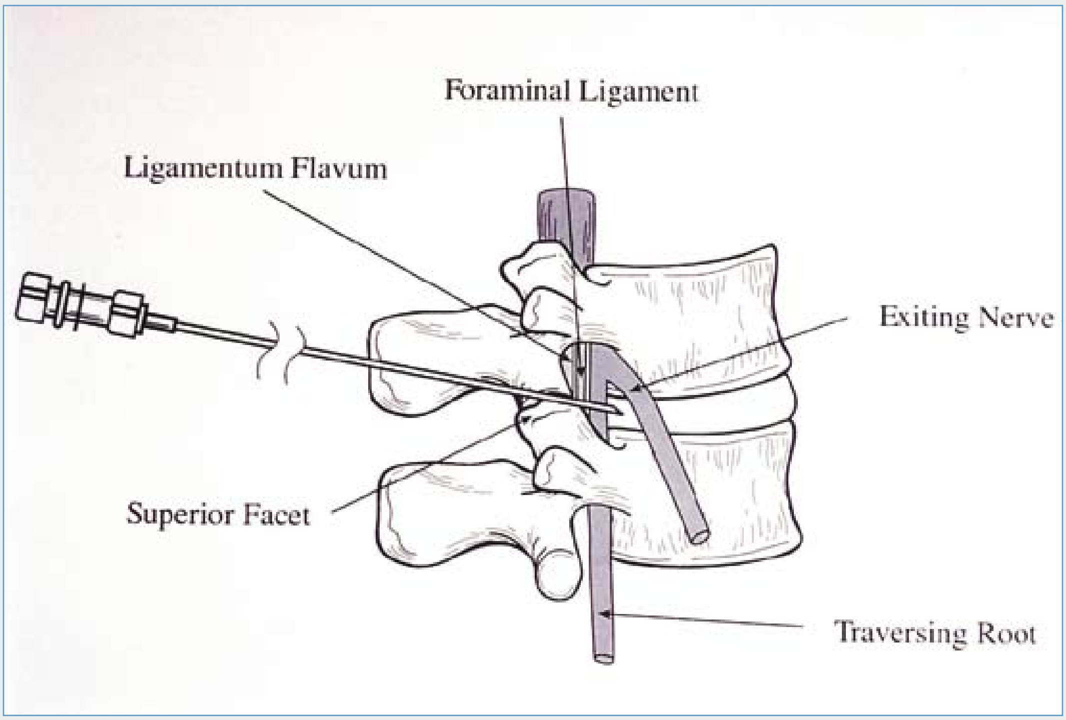

Figure 1:
Kambin's triangular zone is the safe target zone for foraminal access to the disc and epidural space.

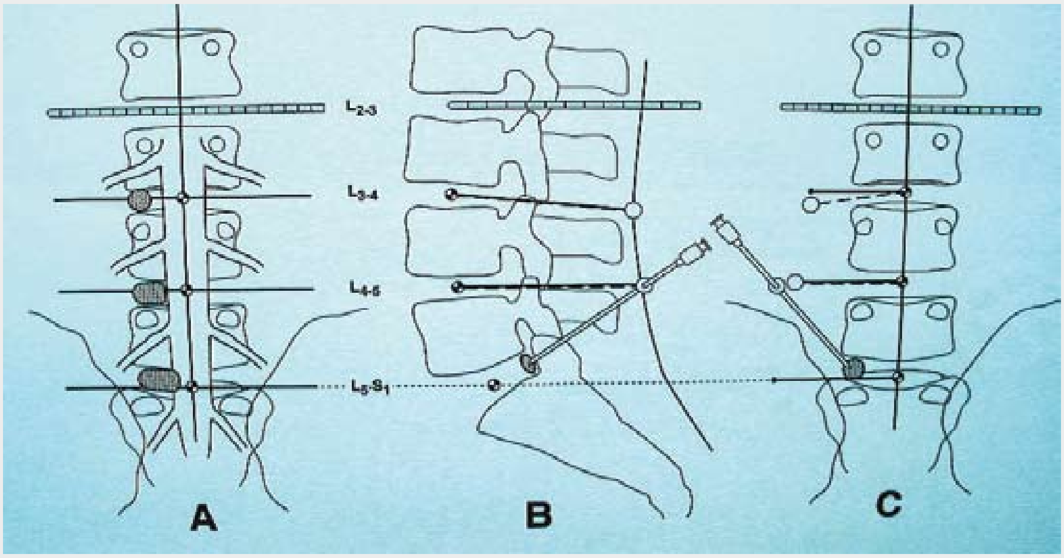

Figure 2:
Fluoroscopic landmarks: **A)** spinous process centered in relation to the pedicles. Line drawn across each disc space to find trajectory parallel to each disc. **B)** line of inclination for each disc drawn in the lateral projection determines position of the skin window cephalad or caudal to the line in A. Distance from the disc center to the skin estimates the distance from the spinous process laterally, to get to the center of the disc. **C)** Distance from the spinous process to the line of inclination far laterally at an angle of 20 degrees determines the ideal position of the initial skin window to reach the disc and epidural space.

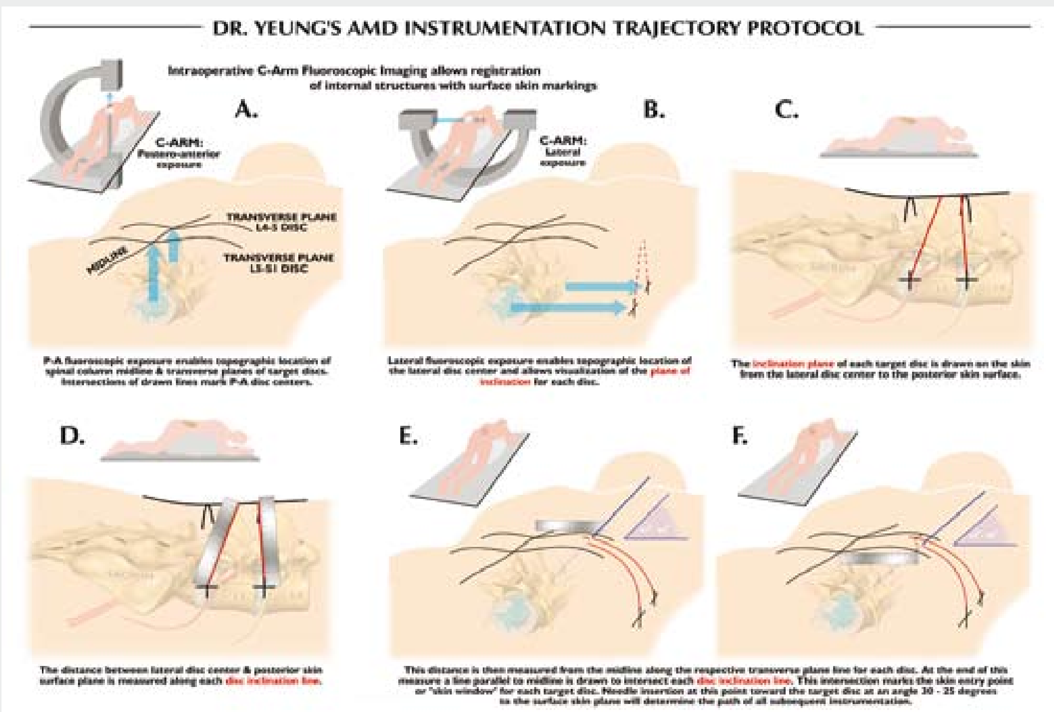

Figure 3:
Protocol for determining cannula and instrument trajectory

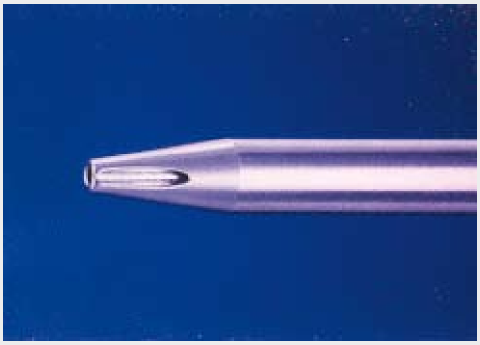

Figure 4:
Two hole obturator has side hole for needle palpation and for delivery of local anesthetic. Spinal probing identifies the pain generators in the foramen.

Figure 5:
Slotted cannula exposes foraminal pathology and protects exiting nerve during endoscopic spine surgery. There are multiple cannula configurations that the endoscopic surgeon can use for tubular access to the patho-anatomy while protecting the spinal nerves and dura.

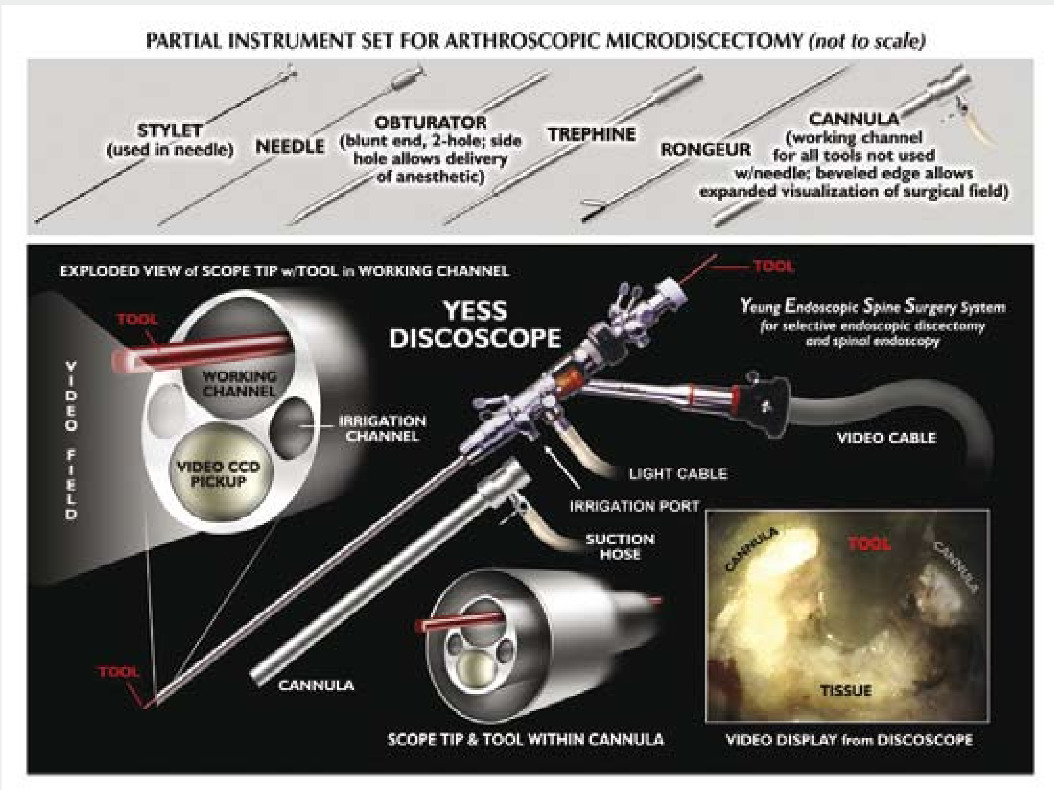

Figure 6:
Multi-channel spine endoscope with 2.8mm working channel offers clear imaging in every case. The distal irrigation channels provide a means to irrigate the disc in addition to decompression and ablation, three vital processes making endoscopic surgery for pain effective.

and various radiofrequency tools and lasers also provided hemostasis and tissue modulation. Clear visualization of vital anatomy and proper cannula placement is the most important factor for avoiding complications in endoscopic surgery.

Avoidance of complications can also be averted by keeping the patient awake, and with minimal sedation. The patient will warn the surgeon when he feels any sensation of pain during the surgical procedure. Anomalous anatomy, ie conjoined nerves, furcal nerves, neuromas, and autonomic nerves have been documented endoscopically. With the advent of microsurgical technique and 1 cm incisions, however, surgical exploration was no longer a routine operative option. With the key hole approaches employed in minimally invasive surgery, utilizing as many diagnostic tests available, especially chromo-discography and transforaminal diagnostic and therapeutic injections, is valuable to correlate not only an abnormal image, but the patho-anatomy that must be addressed. It is therefore necessary to correlate the image with the chief complaint. A thorough review of preoperative studies such as CT, MRI, and the addition of chromo-discography provides the imaging guide for endoscopic surgical exploration. The pathologic findings with the initial visualization of the surgical site must correlate well with the patho-anatomy causing pain [(4)]. Understanding the pathophysiology and patho-anatomy of degenerative disc disease requires acquaintance with patho-anatomy and osteo-pathology as found in the works of Rauschning [(5)], and the use of a vital dye for staining tissue through discography helps the surgeon orient himself with the stained tissue from the discogram. Therapeutic measures like foraminal epidural steroids following a discogram and foraminal epiduralgram may also help the surgeon evaluate the anatomic roadblocks to the foraminal approach and its efficacy in the surgical setting.

4. Minimally Invasive versus Traditional Surgery

Skepticism, disbelief, and, at times, hostility have continuously arisen over the concept of percutaneous endoscopic spinal surgery, especially in the early stages by neurosurgeons and orthopedic spine surgeons unfamiliar with endoscopy. Endoscopically assisted microdiscectomy [(6)] and microendoscopic discectomy [(7)] were designed to introduce microsurgeons to endoscopic technique and to resolve two key difficulties presented by percutaneous endoscopic lumbar discectomy. In the posterior endoscopic approach, the anatomy is familiar. The working space was created by mechanical insertion of a special cannula that served to retract muscle and provide access to the disc.

Fessler [(8)], a leading neurosurgical accomplished minimally invasive spine surgeon, now concludes that minimally invasive spinal surgery has brought about the evolution of minimal access spine surgery which allows decreases in operating time, blood loss, postoperative pain, medication use, hospital stays, and costs.

5. Non-visualized Percutaneous Procedures

Non-endoscopic procedures are non-visualized, with dependence on fluoroscopy for instrument localization and no intraoperative visualization of the pathoanatomy or actual disc removal. Chemonucleolysis [(1)] initially depended on unobserved enzymatic denaturalization of the nucleus pulposus. Hijikata [(9)] performed a nucleotomy and an anatomic biopsy of the nucleus pulposus for contained disc protrusions with fluoroscopic monitoring. Onik et al. [(10)] utilized an automated nucleotome to remove nucleus pulposus from the center of the disc space. Intradiscal electrothermal treatment [(11)] and nucleoplasty by coblation [(12)] are relatively new non-endoscopic techniques for treating unremitting discogenic pain, but the clinical experience remains limited for both techniques; and lack of visual confirmation of patho-anatomy as well as insufficient scientific evidence has been gathered to judge efficacy. IDET, one of the most studied nonvisualized minimally invasive procedures, has no reports of serious complications in the literature. Never-the less, its efficacy is questioned. Yeung, in a report of his experience with endoscopic exploration of 12 IDET failures at the Western Orthopedic Association Meeting October 2001, found interpositional disc tissue in the annular fibers and the failure of the annular tear to heal as the most common cause of IDET failure. He also found necrotic disc tissue in 3/12 patients. The efficacy of the heat transmitted to the outer annular surface for collagen modulation and its effect on the disc has been due to these non-visualized methods. Because of successful treatment of contained disc herniations and painful annular tears, a newer version of fluoroscopically guided disc decompression, ablation, and irrigation mimicking the Yeung's visualized endoscopic technique, called Disc FX, offers the potential for improved results by non-visualized endoscopic procedures.

6. The Expansion of Endoscopically Monitored Procedures

Kambin [13] and Hijikata [9], in the early and mid 1970's experimented with mechanical debulking of the nucleus for the management of contained disc herniation. Kambin[5] later evolved his technique to remove protruded and extruded disc herniations still contiguous with the disc. Yeung [14], in 1998, improved the instrumentation and optics of the spinal endoscope with a multi-channel endoscope and specially configured cannulae that allowed for visualized surgical access to the spinal canal and foraminal zone, while the cannula also retracted and protected spinal nerves and dura. This technique allowed for true foraminal spine surgery through the foraminal approach with excellent visualization.

Knight [15] developed visualized endoscopic laser foraminoplasty with a similar working channel endoscope utilizing a side-firing laser. As foraminal surgery evolved, foraminal enlargement included mechanical trephines, rasps, kerrison ronguers and various instruments that allowed the endoscopic surgeon to perform foraminal surgery by direct visualization. Other endoscopic surgeons embraced this operative portal for spondylolisthesis and stenosis in addition to disc excision. As the endoscopic technique evolved, however, so did the potential for complications [16]. Dysesthesia, a neuropathic hypersensitive postoperative condition is underreported because it is almost always temporary. Yeung has reported that this is an unavoidable risk of foraminal surgery because the patho-anatomy in the foramen is varied, and not detectable by current imaging techniques. [17]

7. Reported and Unreported Complications

In a multicenter study [18] of over 26,000 cases combining percutaneous fluoroscopically techniques with endoscopic spine surgery, the overall major complication rate of percutaneous endoscopic discectomy was less than 1%: Treatment consisted of antiinflammatory agents, steroids, foraminal epidural blocks, sympathetic blocks, alpha blockers, and neurontin titrated up to 3200 mg/day. Nine surgeons recorded all 48 cerebrospinal fluid leaks; none of the patients required surgical repair. Of the 61 cases of discitis, only 11 were documented to be bacterial and septic. All patients recovered with appropriate antibiotic therapy. Not all of the 88 motor and sensory deficits were transient, but patient satisfaction ranged from 80%-94%. Although the rate of second surgery was reported to be less than 1%, follow up at many centers was only months, not years; and the real level of reoperation was very likely much higher. Recurrence rates reported by Hoogland (personal correspondence) and Yeung is 4%-6%. Other complications reported in the literature include cauda equina syndrome [19], permanent foot drop [20], and secondary disc herniation [21], Potential, as well as rare complications not reported in the literature include: severe complex regional pain syndrome, foot drop (even when laser or radiofrequency is not used, perforation of the bowel, penetration of the great vessels, spinal epidural hematoma, and mechanical injury of a nerve root. Some of these complications can also occur with open surgery, and is not necessarily due to surgical mishap. The finding of nerve tissue in the surgical specimen occasionally becomes an issue, especially with cases involving malpractice litigation, but does not usually or automatically determine an injury to the traversing or exiting nerve crossing each disc space. The author has personally removed a disc fragment adherent to the undersurface of a spinal nerve missed during posterior surgical discectomy. When the fragment is adherent to a nerve, some nerve filaments may accompany the disc fragment. Neo-neurogenesis and Neo-angiogenesis is commonly seen with endoscopic inspection of the foraminal zone. Furcal nerve branches are also commonly seen branching

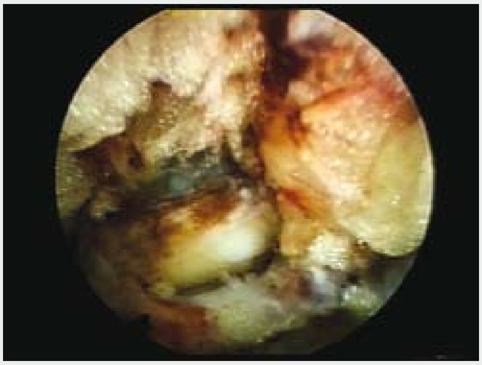

Figure 7:
Furcal nerve (myelinated nerve branch in periannular fat) in Kambin's triangular zone. These 1-2mm nerve branches can be found in the surgical specimen and is not part of the traversing or exiting nerve. The ability to clearly visualize pathology during endoscopic spine surgery is the best way to avoid complications inherent in any surgery.

from the exiting nerve and extending into the Psoas muscle or occasionally connecting with the traversing nerve. These furcal branches are usually only one or two millimeters in diameter and are myelinated. [22] (Figure 7) Surgical biopsy has confirmed that these furcal nerves are myelinated nerves. Removing these furcal branches may cause temporary neuropathic pain, but because they are not part of the main nerve trunk, there are usually no permanent functional residuals if treated with pain management techniques.

8. Prevention of Complications

Most discitis following endoscopic surgeries is sterile. Even with thorough tissue debridement for gram stain and culture, these tissue samples, like needle aspiration, is often negative. With debridement, however, immediate relief of pain and rapid improvement occurs. Because traditional techniques usually involved long term intravenous antibiotics, infectious disease consultants often recommend the use of broad spectrum antibiotics as a precaution. In the author's experience, When the debrided tissue samples are negative, and the patient continues to improve clinically, there has been no incidence of osteomyelitis and residual discitis when antibiotics are discontinued after the cultures are found to be negative. A broad spectrum antibiotic such as vancomycin, 1 gram is injected in the disc in concentrated paste form. There were no recurrences of discitis or osteomyelitis. Zero bacterial wound infection rates have regularly been obtained when bacitracin and polymixin B are added to all irrigating saline in bactericidal doses [23].

The delay in onset and sympathetic mediation suggest that the mechanism for postoperative dysesthesia, paresthesia, and anesthesia may be due to the close proximity of the dorsal root ganglion in the foraminal approach or from the furcal nerve branches that obstruct the foraminal access portal. [22] Mechanical, electrothermal, and laser heat irritation of the dorsal root ganglion appear to be implicated most, but the symptoms of complex regional pain syndrome can occur from trauma distant to the apparent source of this neuropathic process. Neuromonitoring by EMG and SSEP are currently used to investigate the causes of nerve irritation in an attempt to lessen or prevent damage, but dysesthesia, a variant of complex regional pain syndrome, remains elusive, and can occur even if there are no adverse events with neuromonitoring, and even if the patient experiences no pain during the operative procedure. [24] In conclusion, complications in minimally invasive spine surgery can parallel that of traditional surgery. There may be an increase in the complication rate in the initial learning curve that can discourage surgeons who are more comfortable with a familiar procedure, but those surgeons who overcome the steep learning curve and master the minimally invasive surgical techniques usually start to prefer it over traditional techniques because of the lower morbidity and at least equivalent, if not increased efficacy of the procedure. The surgeon factor then becomes a major consideration for avoiding complications.

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