Technical Update in Spinal Mapping, Epidural Disc and Neural Decompression, and Neurostimulation: An Interventional Continuum for Axial and Radicular Pain

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Abstract: A variety of diagnostic and therapeutic modalities for the treatment of chronic low back pain have developed over the five decades since the introduction of the gate control theory of pain by Melzack and Wall.
In this manuscript, we offer a brief overview of the application of both diagnostic and therapeutic modalities. We begin with a brief description of diagnostic spinal pain mapping, and proceed to therapeutic epidural decompression; endoscopic discectomy and neural decompression; and neurostimulation.

Keywords: Pain mapping, epidural decompression, epiduroscopy, discectomy, nerve stimulation, spinal cord stimulation, back pain

INTRODUCTION

Interventional pain management of spinal disorders is algorithmically based on a selective approach to segmental level, and to the anterior or posterior column. The traditional diagnostic approach to determining the column of involvement includes selective injection of the medial branch nerve, the spinal root, and discography with pressure manometry to localize the pain generator. Over the past several years, a variety of additional techniques have been introduced, such as radio frequency stimulation during the diagnostic block [1], and the diagnostic use of flexible (steerable) epiduroscopy for direct visualization of the epidural space. These have increased the importance of clearly conceptualizing the localization of pain generators as being either in the anterior or posterior epidural space, and distinguishing dermatomal from sclerotomal pain patterns using stimulation [2]. The introduction of multidimensional longitudinal and posterolateral endoscopic disc and neural decompression, the introduction of multiple waveforms and decompressive tools to anterior and posterior epiduroscopic spinal space, and the introduction of new electrode designs for spinal cord stimulation have all had direct relevance to the diagnostic and therapeutic algorithm. Currently, the diagnostic and therapeutic use of endoscopic tools, radiofrequency, and laser technology is relatively limited. As a result, a number of therapeutic techniques beyond serial injections, such as neuromodulation of the medial branch and spinal root, and/or laser, quantum, or radiofrequency and minimally invasive longitudinal and posterolateral mechanical decompression and ablation of the disc, must be incorporated into our algorithmic thinking.

SPINAL PAIN MAPPING - POSTERIOR COLUMN

Medial branch (posterior – facet) or spinal root block (posterior – nerve root) relies on the patient's satisfaction with local anesthetic (short term) and corticosteroid (long term) effects. The anesthetic phase provides immediate relief but the patient may have a prolonged improvement; the corticosteroid phase may extend for several weeks. The precision required to target the medial branches or spinal roots requires structural imaging such as xeroradiography, MRI, or CT imaging. These techniques have several disadvantages, including the overlapping clinical presentations of facet-mediated pain and radicular pain, inter-patient differences in pain reporting, and difficulties in interpretation of the correlation between symptoms and structural imaging.

These concerns led to the development of a pain mapping algorithm for use in the operating room [3-7]. A radiofrequency (RF) stimulating needle can be used in an awake patient prior to selective injection (Figures

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1-3). This strategy allows for an additional intra-operative “stimulation phase” reproducing (or not) “concordant sensory paresthesia in the normal painful region(s).” In the authors’ experience, it can help differentiate radicular from segmental pain patterns, and allows objective comparison of the clinical importance of multiple different pain generators (medial branch and spinal root targets) in the same patient. Limitations of this technique include the potential for multiple needle sticks required, safety concerns due to anatomic disruption of these targets in postoperative states, and the possibility of simultaneously stimulating structures with overlapping neural innervations.

Traditionally, patients with concordant RF needle stimulation and with positive anesthetic phase responses from medial branch block have been treated with radiofrequency neurotomy [8-10]. Those patients with concordant RF needle stimulation and positive anesthetic phase responses to spinal root block have been undergone pulsed radiofrequency (PRF), a form of neuromodulation [8-16]. More recently, epidural catheter stimulation mapping of the dorsal ganglion and spinal root has been introduced as a way to accomplish RF stimulation mapping of multiple levels, bilaterally, from a single incision (Figure 4-6).

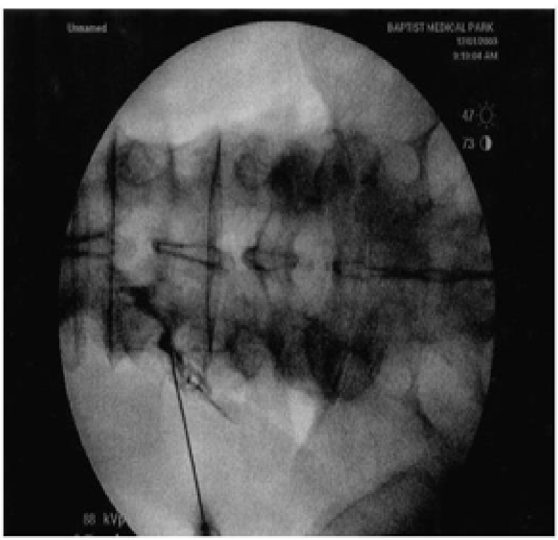

Figure 1. Radiofrequency needle mapping, root block, and lesion. Left L4 selective nerve root block. 50 Hz sensory stimulation produced “concordant” paresthesia mapping to the painful dermatome (with permission).

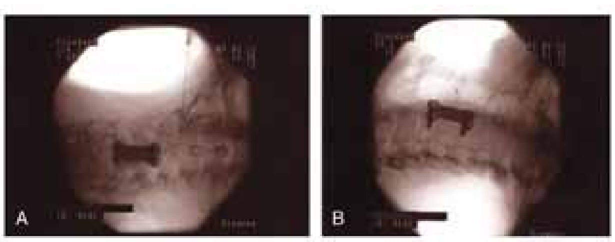

Figure 2. Radiofrequency needle mapping, root block, and lesion. Left C7 extra-foraminal selective nerve root block. 50Hz stimulation produced paresthesia to the painful dermatome. This was followed by a block with Marcaine, Celestone. **A.** AP x-ray. **B.** Oblique x-ray. (with permission).

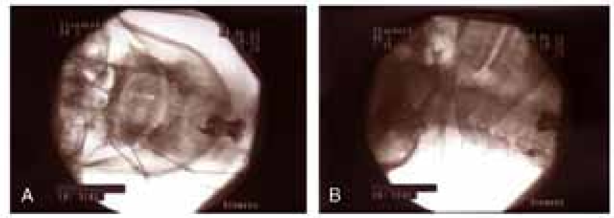

Figure 3. Radiofrequency needle mapping, root block, and lesion. Left C1-2-3 selective nerve root block. 50 Hz stimulation produced paresthesia into posterior occiput. This was followed by a block with Marcaine and Celestone. **A**. AP x-ray **B.** Lateral x-ray (with permission).

Figure 4. Navigator epidural directional catheter used for “mapping”, blocks, and pulsed radiofrequency (with permission Vertical Srl, Italy.)

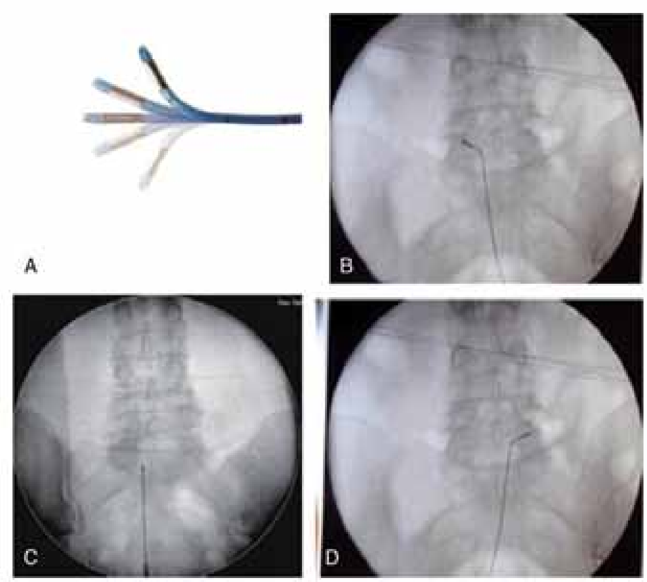

Figure 5. Navigator catheter. **A**. Adjustable tip is demonstrated for maneuverability in the epidural space. **B-D.** X-rays showing catheter entry and maneuverability into each foramen (with permission Vertical Srl, Italy.)

Advantages include:
• Targeting of multiple roots ipsilaterally or bilaterally with one epidural cannulation
• The dorsal root is proximal to the posterior primary ramus, spinal root, medial branch and sinuvertebral nerve
• A contrast epidurogram can be obtained during the intra-operative stimulation phase, before administering local anesthetic.

Documentation of post-injection anesthetic and corticosteroid phase responses are still feasible, but may be bypassed in favor of immediate PRF neuromodulation [11-15, 17, 18]. In addition, epidurographic filling defects may indicate the presence of adhesions in the posterior epidural space [19-21]. Limitations of this technique include difficulty with cannulation or managing the epidural obstructions, including fibrosis, as well as infection, bleeding, and nerve injury.

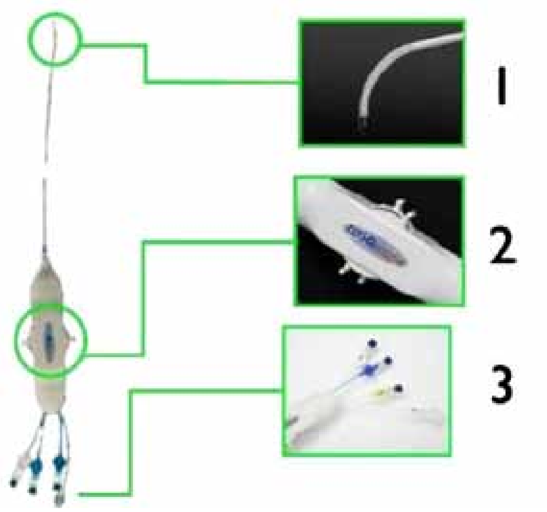

Figure 6. Resascope™. Demonstrated are: **1.** Anti-traumatic tip, **2.** Handle with 4 direction movement, and **3.** Four channel access port for injections and instruments (with permission MRT, Srl, Italy).

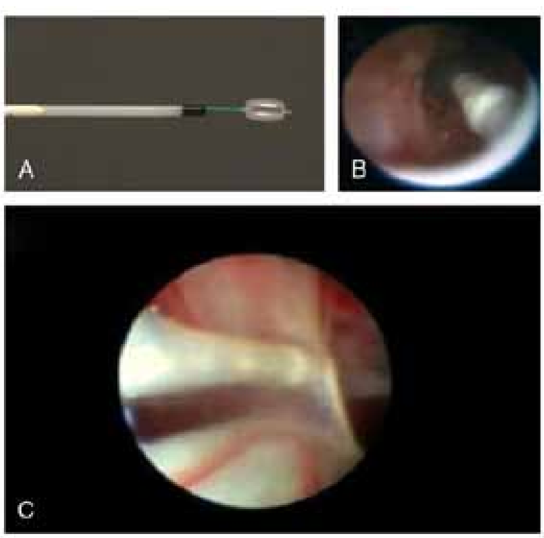

Figure 7. Resaflex™. **A.** Dilating Balloon placed through working port of flexible catheter to assist with neural scar decompression. **B.** Dilating Balloon inflated below nerve root under endoscopic guidance separating scar tethering band to assist neural decompression. **C.** Freed tethered scar band (with permission MRT, Srl, Italy).

SPINAL PAIN MAPPING - MIDDLE AND ANTERIOR COLUMN - POSTERIOR EPIDURAL SPACE

Chemical adhesiolysis under fluoroscopy, augmented with an endoscopic camera, has been the treatment of choice for fibrosis within the posterior epidural space among many physicians which allows better penetration of the injectate through scar [22, 23].

Initially, epiduroscopy, while allowing visualization of acute and chronic inflammatory changes in the posterior epidural space, was limited by low definition optics and inadequate steering capability of the catheters [24-26]. Although positive results with epiduroscopic chemical adhesiolysis were seen [27], scar still resulted in tethering and compression of the roots [21, 23] More recently, multi-port endoscopes have been introduced, allowing more precise and adequate visualization of the posterior epidural space and a greater range of instrumentation [17, 18, 28, 29] These include dilators, stimulating catheters, balloons, and quantum molecular resonance fibers (Figures 6-10). In particular, technical evolution has centered around posterior epiduroscopic neural decompression, in which simultaneous diagnosis and treatment may be accomplished through the epiduroscope [17, 18, 28, 29].

Figure 8. Resaflex™. **Left.** Quantum Molecular Resonance Generator (Resoscope™, with permission AMS Italia) **Right.** Quantum Molecular Resonance Fiber (Resoflex™, with permission MRT, Srl, Italya)

ANTERIOR EPIDURAL SPACE

Anterior epidural endoscopic disc and neural decompression was initially described by Rothstein. Since then, others have validated and expanded the approach [6, 30-37].

Compared to similar techniques, this approach is characterized by an expanded in-line laminotomy and release of the filum terminale in order to facilitate access to the anterior epidural space and disc-nerve interface (Figure 11). This allows for longitudinal diagnostic direct visualization and treatment of anterior disc herniations or extrusions, annular tears, acute neovascularization, and

and chronic scar tethering (Figure 12). Recent publication of multicenter studies [30-32] have documented significant long-term outcomes, in that they targeted significant additional pathologic changes not seen on standard preoperative structural imaging (MRI /CT) [2, 6]. Additionally, these procedures can be performed under general or MAC anesthesia using intraoperative neurophysiologic mapping [6, 7, 38-40]. Awake patients can describe concordant pain reproduction with endoscopic catheter stimulation of the root, annular tear, disc neovascularization/neoinnervation, or sinuvertebral nerve at one or more levels [6]. Continuous somatosensory evoked potentials, motor endplate potentials, and electromyography are employed to monitor patients under general anesthesia similar to those described for use in placement of spinal cord stimulation electrodes [3, 7, 39].

Either pressure or chemical effects can be responsible for the pain associated with disc disruption, and this ambiguity poses a significant clinical problem for the diagnosing physician [41]. MRI and CT structural changes do not always correlate with the patient's clinical presentation. Specifically, the nucleus and annulus are dynamic tissues, yet imaged in most cases in the unloaded or least stressed position. Despite improvements, and in an effort to address these imaging limitations, intranuclear pressurization discography remains inconclusive, limited in application, and controversial [42, 43]. Poor long-term results with intradiscal annuloplasty and significant failure rates with multi-level lumbar stabilization have been described and pose a significant dilemma to the interventional spinal specialist [44, 45].

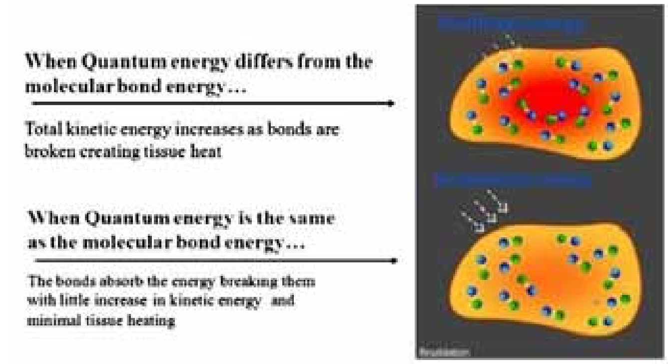

Figure 9. Resablation, mechanism of action. **A.** When the quantum energy differs from the molecular bond energy, the total kinetic energy increases as bonds are broken, creating tissue heat. **B.** When the quantum energy is the same as the molecular bond energy, the bonds absorb the energy, breaking them with little increase in kinetic energy and minimal tissue heating (with permission MRT, Srl, Italy).

Figure 10. Resaflex™. **A.** Quantum Molecular Resonance Fiber in contact with tethered scar band just medial to nerve root. **B.** Quantum Molecular Resonance Fiber activated under endoscopic guidance. **C.** Post Quantum Molecular Resonance Fiber activation scar decompression cavity (with permission MRT, Srl, Italy).

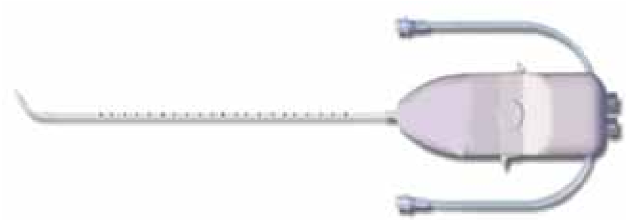

Figure 11. Example of directional multiport flexible catheter and endoscope.

ENDOSCOPIC DISCECTOMY AND NEURAL DECOMPRESSION (EDND)

Two primary approaches may be applied independently or in combination for lumbar epidural endoscopic disc and neural decompression: In-line longitudinal and posterolateral. In-line longitudinal or trans-sacral has been recently described [38]. Posterolateral approaches and tools (Figures 14,15) are updated as follows to include dorsal posterolateral and paracentral (Figure 16) discectomy, nuclectomy and modulation (Figures 16-19).

Patient Preparation

1. Patient brought to the operating room and placed prone onto the radiolucent table. For maximum lumbar flexion the Wilson frame may be used.
2. Mild sedation is administered
3. AP and lateral fluoroscopic images are obtained preoperatively to mark the intended posterolateral (PL) skin incision site.
4. The patient is prepped and draped, and the skin and subcutaneous tissue are anesthetized with 1% lidocaine and epinephrine solution.
5. An 18-gauge spinal needle is introduced under AP and lateral fluoroscopic control.

6. A ventro-medial trajectory into the triangular "safe zone" is used (transforaminal zone lateral to the traversing nerve root and medial to the exiting nerve root) .
7. A more shallow approach is used compared to the standard discogram approach, in order to target the posterolateral vs. paracentral dorsal part (posterior 1/3 of the disc and annulus.)
8. The tip of the needle is directed to a final location that is at the most dorsal part of the disc space on the lateral image and the center of the disc space on the AP fluoroscopic image - the further posterolateral at the skin, the more paracentral the intradiscal cannulation position will be in the anteroposterior radiography, and the more posterior the cannulation will be in the posterior 1/3 of the disc on the lateral image.
9. An intraoperative discogram is performed at the operative level using a mixture of indigo carmine or methylene blue and radiographic contrast medium - selective staining of the nuclear material will occur, aiding differentiation of nuclear vs. annular fibers under direct vision.
10. The radiographic position of herniations or tears are noted and prepared for disc cannula placement.
11. A guide-wire is placed through the spinal needle and fixed within the disc space.
12. Care is taken to ensure that the guide-wire is well placedplaced.
13. The spinal needle is carefully removed.
14. Extra local anesthetic is used for the subcutaneous tissue, if needed.
15. An 11 blade is used to make a 0.5 cm skin incision over the guide-wire.
16. The disc cannula system is comprised of a variety (3.3-6.9 mm) of tissue separators secured over a soft tissue dilator.
17. The entire unit is placed over the guide-wire and gently introduced through the subcutaneous tissue and muscle fascia into the foraminal target zone using a gentle rotating motion. Care is taken to assure the wire does not advance to or thru the contralateral annulus.
18. The cannula is placed at the dorsal surface of the annulus fibrosus.
19. Usually, if responsive, the patient may report axial low back pain at this point.
20. Radicular pain complaints or neurophysiologic EMG monitoring activation may indicate pressure on the nerve root, and re-direction of the device may be required.
21. After safe cannula placement is verified in the subannular position, it is advanced into the dorsal disc space using a twisting motion.
22. After AP and lateral fluoroscopic images verify effective placement of the cannula, the guide-wire and soft tissue dilator are removed.

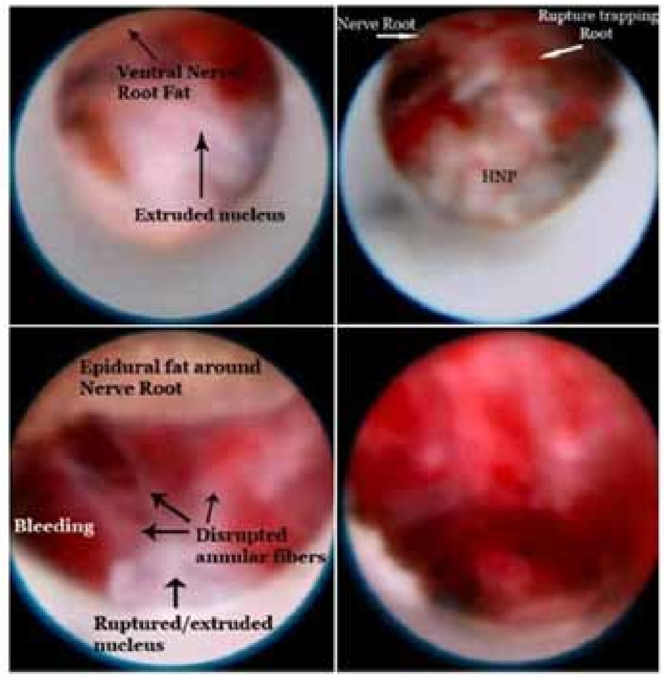

Figure 12. Anterior epidural endoscopic anatomy and pathologies including epidural fat, nerve root, herniated nucleus pulposus, extruded nucleus pulposus with root impingement, annular disruption and tears, epiradicular inflammatory changes including neovascularization and scar tethering (with permission from Journal of Neurosurgical Review, Supplement 1 38).

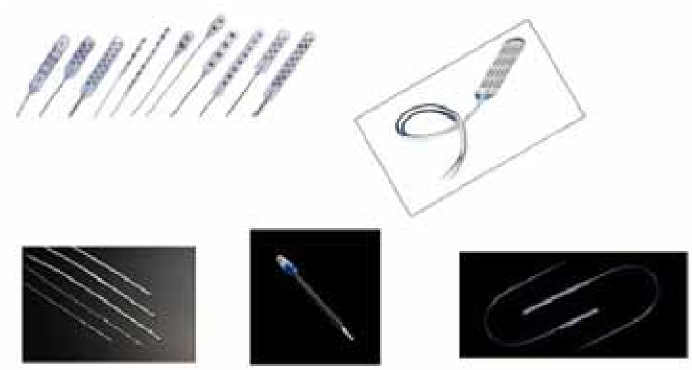

Figure 13. Electrode designs used in spinal cord stimulation (with permission Saint Jude Medical, Plano Texas).

Dorsal Nuclectomy and Disc Decompression

1. Visualize the disc space through the working cannula.
2. Intradiscal decompression can be initiated real-time with a variety of pituitary type graspers (2.5mm to 4mm+ depending on the size of the cannula and fixed camera or microscope placed and the working channels available) (Figure 16).
3. Dorsal disc material is removed in order to create working space and further discectomy and decompression with any number of energy based electro-cautery elements (bipolar, high frequency-radiofrequency, low frequency-radiofrequency, quantum molecular, or laser guide type probes) (Figures 17, 18).

4. Disc material is removed and sent to pathology for permanent specimen.
5. A 2.5 mm-5mm fixed magnifying camera and/or endoscope and/or microscope is introduced continuously or at intermittent points so that direct visualization confirms all decompressive actions and to verify the intradiscal position of the cannula. The disc material is stained blue and this can be differentiated from annular or scar tissue (Figure 19)
6. The remainder of the nucleus decompression or removal of herniation is performed using alternating mechanical removal and combinational electrocautery forms until direct visualization of desired posterolateral and longitudinal anatomy, anterior epidurographic herniation outline, intradiscal resistance and impedance, multidimensional fluoroscopic continuous and spot films, and neurophysiologic monitoring (or any combination of the above) are felt to be maximally optimized.
7. After the herniation is removed, the endoscope is used to verify final adequate decompression (spot or video-graphic images).
8. The cannula is backed out of the nucleus into the dorsal part of the disc space revealing the dorsal annular fibers.
9. It is from this position that the dorsal annular

Dorsal Annular Modulation

1. Using the bipolar, quantum, or radiofrequency electrocautery forms, the dorsal annular fibers can be contracted to treat annular tears.
2. Multiple sweeps across the dorsal annulus are performed to achieve adequate annular remodeling (Figure 19).
3. The position of the probe is concomitantly verified using AP and lateral fluoroscopic imaging along with the fixed camera and direct visualization.
4. Pituitary forceps are reintroduced and any loose disc or peri-annular material is excised.

Closing

1. A final endoscopic visualization is performed in order to verify good dorsal disc decompression and to ensure that no loose disc material is present that could predispose to early re-herniation (Figures 20, 21).
2. The cannula is removed under endoscopic control. The anatomy of the approach is well-visualized during removal. Any sites of bleeding are clearly demonstrated.
3. As the endoscope is removed, the posterior longitudinal ligament is seen followed by the epidural space. The epidural space is notable by the presence of the epidural venous plexus and the epidural fat. Finally, the foraminal ligament is visualized which is the ventral extension of the facet capsule and the ligamentum flavum.

Figure 16. Instrument for intradiscal decompression (Courtesy of Elliquence, LLC)

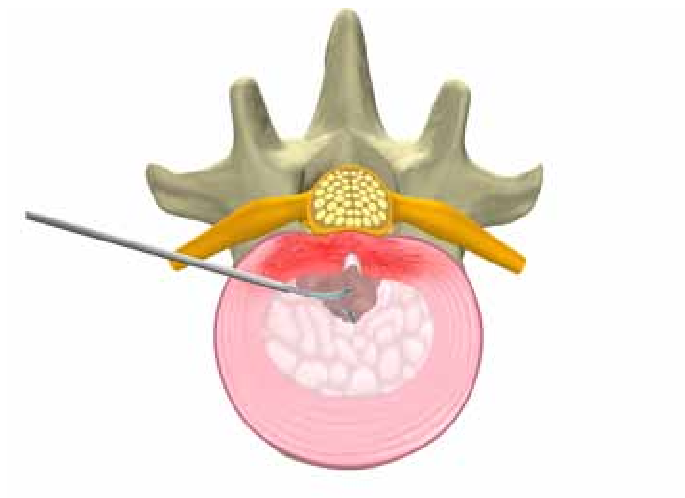

Figure 17. Nucleus Ablation (Courtesy of Elliquence, LLC)

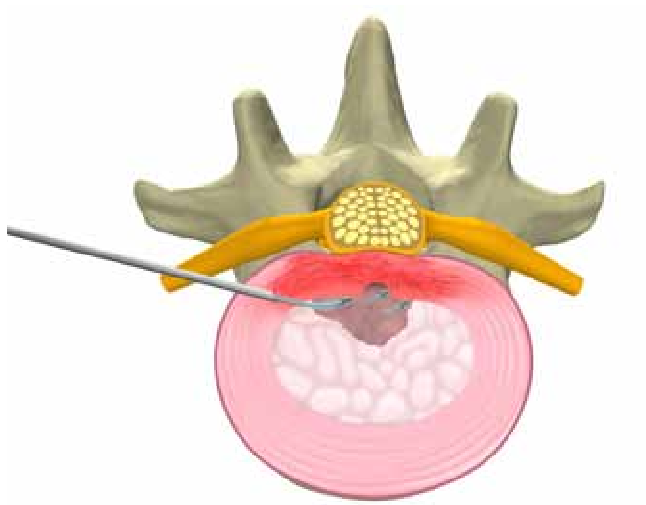

Figure 18. Annulus modulation (Courtesy of Elliquence, LLC)

4. After the cannula is removed, a single absorbable suture is used to close the skin.
5. The incision sites are usually less than a 0.5 cm in length.
6. Standard irrigation and closure and disc material per level sent to pathology for permanent specimen.

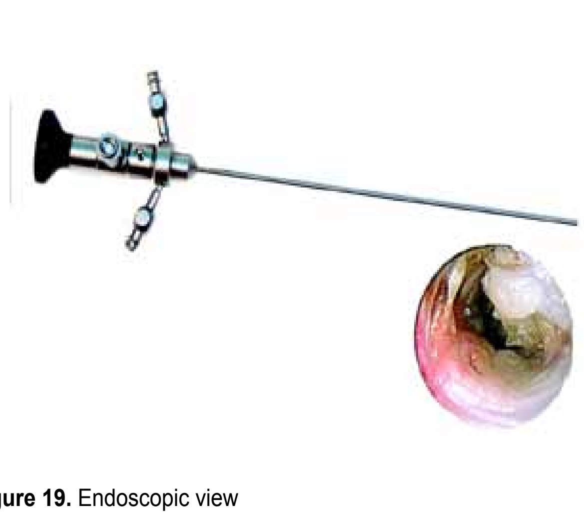

Figure 19. Endoscopic view

NEUROSTIMULATION

Spinal cord stimulation (SCS) has evolved to a well-accepted treatment for refractory low back pain associated with failed back surgery syndrome. A variety of different electrode types, including cylindrical and multicolumn paddle leads are available to map the painful areas [5, 40, 46-57] (Figure 13). Traditionally, intraoperative mapping to induce paresthesia in the distribution of refractory radiculopathy was performed with cylindrical electrodes prone to migration [58]. More advanced paddle leads can now be placed under general anesthesia with the use of intraoperative monitoring [3, 7, 39, 59]. Recent development of percutaneous surgical arrays (Epiducer®, St. Jude Medical, Plano, Texas) has allowed the interventional spinal specialist to map and place surgical paddle constructs in awake patients [60-62].

CONCLUSION

Many different diagnostic and therapeutic options are available to the interventional and MISS physician for the diagnosis and treatment of spinal pain. In this paper we provide an overview of recent advances in diagnostic spinal pain mapping, diagnostic and therapeutic endoscopic longitudinal and posterolateral epidural decompression, and neurostimulation. These minimally invasive techniques continue to evolve in the management of patients suffering from axial and appendicular pain.

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