

Chapter 4

Percutaneous Treatment in Lumbar Disc Herniation

Pier Paolo Maria Menchetti and Walter Bini

Introduction

The conventional surgical approach to disc herniation treatment may cause several complications (relapse, infection, CSF leakage, iatrogenic instability, peridural scar). In order to reduce the incidence rate of the above complications, in the last 30 years, many percutaneous procedures in lumbar disc herniation treatment have been used. All the percutaneous procedures are minimally invasive, and the main purpose is to respect as much as possible the anatomy of spine, reducing postoperative complications with a faster return to daily activities. The development of the percutaneous procedures was driven by the need to improve the efficacy of disc surgery and to reduce morbidity of the open surgical techniques. The goals included sufficient removal of disc material, minimal retraction of the nerve root, meticulous hemostasis, the possibility to approach concomitant pathologies, and the preservation of spinal stability. In addition, minimizing muscle dissection, decreasing postoperative pain, and avoiding general anesthesia in older patients were other objectives. Today, virtual reality, robotic assistance, and CT-scan are already available to surgeons performing minimally invasive spinal surgery, in order to reduce both complications and recovery time respect to surgical open approaches.

The success of the minimally invasive treatments depends exclusively on the appropriate surgical indications, and it is important to know exactly their action, complications, and limits. However, every minimally invasive treatment, in case of persistence of symptoms, permits conventional surgical procedures without any problem. Over the last 30 years, percutaneous lumbar disc herniation treatments

P.P.M. Menchetti, MD, FRCS (US) (✉)
Florence University, Florence, Italy

Department of Orthopaedics, Rome American Hospital, Rome, Italy
e-mail: ppm.menchetti@libero.it

W. Bini, MD, FRCS
Department of Neurosurgery, The City Hospital, Dubai, UAE

have included several procedures such as chemonucleolysis, percutaneous automated nucleotomy, percutaneous manual and endoscopic nucleotomy, IDET (intra discal electro thermal) therapy, nucleoplasty (coblation), PLDD (percutaneous laser disc decompression), and hydrodiscectomy.

Background

Minimally invasive surgery of spine could have originated in 1963, when Smith [1] began to use intradiscal injection of chymopapain in patients affected by sciatica. This procedure had a widespread clinical use in the 1970s but lost popularity because of severe complications, such as transverse myelitis and anaphylactic shock. In 1978, Williams [2] modified the operating microscope from brain surgery to discectomy, publishing the first series. The advantages of minimally invasive spinal surgery were shown compared to the traditional surgical approach. The advantages included one-inch incision, improved visualization and illumination, reduced operating time, and shortening of the hospitalization with a faster return to daily activities. The need to improve the efficacy of disc surgery and to reduce morbidity, mortality, and the cost of the procedures provided the impetus for the development of chemonucleolysis and microdiscectomy. Surgical goals included sufficient disc removal, minimal nerve root retraction, excellent hemostasis, ability to detect and evaluate concomitant pathology, and preservation of spinal instability.

In order to find further surgical alternatives to laminectomy and open discectomy, Hijikata [3] in 1975 performed a percutaneous nucleotomy under local anesthesia coupled with a partial resection of the disc material by a posterolateral surgical approach. Intradiscal pressure was strongly reduced with removal of nucleus pulposus inside the central portion of the disc, releasing thereby irritation of the nerve root and the pain receptors around the disc herniation. However because of the posterolateral surgical approach and the instrumentations to be improved, a small amount of disc material could be removed. Anatomic structures into the spinal canal could not be directly visualized, but 2–3 g of disc were extracted by initial penetration of the capsule with a fenestrated punch and serial insertion of punch forceps through cannulas of increasing size. After performing discography by introducing Evans blue dye into the disc, only blue-stained material was removed. The percutaneous approach was further developed with modified instrumentation. The outer diameter of the working sheath was enlarged to 6.9 mm and the inner 1–5 mm, allowing the introduction of upbiting and deflecting forceps. Finally, with the introduction of small-caliber glass fiber optics, visualization of the foraminal and extraforaminal regions was possible.

By 1985, Onik and his coworkers [4] developed a blunt-tipped suction cutting probe for automated percutaneous lumbar discectomy in contained disc herniation treatment. The simultaneous cutting and aspirating of the nucleus pulposus was monitored under C-arm fluoroscopy. Subsequently, a curved cannula through which

a flexible nucleotome could be placed also into the L5–S1 disc space was designed. In 1983, Friedman [5] used a chest tube and speculum introduced into the disc through a 1-in. incision over the iliac crest. Shepperd [6] designed retroacting rongeurs to retrieve material from the posterior region of the disc, but none of the above-mentioned techniques were effective for sequestered fragments or important degenerative changes. Intradiscal pressure studies before and after laser treatment of cadaveric disc were performed by Asher [7] beginning in 1985. Percutaneous intradiscal laser nucleotomy with a special tip pressure transducer was also reported by Yonezawa [8] in 1990, demonstrating that after laser vaporization, the nucleus pulposus was replaced with cartilaginous fibrous tissue, obtaining similar changes after open laminectomy and discectomy.

Considering the increasing demand for a minimally invasive spinal approach, the following criteria for percutaneous nucleotomy were set: (1) age less than 45 years, (2) no perforation of the posterior longitudinal ligament, (3) no preexisting of degenerative spinal canal stenosis, (4) no malformation of the neural structures, (5) at least 6 months conservative treatment without a response. In addition, the goal was a removal of disc from posterior part of herniation, preserving the central nuclear material.

In 1995, percutaneous radiofrequency thermocoagulation was introduced by Troussier [9]. Using a bipolar radiofrequency electrode and a radiofrequency alternating current could coagulate and necrose the nucleus pulposus, decompressing the nerve root. The current state of the art in minimally invasive spinal surgery is quite interesting, enabling skilled spinal surgeons to make an accurate diagnosis and to perform more effective operations with lower morbidity.

Percutaneous Procedures for Lumbar Disc Herniation Treatment

Chemonucleolysis

Chemonucleolysis is the term used to denote chemical destruction of nucleus pulposus (chemo–nucleo–lysis). The history of chemonucleolysis is related to Lyman Smith's studies [10]. Intradiscal injection of chymopapain, an enzyme derived from papyrus, causes hydrolysis of the cementing proteins of the nucleus pulposus, without any damage on the annulus. The enzyme works in about 2 or 3 weeks, reducing the symptomatic bulging or protruded disc. Nucleus pulposus is soft, gelatinous material in the center of the disc, surrounded by a tough fibrous coating (annulus). In disc herniation, weakened or torn annulus allows nucleus pulposus to ooze out. A protruded disc is intact, but bulging. In an extruded disc the fibrous coating has torn, but it is still connected to the disc. In a sequestered disc, a fragment of nucleus pulposus has broken loose from the disc and is free in the spinal canal. Chemonucleolysis is not effective in sequestered discs.

Indications

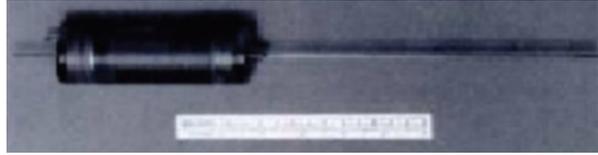
1. 18–50-year-old patient with contained disc herniation
2. No neurological deficits
3. Leg pain worse than lower back pain
4. Conservative treatment failure
5. Patient wishes to avoid surgery

The procedure is performed in the operating room, generally under local anesthesia. A small-gauge needle is placed under C-arm control in the center of the affected disc. Once needle placement is confirmed, discography is advisable. Next, only a small test dose of chymopapain is injected, following by a 10–15 min waiting period in order to observe signs of an allergic reaction. If no allergic reaction is noted, the procedure is completed. Patient is discharged in 24 h with absolute rest of 1 week. Because chymopapain is derived from papaya, about 0.3 % of patients are allergic to chymopapain and go into life-threatening shock when exposed to the enzyme. Symptoms of anaphylactic shock usually develop immediately, but can also occur up to 2 h after procedure. Other signs of less severe allergic reaction such as rash, urticarial, could take place immediately or up to 15 days after the procedure. Neurological complications included acute transverse myelitis/myelopathy (ATM), paralysis, leg pain or weakness, foot drop, and numbness [11, 12]. The rate of good/excellent results is generally about 70–80 %, but about 30 % of patients require 6 weeks for relief of pain [11, 12]. In the United States, the procedure is accepted only on lumbar discs. The complication rate reported is about 0.2–0.5 %. The mortality rate is less than 0.2 % [11, 12].

Automated Percutaneous Nucleotomy

Automated percutaneous nucleotomy was introduced by Onik in 1985 [13].

In 1975, Hijikata [14] introduced the percutaneous manual nucleotomy, which was expanded by Onik, a radiologist, who developed an automated device (the nucleotome), consisting of a modified 2.5 mm probe. The probe contains a cutter and a suction mechanism. The first nucleotome aspiration probe had an attached needle 8 in. (20.3 cm) long, 2 mm diameter. It involved a rounded closed end with a single side port close to the distal end (Fig. 4.1). The nuclear material is cut and suctioned to an outside reservoir. The exact mechanism of action of the probe is not clear, and in 65–70 % of cases postoperative CT scan performed at 6 and 11 months after the procedure does not show significant change in the intervertebral disc [15]. Since 1985, more than 200,000 procedures have been performed with a recorded success rate of about 70–80 % [16]. Biomechanical studies suggest a reduction of the height of the disc with a reduction of the intradiscal pressure, in order to decompress the corresponding nerve root with a resolution of the symptoms.

Fig. 4.1 Onik's nucleotome

Indications

1. Patients under 45 years of age with leg pain greater than back pain
2. Contained disc herniation on CT scan and/or MRI
3. Failure after 6 weeks conservative treatment
4. No spondilosis
5. No central or lateral spinal stenosis

Provocative discography is advisable. When there is doubt about disc extrusion, discography could investigate annulus integrity and posterior longitudinal ligament. A free flow of contrast into the epidural space could confirm a complete tear, while flow into the area of herniation shows a communication with the nucleus pulposus. In the presence of multiple levels of disc disease on CT or MRI, provocative discography revealed the levels requiring the surgical procedure. The procedure is performed in the operating room under local anesthesia and/or EVS (endovenous sedation). Under antero-posterior and lateral C-arm control, the 2.5 mm probe is positioned into the nucleus pulposus via a standard posterolateral approach. The opening at the tip of the nucleotome in combination with the cutting blade allows the nuclear material to be pulled into the opening cut, and transferred to the suction section. The probe takes about 15–20 min to permit the cut and suction of about 2–5 g of intervertebral disc.

Many patients feel immediate relief from pain following the procedure, and most of them are able to perform daily living activities within 24 h. A hospitalization of 24 h may be advisable because, in some cases, low back spasms last a few days. Postoperatively, a physical therapy program is recommended.

The reported success rates of this operation by itself vary from 29 % [17] to 75 % [18]. From the above considerations, the best candidates for the procedure are those with small contained disc herniation; the disc should have a minimal amount of degeneration and should not be decreased in height too much. Noncontained disc herniation or sequestered disc are serious contraindications. Several days of postoperative low back pain have been described. The overall complications rate is very low.

Percutaneous Manual and Endoscopic Nucleotomy

The first report of percutaneous nucleotomy was in 1975 [14], through a posterolateral approach to the disc. In the first series, the approach to the disc was both unilateral that bilateral, using progressive dilators (3.5–4.5 mm) in which relative forceps,

under C-arm control, were introduced for disc removal. The instrumentation used for the procedure involved an annulus cutter, forceps, and graspers to cut and remove nucleus pulposus from the center of the disc. One drawback of the procedure was the repeated in-and-out movement of the probe through the disc, which is not good for the annulus. The technique resected the nuclear substance of the disc, and not the herniated portion, in order to reduce the intradiscal pressure, which in turn retracted the contained herniation back into the disc, relieving compression on the nerve root. Initial results of the procedure were satisfactory, with a 72 % success rate [19]. Because of vascular injuries and discitis, the need for further innovation was recognized.

In the early 1990s, Kambin [20] introduced the use of endoscope in the spine through an anatomic landmark called “Kambin’s triangle” (Fig. 4.2a, b), in order to permit the direct surgical visualization of the nerve root and the disc herniation. Kambin’s triangle is the site of surgical access for posterolateral endoscopic discectomy. It is defined as a right triangle over the dorsolateral disc. The hypotenuse is the exiting nerve, the base (width) is the superior border of the caudal vertebra, and the height is the traversing nerve root. Kambin initially emphasized avoiding the spinal canal and staying within the confines of the triangular zone. The endoscope and instruments are introduced through a cannula between the traversing and exiting nerves in the area known as Kambin’s triangle (Fig. 4.2a, b).

Indications

- Patients with radicular pain persisting more than 3 months, relieving at rest
- Radicular pain radiating in standing position
- Contained disc herniation on CT scan and/or MRI
- Up to 50 % reduction of the spinal canal without central or lateral spinal stenosis
- Foraminal disc herniation

The equipment for the endoscopic discectomy is dedicated. A specially designed multichannel discoscope (Fig. 4.3a) with a large working channel provides the quality imaging needed to target disc pathology. The flow integrated system permits keeping the surgical field clear, even in case of bleeding. A pressure and volume controlled pump, coupled with a bipolar radiofrequency, helps to control the bleeding. Evocative discography is performed before the procedure, under fluoroscopic control, and following the discography, a guidewire is inserted into a 18-gauge (1.1 mm) spinal needle used for discography, followed by an incision with a no. 11 scalpel. An obturator dilates the muscles up the annulus, then a blunt technique is used to fenestrate the annulus and a cannula is inserted around the obturator as the tubular access to the disc. A beveled or open slotted cannula with a tang is employed to anchor the ventral portion of the cannula onto the annulus, leaving the dorsal window open towards the epidural space. The disc, posterior annulus, and the epidural space are in the field of vision of a 20° wide-angle endoscope (Fig. 4.3b). Special instruments, such as pituitary forceps and flexible shavers permit one to remove the disc, under direct endoscopic visualization.

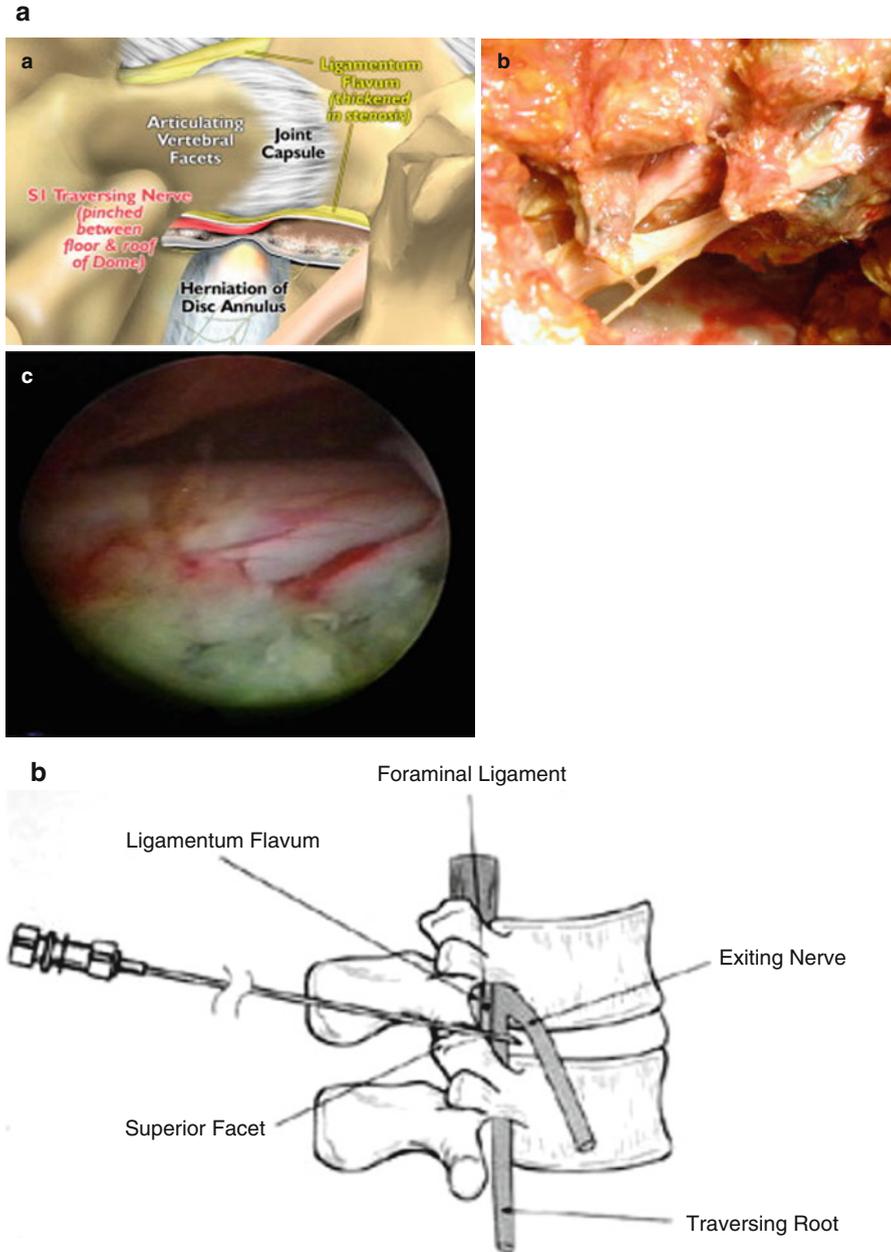
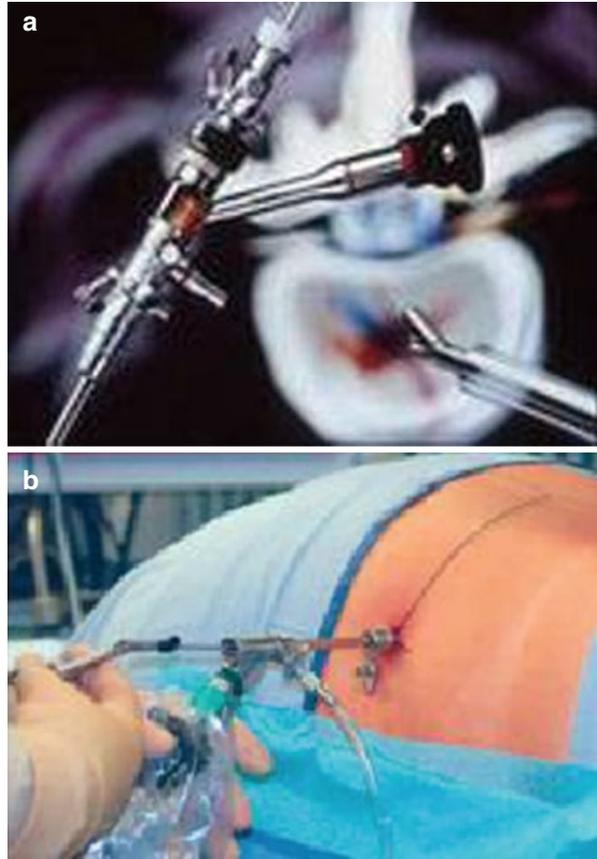


Fig. 4.2 (a) Kambin's triangle, a right triangle over the dorsolateral disc. The hypotenuse is the exiting nerve, the base (width) is the superior border of the caudal vertebra, and the height is the traversing nerve root. (b) Kambin's triangle anatomical landmarks on specimen spine. (c) intraoperative endoscopic view of disc herniation (at 6 o'clock) and nerve root (between 3 o'clock and 9 o'clock)

Fig. 4.3 (a) YESS® Spine Endoscope (Richard Wolf, Germany): Original Wolf spine endoscope, dual irrigation channels for a clearer field, rod lens optics for pristine images, 2.7 mm working channel accepts a wide range of instrumentation, including spine endoscopy forceps, trigger-flex bipolar probe, shaver blades and burrs, laser and water-jet cutter. (b) Transforaminal approach for lumbar discectomy



A strict selection of the surgical cases with a growing knowledge of the endoscopic techniques may give excellent/good results up to 72–88 %. Clinical outcome in over 2,500 patients evaluated both retrospectively and using an SF-36 questionnaire stated excellent/good results in more than 70 % of patients. No infection or nerve injury was found, but we must advance along the learning curve of the procedure in order to safely use the endoscope [21]. An interesting study [22] comparing microdiscectomy and percutaneous endoscopic discectomy showed, after 2 years, a success rate of 80 % using endoscopy, versus 65 % using microdiscectomy; after endoscopic discectomy, neurological deficits disappeared in 90 % of cases, versus 70 % after microdiscectomy. The return to daily activities was faster and at a higher percentage (95 %) after endoscopy compared to microsurgery (72 %).

From the above considerations, it appears that percutaneous discectomy (manual or endoscopically assisted) reduces postoperative complications and hyatrogenic damage due to open surgical approach for the following reasons:

- Posterolateral approach does not enter the spinal canal
- No periradicular/peridural scar formation (reported in 6–8 % after open surgery)
- Reduction of infection rate
- Does not give postoperative hyatrogenic instability
- Day surgery hospitalization
- Avoidance of general anesthesia
- Faster return to daily activities

In 1993, Destandau [23] designed a specially modified endoscopic instrumentation, the Destandau Endospine[®] System, Karl Storz (Fig. 4.4a, b), in order to realize an “endoscopically assisted lumbar microdiscectomy.” The instrumentation was designed to resolve two main difficulties presented by endoscopic disc removal. First, the working space was created mechanically and not by fluid pressure. Second, the angle between the working channel and the optics channel provided the triangulation necessary to keep the distal ends of the instruments constantly in view.

In 1998, complete standard instrumentation was available (Karl Storz, Tuttlingen, Germany). Under general anesthesia and fluoroscopic control, in prone position, a 15 mm paramedian incision was performed, a 12 mm osteotome was inserted down to the lamina, and the ENDOSPINE[™] tube with obturator was inserted down to the lamina. The device housed three access tubes, respectively for endoscope, suction cannula (4 mm diameter), and the largest (9 mm diameter) for surgical instruments. The first two were parallel, and the third was with an angle of 12° with the tubes converging into the plane of the posterior longitudinal ligaments. The angulation enabled the surgeon to keep the distal ends of the instruments in view at all times and to use the suction cannula as a second dissecting instrument. The system included also a nerve root retractor. Part of superior lamina and articular process was resected to expose the nerve root. Dissection of the nerve root and disc herniation removal proceeded only after adequate nerve root visualization under endoscopic illumination and magnification. Epidural veins and any bleeding points were cauterized if necessary. The total time for the procedure, after an adequately long learning curve, could vary from 60 to 120 min. Patient satisfaction was over 85 %. Low complication rates, less than 2 %, have been reported. The endoscope allowed the same access port and the same surgical technique to be used classically on the spinal canal and disc, reducing the skin incision and the overall tissue dissection. The advantages of this technique were the same as open microdiscectomy, but the immediate postoperative effects were reduced, providing a more rapid rehabilitation and return to daily activities. The method allowed a paramedial approach by partial bony resection of the isthmus, regardless of the location of the herniation and the level involved. The appropriate endoscopic view of the nerve root and ganglion reduced the risk for neural damage to a minimum.

In summary, the Destandau procedure, transporting the surgeon’s field of vision directly into the operative site, enhances the visualization of structures and more than compensates for the absence of three-dimensional perception. The relatively wide angle of vision permits also a good approach to foraminal disc herniation.

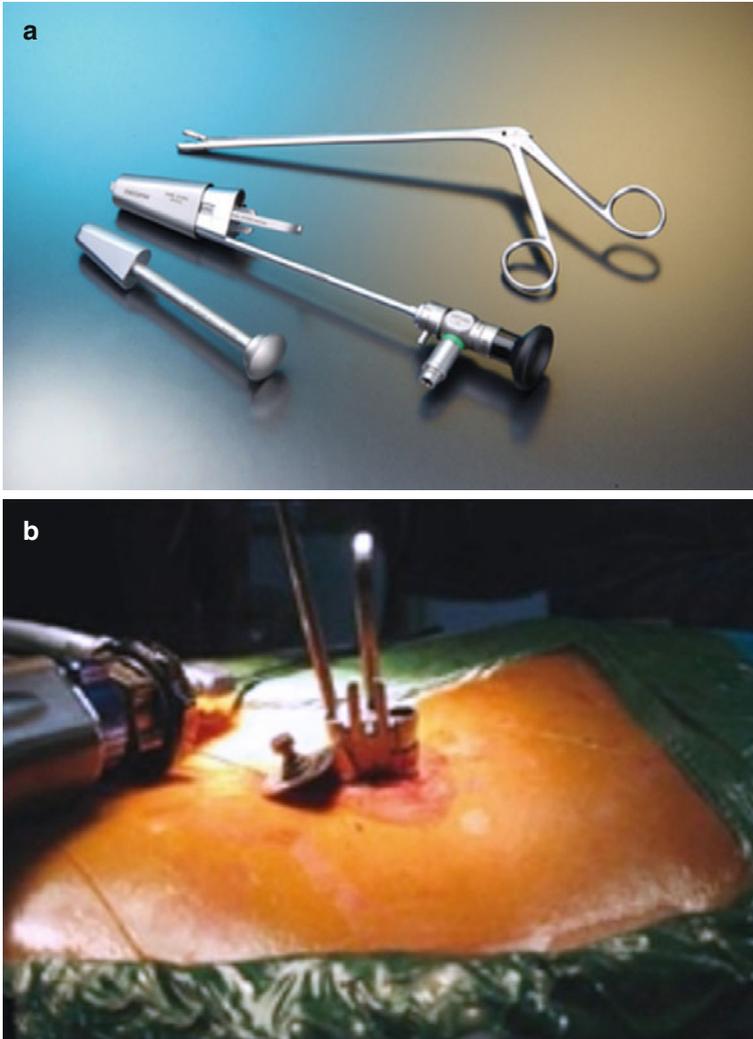


Fig. 4.4 (a) Destandau Endospine® System (Karl Storz). (b) Destandau Endospine® System (Karl Storz), patient positioning and operative setup

The paramedial endoscopic technique can also be applied for decompressing segmental stenosis and the wide field of view permits decompression of both sides through unilateral access.

Over the years, percutaneous discectomy, since its introduction, has experienced several innovations, due not only to the minimally invasive approach to the spinal canal with smaller instrumentations but also to the availability of several physical systems in order to decompress the compressed nerve root through a reduction of the volume of the herniated disc. Because the intervertebral disc could be

considered a closed hydraulic space, from a physilas point of view, a small reduction of volume will give a great reduction of the intradiscal pressure.

For these reasons, since 1990, several physical energies have been used for percutaneous discectomy: monopolar radiofrequency, bipolar radiofrequency, and laser.

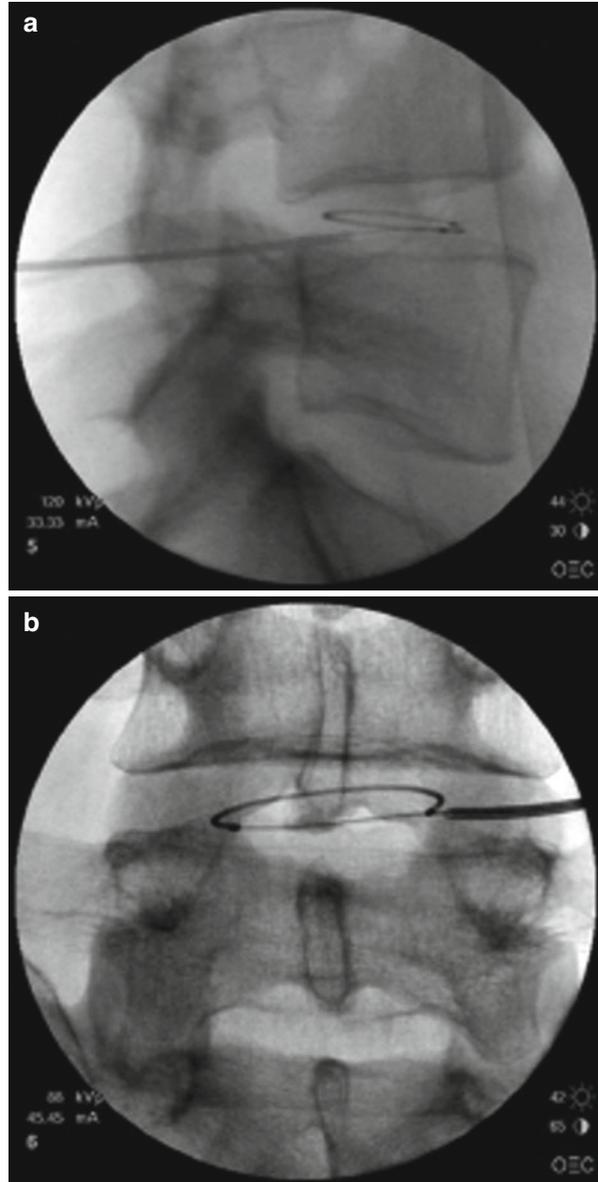
IDET (Intra Discal Electro Thermal) Therapy

Intra discal electro thermal therapy (IDET) has been introduced in latter the half of 1990s for the treatment of chronic discogenic low back pain due to ruptured annulus and/or small contained disc herniation. In 1997, Saal [24] proposed repairing the torn annulus with heat from a thermal resistive coil. Previous application in arthroscopy of radiofrequency current used for stabilizing a joint capsule by shrinkage of collagen and granulation tissue cauterization, followed by peripheral nerve tissue damage, lead to the understanding that intradiscal thermal resistive heating can increase annular temperatures to levels sufficient to obtain pain relief due to nociceptor neutralization. Original instrumentation involved the percutaneous threading of a flexible catheter into the disc under fluoroscopic control (Fig. 4.5a, b). The catheter, composed of thermal resistive coil, heats the posterior annulus of the disc, causing contraction of collagen fibers and destruction of afferent nociceptors. IDET is thought to decrease discogenic pain by two different mechanisms:

- Thermal modification of collagen fibers
- Destruction of disc nociceptors

Thermal modification of collagen fibers is the result of breakage of heat-sensitive hydrogen bonds of collagen, causing collagen contraction up to 35 % of its original size. The tightening of annular tissue may enhance the structural integrity of degenerated disc and repair the annular fissures. Destruction of nociceptors in the annulus is believed to contribute to pain relief. A particular thermal catheter is used for the procedure (SpineCATH System, Oratec Interventions, Inc., Menlo Park, CA). IDET is usually performed under local anesthesia or endovenous sedation. The catheter of 1.3 mm of diameter should be placed circumferentially around the inner surface of the posterior annulus (Fig. 4.5a, b), and after right positioning, it is heated from 37 to 65 °C. After temperature remains for 1 min without referred pain, the temperature is increased by 1 °C every 30 s until 80 and 90 °C. A maximum temperature of 72 °C was found in the disc, with a 46 °C in the outer annulus with catheter tip at 90 °C. It is important to understand that tissue temperature is highly dependent on the distance from the thermal source. An interesting study [25] formulated a predictive temperature map relative to the distance from the tip of the catheter. Using human specimen discs, multiple sensors were placed along the anterior annulus, posterior annulus, and endplates. Temperatures greater than 65 °C were reached at distances up to 2 mm from the SpineCATH. Temperatures of more than 60 °C were reached at distances between 2 and 4 mm from the SpineCATH in all discs. More than 45 °C was reached in all discs at distances of 9–14 mm from the catheter. Because collagen

Fig. 4.5 (a) SpineCATH System inserted into the disc under fluoroscopic control (lateral view).
 (b) SpineCATH System inserted into the disc under fluoroscopic control (anteroposterior view)



denaturation it is considered to take place between 60 and 65 °C, sufficient denaturation thresholds are achieved within 2 and 4 mm from the SpineCATH.

Indications

- Age of patients 18–50 years
- Chronic low back pain that does not respond to at least 6 months of conservative therapy

- Prevalence of low back pain compared to leg pain
- Increasing of low back pain in standing or sitting position
- Normal disc height on lateral X-ray
- Contained disc herniation on MRI or CT scan not obliterating more than 30 % of spinal canal

After the operation, the patient might experience a significant increase in pain. Significant pain relief may take 8–12 weeks, with healing process reaching its peak 4 months after the procedure. In general, patients can return to heavy physical works after 4 months. A gradual increase in daily activities is recommended and a lumbar brace should be worn in the first 6 weeks. Results, in case of proper indication and appropriate selection of cases, are satisfied in 70 % of cases [24]. In summary, IDET is a safe procedure for patients with chronic lumbar discogenic back pain and with proper cases selection could be considered prior to the more aggressive surgical option such as fusion or disc replacement.

It must be stressed that IDET should be used in chronic low back pain treatment and not for relief of leg pain.

Nucleoplasty (Coblation)

Introduced in 2000, nucleoplasty seems to be the natural evolution of IDET. Because of the strict indications related to the prevalence of chronic low back pain and the surgical difficulties in the management of the catheter, there has not been a large diffusion of IDET. Coblation (controlled ablation) technology involves transmitting radio waves through a specially dedicated catheter called PercDCWand™ (ArthroCare® Spine, Sunnyvale, CA) (Fig. 4.6). The procedure generates a unique low-temperature plasma field in order to obtain a controlled ablation, avoiding the risks of thermal injury to vertebral end plates and surrounding tissues. By using bipolar radiofrequency, the instrument creates a series of channels into the disc by tissue ablation and coagulation, with a temperature between 40 and 70 °C. The tissue is broken down to low molecular weight gases that exit through the 17-gauge introducer needle. The plasma zone has approximately 1 mm radius, and about 1 cc of disc material is removed after creating six channels. Bipolar radiofrequency coagulation during withdrawal of the SpineWand™ denatured the adjacent collagen and proteoglycan within the nucleus for volume and pressure reduction. In the outer part of the channel there were viable cells. A total energy of 120 V is generated at the tip of the wand with a tip temperature of 50–70 °C. In this manner, a plasma field is created at the tip of highly energized particles resulting in molecular dissociation of the disc material directly in front of the tip. During the procedure, a channel is created from the posterolateral to the anterolateral annulus. On withdrawal, the coagulation mode is 60 V energy and a tip temperature of 70 °C. One millimeter from the catheter tip are 50 °C for coagulation and 40° for ablation. The nuclear tissue is ablated using bipolar radiofrequency energy with high voltage (100–300 V) and with a frequency of 120 KHz. This current creates a plasmatic field thickness of



Fig. 4.6 (a) PercDCWand™ (ArthroCare® Spine) inserted into 19 G needle. (b, c) Plasma field action created by PercDCWand™

approximately 75 μm , composed of ionized particles that have sufficient energy to break the organic molecular connections in the disk nucleus tissue and to vaporize thus this tissue.

Biochemical modification after the procedure has been found in the disc, with a reduction of interleukin-1 (associated with disc degeneration) and an increase of interleukin-8 (associated with tissue vascularization). Bipolar radiofrequency coagulation during withdrawal of the SpineWand™ denatured the adjacent collagen and proteoglycan within the nucleus for additional volume and pressure reduction.

On either side of the channel created, viable cells have been found on histologic studies, and any chance of structural damage to the endplates was minimal [26].

The procedure is performed under local anesthesia and/or endovenous sedation. Under fluoroscopic control, a 17-gauge needle is introduced into the disc through a posterolateral access. The needle is used as cannula for the Spine Wand™. For disc decompression, usually six channels are created at 2, 4, 6, 8, 10 and 12 o'clock, all extending in an anteromedial direction from the posterolateral annulus. The six channels decompress a cone-shaped area of nucleus. Potential complications include dysesthesia (worsening pain temporarily on the needle entry side in 10 %), nerve damage (rare), bleeding, and infection. Patients usually are discharged the same day of the procedure and allowed unlimited walking, standing, or sitting, but are not to perform any bending, lifting, or stooping. Return to work is allowed after 7 days, and usually physical therapy for lumbar stabilization is started 3 weeks after the procedure. To ensure a successful outcome, a proper preoperative evaluation combined with clinical history and imaging is mandatory. Physical examination has to show nerve root irritation with a positive straight leg raising, but a positive cross straight leg raising indicating an extruded disc or a non-contained disc herniation does not indicate coblation. MRI should demonstrate that the nuclear material is less than 50 % of the anteroposterior diameter of the thecal sac space and a narrowing of the disc does not exist.

Indications

- Patients age 20–55 years
- Prevalence of radicular pain on low back pain, nonresponding to at least 8 weeks conservative therapy
- Contained disc herniation on MRI and/or CT scan
- Disc height on lateral X-ray ≥ 75 %

Exclusion criteria included noncontained disc herniation, massive rupture of the annulus on MRI, disc height on lateral X-ray ≤ 50 %, and spinal canal stenosis. Excellent or good results are reported in about 70 % of cases [27]. However, in the most of cases the evaluation included only VAS (visual analogue scale), and it could be advisable to perform other investigations. From the above considerations, lumbar nucleoplasty becomes an alternative to conventional disc surgery. It is essential that the procedure is performed by experienced doctors with proper indications. In conclusion, there have been no major blood vessel injuries or permanent damage to the disc and supporting structures resulting in significant possible narrowing of the disc space or spinal instability following nucleoplasty.

Percutaneous Laser Discectomy

The word *laser* is an acronym for Light Amplification (by) Stimulated Emission (of) Radiation. In 1958, Schawlow and Townes published *Infrared and Optical Masers*, in the attempt to create a device for studying molecular structure, and extending their research from microwaves to infrared spectrum, they focused the

shorter wavelengths. In 1960, a patent was granted for the laser. The Stimulated Emission of Radiation can be obtained by external stimulation of gas (CO₂ – carbon dioxide laser, CO – carbon monoxide laser, excited dimer – employed in ophthalmology), of solid (Nd:YAG – neodymium:YAG laser, Ho:YAG – holmium:YAG laser, Er:YAG – erbium:YAG laser, KTP – titanium and potassium phosphate) or a semiconductor (diode laser). Each laser has a respective specific wavelength in the emission of the energy, depending on the stimulated medium (gas, solid, semiconductor). Since 1960, laser has been used in ophthalmology, urology, vascular surgery, plastic surgery, and neurosurgery. Because of the characteristics of laser energy – high intensity, monochromatic, coherence, focusing – the high-intensity energy can be concentrated in a tissue with minimal leakage. The interaction between laser and the biologic tissue is determined both from the physical property of laser energy, such as wavelength, the mode of energy emission (continuous or pulsed), the time of energy emission, power energy, and the physiologic characteristics of the tissue, such as absorption, dispersion, and energy conduction in the treated tissue. From the above considerations, using the same laser energy and depending on the parameters employed, several effects can be obtained in the treated tissue – coagulation, vaporization, and thermal ablation.

Asher [28] was among the first investigators to use the carbon dioxide (CO₂) and Nd:YAG – neodymium YAG laser in neurosurgery. He applied to lumbar discs, the laser experience in the treatment of the tumors in the brain with hemostasis and vaporization. Using different lasers (CO₂, Nd:YAG, KTP), a vaporization of the treated tissue was obtained, with a decompression of the herniated nucleus pulposus [29]. Absorption of nucleus pulposus is overlapping to avascularized biological tissues, with a peak absorption in the ultraviolet spectrum (wavelength 200–300 nm) and in the infrared (wavelength 750–10,000 nm). Peak absorption is the water absorption of the water contained in the intervertebral disc. Considering the above-mentioned evaluations, the most commonly used lasers for disc decompression and vaporization were Nd:YAG (neodymium:YAG) and Ho:YAG (holmium:YAG). The Nd:YAG laser wavelength is 1,064 nm, and by applying 1,000 J energy on the intervertebral disc, intradiscal pressure decreases by more than 50 % [30]. The Ho:YAG laser wavelength is 2,100 nm and the high water disc content peak absorption, increasing the temperatures in the adjacent tissues, needs to be applied under endoscopic irrigation control. The action of Ho:YAG laser in the disc is due to both vaporization and shrinkage (like a pneumatic mallet).

At the end of 1990, diode laser (wavelength 940–980 nm) was introduced in order to have the same Nd:YAG effects, but with improved handling and emission stability. Moreover, peak water disc content at 980 nm is five times more than at 1,064 nm (Nd:YAG laser wavelength), permitting application of energy with less dispersion on surrounding tissues and reducing the complication rate. The diode 980 nm laser contact fibers (400 μm) can be inserted into the disc through a 21-gauge needle (0.7 mm diameter) and the emission mode (pulsed) is able to concentrate linear energy on a few square millimeters with no damage to surrounding tissues. Percutaneous laser disc decompression and nucleotomy is based on a reduction of volume in a closed hydraulic space, resulting in a great drop in pressure. Because

Fig. 4.7 Diode laser 980 nm (Biolitec, Germany)



water is the major component of the intervertebral disc and in disc herniation pain is caused by the disc protrusion pressing against the nerve root, vaporizing and shrinking the nucleus pulposus leads to immediate decompression of the nerve root [31, 32]. Since its first application [33], several types of lasers (Nd:YAG 1,064 nm, 1,320 nm; KTP 532 nm; CO₂ 10.6 mm; Ho:YAG 2,100 nm; diode 940 nm, 810 nm) have been employed over the years.

We believe that 980 nm is the optimal wavelength for laser disc decompression and nucleotomy because 980 nm is ten times more absorbent than 810 nm and five times more absorbent than 1,064 nm, requiring less laser energy, which implies less heat diffusion in surrounding tissues. Moreover 980 nm is easier to handle (Fig. 4.7), permitting a better use in different surgical cases.

Percutaneous laser disc decompression and nucleotomy have been performed worldwide on more than 40,000 patients. The most commonly used lasers were KTP 532 nm, Ho:YAG 2,100 nm, and Nd: YAG 1,064 nm. Their combined success rate (excellent/good to fair) according to the Macnab and Oswestry score was more than 80 %, with a complication rate of less than 1.5 % [34–36]. In order to obtain a good result it is important not only to properly select patients but also to carefully choose the laser. We believe the diode 980 nm to be the best and most advanced laser in the treatment of disc herniation with optimal water absorption. Because 980 nm is ten times more absorbent than 810 nm and five times more absorbent than 1,064 nm, requiring less laser energy, it implies less heat diffusion in surrounding tissues and no undesirable side effects. A first introduction of diode 940 nm in disc herniation treatment was performed in 1998 by Hellinger [37] in a prospective randomized study versus Nd: YAG 1,064 nm. The overall success rate (90 %) confirmed the proper use of diode in order to decompress the nerve root in disc herniation. Nakai et al. [38] also confirmed, in an experimental study with a diode 810 nm, that diode is less aggressive in the surrounding tissue, preserving the end plate and the vertebral body from any damage. No secondary changes on the intervertebral disc and adjacent vertebral body after diode laser disc irradiation were

detected. Experimental studies performed both on human and specimen lumbar discs using the diode laser 980 nm showed an absorption of laser light of 90.27 % in the disc and a retraction of about 55 % on 2.7 mm of the tissue after laser treatment [39].

Indications

1. Radicular pain persisting more than 6 months (even associated with paresthesia and reduced muscular strength), resistant to conservative therapy (rest, anti-inflammatory medicine, physical therapy)
2. Contained disc herniation on CT-Scan or MRI
3. Disc height >30 %.

Absolute contraindications include noncontained disc herniation, sequestration, mild lumbar spinal stenosis, and periradicular scar following previous surgery.

The procedure is normally performed under local anesthesia and endovenous sedation. Under C-arm control or CT scan guidance, a 21 G needle (0.8 mm) is inserted into the disc and the disposable fiber optic (360 μ m) advances into the disc. Under CT scan guidance it is possible to visualize both the nerve root and the needle (Fig. 4.8). Few complications have been reported in literature:

- Problems following puncture of the disc: nerve root damage has been reported in 0.46 % [40], compared to nerve root damage following microdiscectomy – up to 8 %.
- Hematoma: after repeated puncture attempts, psoas hematoma has been recorded in 1.7 % [41] versus 1 % reported in open spinal surgery.
- Intraabdominal injuries: the incidence of abdominal injuries, including vessels and ureter, was 1 in 3,000 cases [42].
- Infections: an intradiscal abscess was observed after percutaneous laser disc decompression and nucleotomy [43] in more than 3,000 lumbar cases, corresponding to previous reported incidence [28, 44, 45].
- Neurological complications: in lumbar cases, four cases of deteriorations have been detected of preexisting footdrops and in six cases a temporary weakness of muscles was observed. Other authors [40] reported five nerve root injuries in more than 3,000 patients. In open procedures of lumbar spine, neurological complications have been reported at 2 % [46].
- Damage to endplates: as a result of heat damage, there have been described lesions to the endplates following the Nd:YAG laser [47, 48], but no instabilities were found [43, 44].

In conclusion, the introduction of nonendoscopic percutaneous laser disc decompression and nucleotomy with Nd:YAG laser and diode laser 940–980 nm [47] has brought the contained disc herniation treatment to a new level of quality. The published advantages of intradiscal laser treatment include percutaneous minimally invasive option, small caliber of instruments (less than 1 mm), documented reduction of intradiscal pressure, low rate of complications of less than 1 %, and no spinal instability.

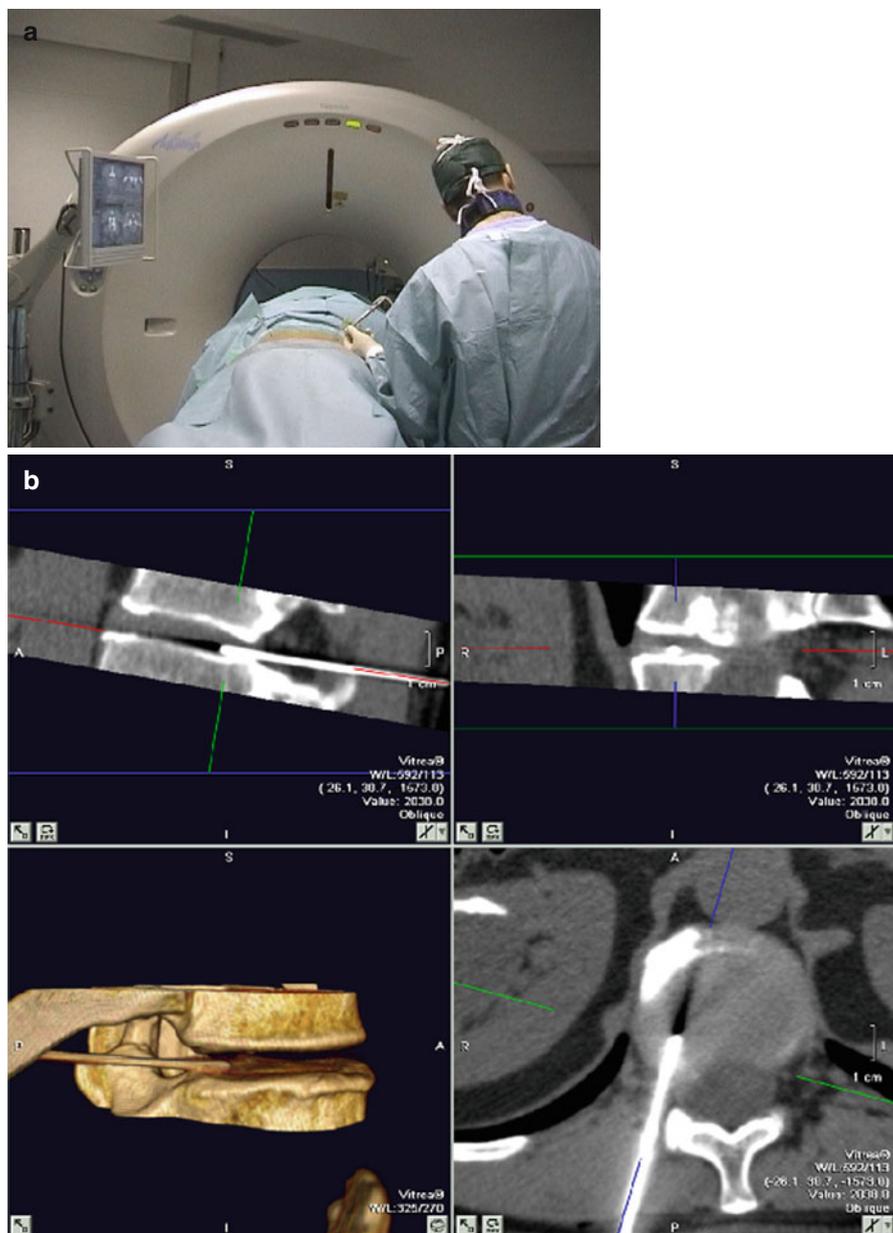


Fig. 4.8 (a, b) Percutaneous laser disc decompression and nucleotomy under CT scan guidance

Hydrodiscectomy

In 2003, a percutaneous procedure was developed using a high-speed water stream to remove herniated disc. This technique generates a power equivalent to energy procedures (radiofrequency, laser) without heating the surrounding tissues. The SpineJet® Hydrosurgery System (HydroCision, Inc., Billerica, MA, USA) (Fig. 4.9), using high-pressure fluidjet technology, has been adapted for percutaneous disc herniation removal. The SpineJet® System jets saline fluid with high velocity (900 km/h) to cut, ablate, and evacuate the disrupted disc materials safely, quickly, and efficiently. Using a cadaver model, it has been demonstrated that the SpineJet® XL (a similar disposable handpiece with SpineJet® MicroResector) removed nearly 96 % more nucleus pulposus from the posterior contralateral region compared to conventional instruments.

With local anesthesia, under fluoroscopic A-P and L-L control, a guide needle is inserted into the disc, then a dilator is inserted over the needle, and finally the introducer cannula is advanced over the dilator to the correct level. After the removal of the dilator and needle, the SpineJet Micro-Resector® is inserted through the access cannula to remove the protruded disc materials and decompress the nerve root. During the procedure the surgeon must constantly evaluate the exact position of each instrument under continuous fluoroscopic control, in order to avoid penetrating the ALL (anterior longitudinal ligament) and avoiding a dangerous bleeding. The procedure is indicated in contained disc herniation, with radicular pain more severe than low back pain, resisting to at least 6 months of conservative therapy, without spondilolysthesis and spinal stenosis. Preliminary results [49, 50] are interesting and it could be considered an alternative to percutaneous surgical techniques using energy, permitting avoidance of the potential complication resulting from heat damage to intradiscal structures and surrounding tissues.

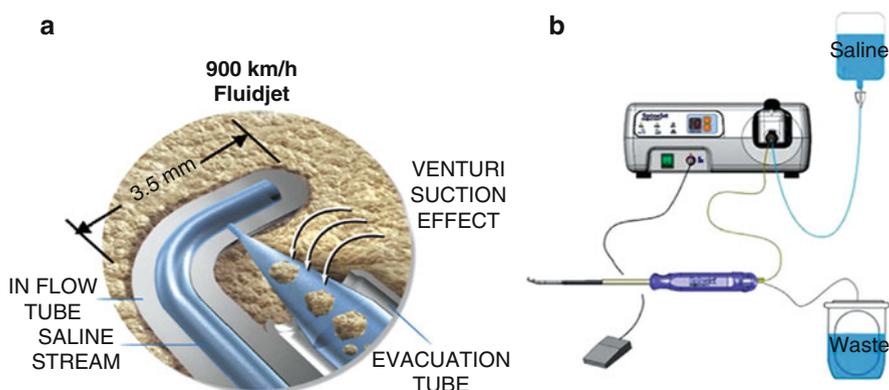


Fig. 4.9 The SpineJet® Hydrosurgery System (HydroCision, Inc.) (a) high velocity irrigation system and evacuation of disrupted disc (b) dedicated instrumentation for hydrodiscectomy

Conclusion

In conclusion, the history of minimalism in spinal medicine and surgery has moved forward in great leaps. In the last 30 years, magnetic resonance imaging has been able to investigate the spinal canal, opening the field to several advances in nonoperative pain management, including CT scan-guided treatments. Arthroscopic monitoring introduced by Kambin [20] advanced the percutaneous safety of minimally invasive surgery in disc herniation treatments. Ergonomics for spinal disorders, including restorative surgical care for intervertebral disc shock absorption, flexibility, and stability, permits management of the degenerative cascade in several steps, maintaining spinal segment motion and preserving the integrity of the vertebral joint.

Thus, today, minimally invasive spinal surgery often replaces open surgery. Procedures are safe, less traumatic, and well accepted by the patients because of day hospitalization, minimal blood loss, early mobilization, and fast recovery. Moreover, many elderly patients can be successfully treated avoiding general anesthesia and reducing postoperative complications related to surgical wounds, infection rate, and surgical pain. All the percutaneous procedures in disc herniation treatment and the relative results are strictly connected to the right indication. Only contained disc herniation without neurological deficits, resistant to at least 6 months of conservative therapy, should be managed and successfully treated.

Preserving spinal stability, tissue sparing, avoiding the spinal canal, and reducing bleeding, scar formation, and postoperative complications are the main benefits of the percutaneous treatments of disc herniation. In addition, the treatment does not preclude open surgery in case of failure.

References

1. Smith L. Enzyme dissolution of nucleus pulposus in humans. *JAMA*. 1964;18:137–43.
2. Williams RW. Microlumbar discectomy: a conservative surgical approach to the virgin herniated disc. *Spine*. 1978;3:175–82.
3. Hijikata S, et al. Percutaneous nucleotomy. A new treatment method for lumbar disc herniation. *J Toden Hosp*. 1975;5:5–13.
4. Onik G, Helms CA, Ginsburg L, et al. Percutaneous lumbar discectomy using a new aspiration probe. *Am J Neuroradiol*. 1985;6:290–6.
5. Friedman WA. Percutaneous discectomy. An alternative to chemonucleolysis. *J Neurosurg*. 1983;13:542–7.
6. Shepperd J, James S, Leach B. Percutaneous disc surgery. *Clin Orthop*. 1989;238:43–8.
7. Asher PW. Application of the laser in neurosurgery. *Lasers Surg Med*. 1986;2:91–7.
8. Yonezawa T. Percutaneous nucleotomy: an anatomic study of the risk of root injury. *Spine*. 1990;15:1175–85.
9. Troussier B. Percutaneous intradiscal radio-frequency thermocoagulation. *Spine*. 1995;20:1713–8.
10. Smith L. Chemonucleolysis. *Clin Orthop*. 1969;67:72–80.
11. Shah NH, Dastgir N, Gilmore MF. Medium to long-term functional outcome of patients after chemonucleolysis. *Acta Orthop Belg*. 2003;69(4):346–9.

12. Simmons JE, Nordby EJ, Hadjipavlou AG. Chemonucleolysis. The state of the art. *Eur Spine J*. 2001;10(3):192–202.
13. Onik G, Mooney V, Maroon JC, et al. Automated percutaneous discectomy: a prospective multi-institutional study. *Neurosurgery*. 1990;26:228–33.
14. Hijikata S, Yamagishi M, Nakayama T, et al. Percutaneous nucleotomy: a new treatment method for lumbar disc herniation. *J Toden Hosp*. 1975;5:39–42.
15. Dullerud R, et al. In: di Postacchini F, Percutaneous Treatments, Postacchini F, Mayer HM, editor. *Lumbar disc herniation*. New York: Springer Wien; 1999. p. 403–8.
16. Rezaian SM, Ghista DN. Percutaneous discectomy: technique, indications, and contraindications, 285 cases and results. *J Neurol Orthop Med Surg*. 1995;16:1–6.
17. Chatterjee S, Foy PM, Findlay GF. Report of a controlled clinical trial comparing automated percutaneous lumbar discectomy and microdiscectomy in the treatment of contained lumbar disc herniation. *Spine*. 1995;20(6):734–8.
18. Onik G, Mooney V, Helms C, et al. Automated percutaneous discectomy: a prospective multi-institutional study. *Neurosurgery*. 1990;28:226–32.
19. Hijikata S. Percutaneous nucleotomy. A new concept technique and 12 years' experience. *Clin Orthop Relat Res*. 1989;238:9–23.
20. Kambin PK. Posterolateral percutaneous lumbar discectomy and decompression: arthroscopic microdiscectomy. In: Kambin PK, editor. *Arthroscopic microdiscectomy: minimal intervention in spinal surgery*. Baltimore: Urban & Schwarzenberg; 1991. p. 67–100.
21. Yeung AT, Yeung CA. Advances in endoscopic disc and spine surgery: foraminal approach. *Surg Technol Int*. 2003;XI:253–61.
22. Mayer H, Brock M. Percutaneous endoscopic discectomy. Surgical technique and preliminary results compared to microsurgical discectomy. *J Neurosurg*. 1993;78:216–25.
23. Destandau J. A special device for endoscopic surgery of lumbar disc herniation. *Neurol Res*. 1999;21(1):39–42.
24. Saal JA, Saal JS. Intradiscal electrothermal treatment for chronic discogenic low back pain: a prospective outcome study with a minimum 2 year follow-up. *Spine*. 2002;27:966–74.
25. Bono CM, Iki K, Jalota A, et al. Temperatures within the lumbar disc and endplates during intradiscal electrothermal therapy: formulation of a predictive temperature map in relation to distance from the catheter. *Spine*. 2004;29:1124–31.
26. Singh V, Piryani C, Liao K, et al. Percutaneous disc decompression using coblation (nucleoplasty) in the treatment of chronic discogenic pain. *Pain Physician*. 2002;5:250–9.
27. Sharps L, Isaac Z. Percutaneous disc decompression using nucleoplasty. *Pain Physician*. 2002;5:121–6.
28. Asher PW. Perkutane Bandscheibengbehandlung mit verschiedenen Lasern. In: *Laser in medicine*. Heidelberg: Springer; 1995. p. 165–9.
29. Danaïla L, Pascu ML. Lasers in neurosurgery. Bucharest: Ed. Ac.Romane; 2001. p. 543–54.
30. Choy DSJ, Altman P. Fall of intradiscal pressure with laser ablation. *Spine*. 1993;7(1):23–9.
31. Case RBC, Choy DS, Altman P. Intervertebral disc pressure as a function of fluid volume infused. *J Clin Laser Med Surg*. 1985;13:143–7.
32. Choy DS, Asher PW, Ranu HS, Alkatis D, Leibler W, Altman P. Percutaneous laser disc decompression. A new therapeutic modality. *Spine*. 1993;18(7):939.
33. Asher PW. Application of the laser in neurosurgery. *Lasers Surg Med*. 1986;2:291–7.
34. Turgut A. Effect of Nd:YAG laser on experimental disc degeneration, part 2. Histological and MRI findings. *Acta Neurochir*. 1996;138:1355–61.
35. Tonami H, Yokota H, Nakagawa T, et al. Percutaneous laser discectomy: MRI findings within the first 24 hours after treatment and their relationship to clinical outcome. *Clin Radiol*. 1997;52(12):938–44.
36. Yonezawa T, Onomura T, et al. The system and procedures of percutaneous intradiscal laser nucleotomy. *Spine*. 1990;15(11):1175–85.
37. Hellinger J. Introduce of diode laser (940 nm) PLDN. *Mediziert* 2000;335–58

38. Nakai S, Naga K, Maehara K, Nishimoto S. Experimental study using diode laser in discs the healing processes in discs and adjacent vertebrae after laser irradiation. *Lasers Med Sci.* 2003;18–19.
39. Menchetti PPM, Longo L, Canero G, et al. Diode laser effect on intervertebral disc. *PL3D Rationale Laser Med Sci.* 2005;20:S17.
40. Mayer HM, Scheetlick G. Komplikationen der perkutanen Bandscheibenchirurgie. *Orthop Mitteilungen.* 1993;1:23–33.
41. Hilbert J, Braun A, Papp J, et al. Erfahrungen mit der perkutanen Laserdiskus-dekompression beim lumbalen Bandscheibenschaden. *Orthop. Praxis.* 1995;31:217–21.
42. Schwartz AM, Brodkey JS. Bowel perforation following microsurgical lumbar discectomy. *Spine.* 1989;4:104–6.
43. Hellinger J, Hellinger S. Complications of nonendoscopic percutaneous laser disc decompression and nucleotomy. *J Min Inv Spinal Tech.* 2002;2:66–9.
44. Siebert W. Percutaneous laser disc decompression: the European experience. *Spine.* 1993;7:103–33.
45. Choy DSJ. Percutaneous laser disc decompression (PLDD): 12 years' experience with 752 procedures in 518 patients. *J Clin Laser Med Surg.* 1998;16:325–31.
46. Messing-Jünger AM, Bock WJ. Lumbale Nerwenwurzel-kompression: Ein kooperatives Projekt zur Qualitätssicherung in der Neurochirurgie. *Zentralbl Neurochir.* 1995;56:19–26.
47. Simons P, Lensker E, von Wild K. Percutaneous nucleus pulposus denaturation in treatment of lumbar disc protrusion. *Eur Spine J.* 1994;3:219–21.
48. Grasshoff TH, Mahlfeld K, Kayser R. Komplikationen nach perkutanen Laser-Diskus Dekompression (PLDD) mit dem Nd:YAG Laser. *Lasermedizin.* 1998;14:3–7.
49. Wang W, Yu X, Cui J, Wu D, et al. The treatment of lumbar disc herniation through percutaneous hydrodiscectomy. *Chinese J Pain Med.* 2010;16(2)71–5.
50. Han HJ, Kim WK, Park CK, et al. Minimally invasive percutaneous hydrodiscectomy: preliminary report. *Kor J Spine.* 2009;6(3):187–91.