Minimally Invasive Treatment of Herniated Discs: How to Remove the Disc with Physical Tools

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10.1 Introduction

Radicular pain, which is usually caused by herniation of an intervertebral disc, is a common problem with an annual incidence of 5 per 1000 [1, 2]. Radiculopathy arises from direct neural compression by disc herniations and associated inflammatory and ischemic phenomena. Symptoms can also arise from a disc protrusion because of the effect on heavily innervated surrounding structures such as the outer annulus and posterior longitudinal ligament. The severity of symptoms does not always correlate with the extent of the herniation [3]. Sensitization of the central nervous system has also been suggested to be a possible causative factor of chronicity in some spinal pain conditions.

Patients suffering from radicular pain, in which spinal imaging shows a herniated disc compressing the nerve root involved in the radiculopathy, have historically been considered as possible candidates for open surgical discectomy, with the intent of providing decompression of the nerve root by removing the herniated disc. With surgical approaches, there is direct visualization of the herniated disc and removal of the portion of the disc compressing the adjacent nerve root. Numerous surgical

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treatments for discogenic pain have been developed, ranging from disc excision with laminectomy, microdiscectomy, spinal fusion to artificial disc replacement. Although open surgery is effective, it has well-known disadvantages, including epidural scarring, damage to bone, denervation of paraspinal muscles with consequent lumbar instability, long postoperative inactivity, and the not infrequent "failed back surgery syndrome." Patients with the latter are in fact often untreatable and severely disabled. Because of the considerable morbidity and convalescence period inherent to conventional lumbar disc surgery, there has been an ongoing search for less invasive methods of treatment. Lyman Smith opened the path in 1963, describing a minimally invasive attempt to treat sciatica through a percutaneous injection of chymopapain into the disc, with the intent of achieving enzymatic chemolysis of the nucleus pulposus and of its protruding fragments compressing the nerve root [4–6]. Since then, and from the 1970s onwards, multiple percutaneous minimally invasive interventional techniques to achieve disc decompression have been described, entailing both chemical and physical tools [7–13]. The latter will be discussed in this chapter.

Percutaneous discectomy techniques attempt nerve root decompression indirectly by decreasing the central disc pressure. The treatment principle of percutaneous disc decompression is based on the concept of the intervertebral disc being a closed hydraulic system. This system consists of the nucleus pulposus, containing a large amount of water, surrounded by the inelastic annulus fibrosus. An increase in water content of the nucleus pulposus leads to a disproportional increase of intradiscal pressure. On the other hand, a decrease of intradiscal volume causes a disproportionally large decrease in intradiscal pressure [14, 15]. Central decompression is achieved by the removal of material from the nucleus pulposus. The most often stated goal of central nuclear decompression is to lower the pressure in the nucleus and to allow room for the herniated fragment to recede inward. The theory postulates that intact outer annular fibers will be able to contract enough to reduce the tension on both the nerve root and annulus. Additional suggested effects of central decompression include denaturation and fibrotic changes in the nucleus pulposus, which should in turn limit the ability of the nuclear matrix to attract water, thereby causing a long-lasting pressure reduction [16], and reinforce the inner annular fibers, reducing the tendency of the central components of the disc to herniate toward the spinal canal [17]. The goal is to allow sufficient tissue removal while minimizing collateral tissue damage and avoiding destabilization of the discovertebral unit. The benefits of percutaneous discectomy are greater than just avoidance of open surgery. Small contained disc protrusions have been shown to be less likely than larger disc extrusions to undergo spontaneous resorption [18] and are associated with worse surgical outcomes following discectomy [19]. Fortunately, this is the subtype of herniation most responsive to percutaneous techniques. Finally, percutaneous disc procedures have the advantage of a high patient psychological acceptance, tolerance, and satisfaction.

10.2 Indications

Percutaneous decompression has been shown effective in relieving radicular pain and to a lesser extent axial pain from contained disc protrusions. Patient selection criteria include the presence of a contained disc herniation documented by spinal imaging, causing radicular pain greater than axial pain, for 6 months or longer, and the patient having failed conservative measures, including anti-inflammatory and analgesic medications and physical therapy. Imaging and clinical correlation is of utmost importance. In doubtful cases, diagnostic selective nerve root blocks, facet blocks, and provocative discography might help target the correct pain generator. The success of the procedure depends greatly on selecting the lesions to treat (Fig. 10.1); the protruding nucleus pulposus must be at least partially contained by the external fibers of the disc, without a large extrusion or migrated fragments [20, 21]. The herniation should not be pinched off by the endplates and should be without significant prolapse above or below the disc level. The disc should have maintained at least 50% of its height on imaging studies. The discs with more advanced degrees of degeneration are more difficult to access and are less likely to achieve much further pressure reduction [22]. Contained disc herniations are often circumferential bulges or protrusions, which appear broad on axial MRI or computed tomography (CT) [21–24]. Because MRI and CT do not usually enable distinction of a contained from an uncontained prolapse, in doubtful cases, discography or CT discography may help in assessing annular tears and extruded lesions, revealed by epidural spread of contrast injected in the nucleus pulposus (Fig. 10.1). CT discography may also show the size of the "neck" connecting the protruded part of the disc with the central nucleus pulposus: the wider the connection, the more likely efficient transmission of pressure toward the center of the disc, and the more likely the clinical success of the procedure [24–26].

Purely, clinical criteria are also very important. Patients with a contained herniation, a good indication for percutaneous treatment, typically have a relatively long history (6 months or more) of back and/or leg pain of variable intensity, more intense under loading of the lumbar spine and particularly in a sitting position (typically, driving a car). The pain is not disabling, but becomes more and more incompatible with a good quality of life, in part because of a progressive reduction in the psychological threshold of pain tolerance. It is probable that these features correlate with a contained disc lesion, and root compression becomes evident only when a static or dynamic load on the spine provokes outward transmission of pressure from the center of the disc through rents in the inner fibers of the annulus, with secondary increase in the external diameter of the disc. The pressure within the disc and its volume decrease with rest, owing to integrity of the outer annular fibers and ligaments. Uncontained extrusions of the nucleus pulposus or sequestrated fragments, which are not a good indication for disc decompression, cause sustained, firmer compression of the nerve root (probably along with inflammatory phenomena

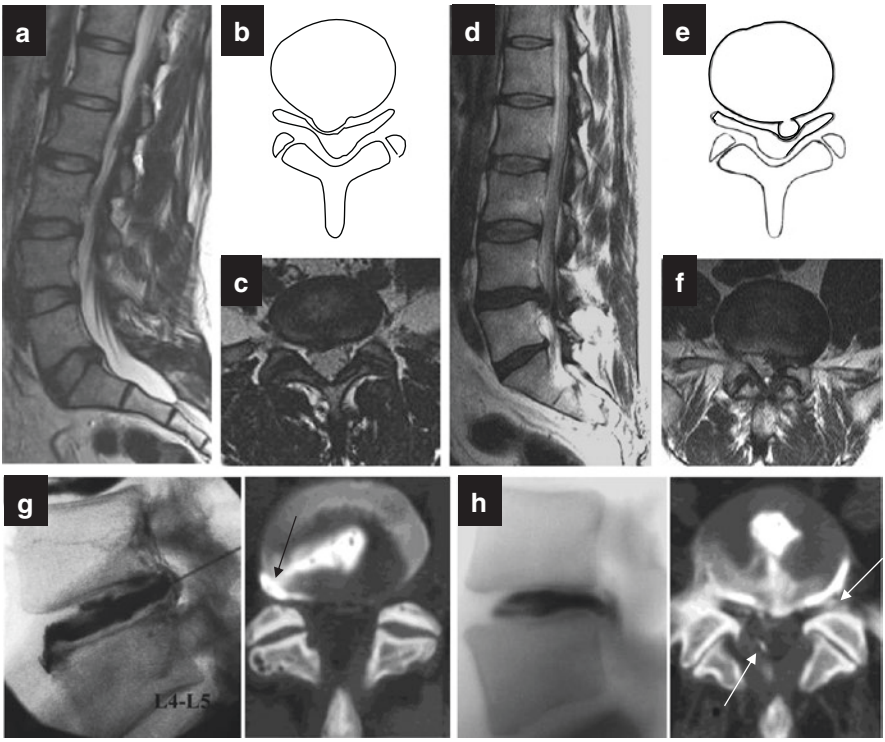

Fig. 10.1 Contained and extruded disc herniations. (**a**–**c**) Show the MR appearance and the schematic drawing of a contained disc herniation; note the broad base on axial and sagittal plane, the disc-endplates do not "pinch off" the herniation, and the disc height is preserved; in the appropriate clinical setting this might represent a good indication for disc decompression. (**d**–**f**) Show the non-contained counterpart of disc herniation, with long sagittal dimension, and "pinched-off" aspect, that, based on morphological characteristics, is not likely to respond to a procedure of disc decompression. (**g**) Shows the discography and CT discography features of a contained disc herniation (arrow), with contrast contained by the external fibers of the annulus, while (**h**) shows a non-contained disc herniation, as revealed by epidural spread of contrast injected in the nucleus pulposus (arrows). CT discography is the most accurate imaging technique to differentiate between contained and non-contained disc herniations

primed by the presence of nucleus pulposus, recognized as a foreign body, in the epidural space) and therefore more constant, intense, and often disabling pain. These clinical landmarks, when they last for at least 6–8 weeks, justify open surgery as the treatment of choice.

Contraindications include sequestered herniation, herniation greater than one-third of the sagittal diameter of the spinal canal, progressive neurologic deficit, infection, bony deformity not allowing a safe percutaneous image-guided disc access, or other bone lesions which could compress a root and cause radicular symptoms [27]. Applying strict selection criteria, Onik estimated that only 5–10% of the patients with disc herniation who eventually undergo surgery would be

eligible for percutaneous disc decompression [28]. Given its low morbidity, however, disclosing the lesser likelihood of clinical success of the procedure, the minimally invasive therapeutic option can be ethically offered to a wider range of patients, such as the ones with partially uncontained prolapses, as an attempt to avoid surgery, or when the risks of open surgery are higher because of age, general medical conditions, or other contraindications [28]. This typically applies to patients who have already undergone open surgery at the same level because of the possibility of symptomatic epidural scar and to elderly people. In fact, an observational study on a large cohort of patients reports these subgroups of patients as good responders to automated disc decompression (APLD) [17]. Although the satisfactory outcome can be attributed to several factors, the one that supersedes all is that in these patients, with a nerve root confined and compressed in a small space, either due to epidural fibrosis or arthropathic degenerative bone changes, even a small reduction in the volume of the disc by disc decompression might result in radicular decompression and clinical improvement.

10.3 Techniques of Percutaneous Disc Access

The procedure can be performed with the patient in either the prone or lateral decubitus position. When the prone position is used, bolsters are placed underneath the patient's abdomen to flatten the lordosis and open the disc spaces posteriorly (Fig. 10.2). This will allow easier disc access and better transmission of the pressure drop caused in the center of the disc by the decompression procedure to the

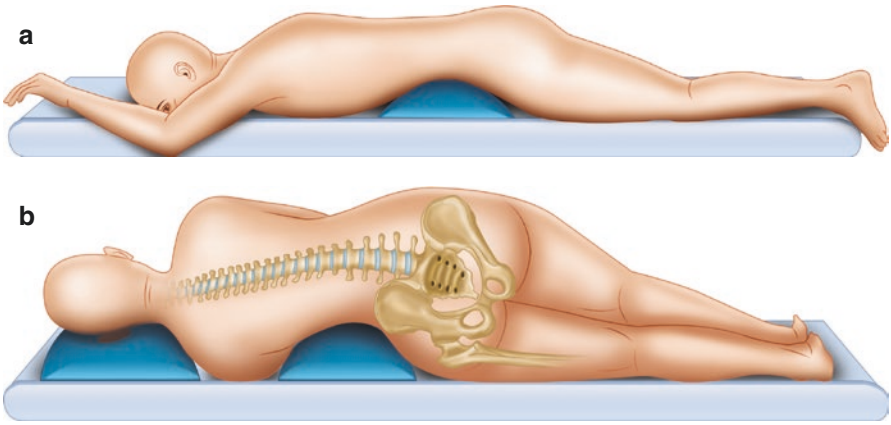

Fig. 10.2 Patient positioning for lumbar discectomy. (**a**) Shows the use of a bolster to be placed under the lower abdomen when the patient is in prone decubitus, to flatten the lumbar lordosis, and to open the disc space posteriorly for an easier access and better transmission of the pressure drop to the herniated disc component. Similarly, the patient is flexed when in the lateral decubitus position, by positioning a bolster under the recumbent side (**b**), approximately at the level of the disc to be treated, with the intent of opening the disc space on the entry side, and of tilting away the iliac crest for access to the L5–S1 disc

herniated disc component. For the same reason, the patient is flexed when in the lateral decubitus position, by positioning a bolster under the recumbent side, approximately at the level of the disc to be treated (Fig. 10.2). The entry route is posterolateral. Correct positioning of the guiding needle in the disc is the most delicate part of the procedure and is crucial to the result. The procedure is monitored fluoroscopically. If, while approaching the disc, a radicular paresthesia or a true radicular pain is elicited, the needle needs to be retracted and redirected. If the nerve root is touched, the patient experiences radicular symptoms, usually a sensation described as a sudden "electrical shock" which may radiate as distal as the foot, depending on the root that has been abutted. In contrast, the pain originating directly from the nociceptive fibers of the external annulus is less intense and does not typically refers below the knee.

10.3.1 Oblique View for Disc Access

The most reliable, standardized, and safe technique to perform percutaneous fluoroscopy guided lumbar disc access implies the use of the so-called tunnel vision view. According to this technique, the fluoroscopy tube is angled along the projected path of the needle from the skin to the desired final position of the needle tip within the disc, with an oblique posterolateral paravertebral approach. To identify the correct angle and obliquity of the access, from a true AP view of the disc space of interest, the tube is angled obliquely, toward the side of the preferred approach, under continuous fluoroscopic view, until the anatomical landmark of the "Scottie dog" appears, with its ear (the superior articular process of the vertebra below) superimposed on the disc space. The target point is in the middle of the disc space, as seen on this oblique projection, just lateral and anterior to the superior articular process. The position of the superior articular process along the disc endplate line is the determinant of the obliquity of the disc access and eventually of the position of the needle's tip in the disc space. A degree of obliquity such as the anterior profile of the ear of the Scottie dog bisects the endplate line ensures a final position of the needle's tip in the exact center of the disc. A more external position of the Scottie dog's ear predicts a more peripheral and ipsilateral final position of the needle's tip, along with a higher chance to hit the exiting nerve root, while a more medial position of the ear of the Scottie dog along the disc endplate line allows a more posterior final position of the needle's tip within the disc, but increases the risk of straying in the epidural space and potentially entering the dural sac (Fig. 10.3). For a routine intradiscal decompression, the needle must be placed with its tip in the AP midline, at the junction of the middle and posterior thirds of the disc, where the normal nucleus pulposus lies. In cases of large, posterior protrusions indenting the spinal canal, it is preferable to aim for a more posterior position of the needle; therefore, a more oblique view, with the ear of the Scottie dog located toward the medial end of the disc endplate line, is chosen. Eventually, the degree of obliquity and the

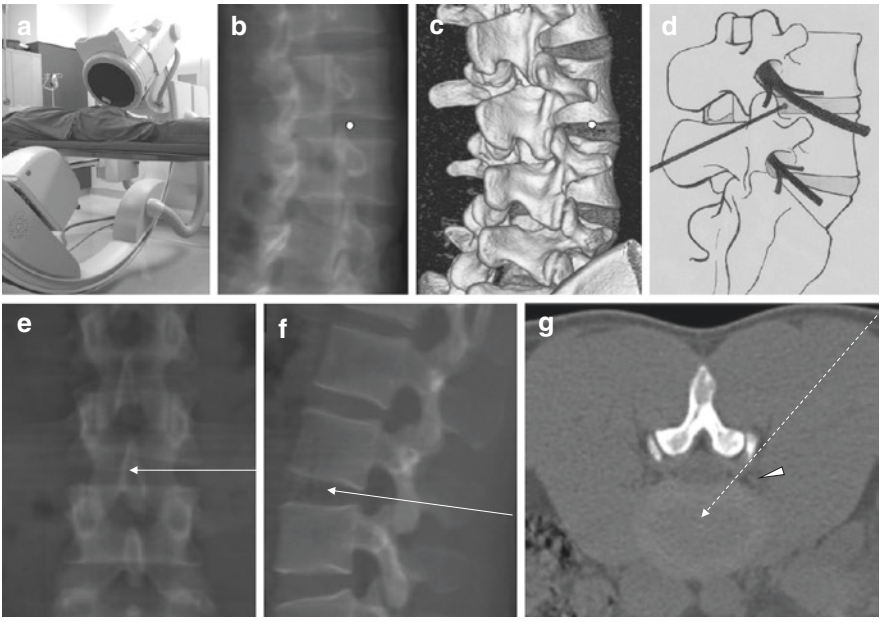

Fig. 10.3 Fluoroscopy and CT correlates of disc access anatomy. (**a**) shows the fluoroscopic tube angle to obtain a correct "tunnel vision" for a right posterolateral percutaneous access to the disc L3–L4 (**b**), as also shown on the correspondent 3D volume rendering CT model (**c**). The cranio-caudal angle of the tube is such that the disc space is well profiled at the level of interest, and the right-to-left (RL) obliquity is such that the superior articular process (ear of the Scottie dog) of L4 is superimposed on the midpoint of the disc-endplate line. This ensures an access window for the needle (white dot on **b** and **c**) posterior, inferior, and medial to the exiting nerve root (**d**). (**e**, **f**) show the final location of the needle (arrow) in the center of the nucleus pulposus on the AP and LL views. (**g**) shows the axial CT section through the disc space and the ideal needle path (dashed arrow); note that steep obliquity, tangent to the superior articular process of the facet, is necessary to have a correct access to the disc and to avoid the exiting nerve root (arrowhead)

trajectory of the needle as tangent as possible to the ear of the Scottie dog determine the safety of this trajectory in avoiding the exiting nerve root, usually located superior and anterior to the needle's entry point in the annulus. Once the specific oblique projection has been identified, the entry point of the needle in the skin projects over the target, and the needle is inserted accordingly to the tube angle, and along its whole path, from the skin to the target and it will appear as a single radiopaque dot superimposed to the target. Of course, as always in radiology, the position of an object must be confirmed in two orthogonal projections; in this case, the depth of the needle tip and its final correct position on the target must be controlled intermittently, and finally confirmed, by the two strict AP and LL views. Adherence to this, methodology guarantees the safest and most reproducible needle approach to the disc.

10.3.2 L5–S1 Disc Access: Special Considerations

The anatomy, and consequently the fluoroscopic views, is different at the L5–S1 level because of the prominent lordosis and the presence of the iliac crest. The presence of the iliac crests often obstructs the desired posteriolateral oblique trajectory of the needle into the disc space. Performing the procedure with the patient lying in the lateral decubitus position increases the probability of correctly entering the L5–S1 disc. A soft silicone gel cushion or other similar prop wedged just superior to the iliac crest will laterally flex and lower the iliac crest on the entry side, thus opening a trajectory to access the L5–S1 disc (Fig. 10.2). When moving the C-arm to the oblique orientation, as mentioned above, the L5–S1 facet joint moves across the disc space and the iliac crest starts to overlap the disc. When the beam is at approximately a 45° angle, the superior articular process of S1 is seen bisecting the S1 endplate, and a triangular window at the center of the disc space is seen (Fig. 10.4). This triangle is bounded laterally by the iliac crest, medially by the anterior surface of the superior articular process of S1, and superiorly by the inferior endplate of the L5 vertebra. The center of the triangle, superimposed on the disc space, is our target.

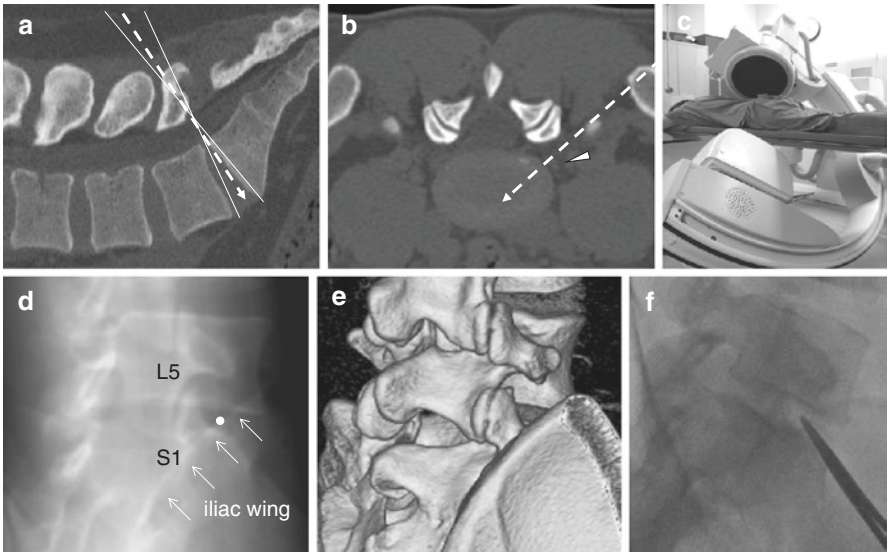

Fig. 10.4 L5–S1 disc access. (**a**) Shows how the lordotic curvature causes the disc-endplates not to be parallel mainly at L5–S1, and in some patients also at L4–L5. The most appropriate craniocaudal obliquity of the fluoroscopy tube to access these discs (dashed arrow) is, therefore, in between the angles necessary to profile the superior and the inferior disc-endplates (dotted lines). (**b**) shows the CT axial section through the L5–S1 disc; note that the RL obliquity of the disc access (dashed arrow) is limited by the iliac crest and by the superior articular facet, whereas the needle trajectory needs to avoid the nerve root (arrowhead). (**c**–**f**) show the fluoroscopic access to the L5–S1 disc, with the 3D-CT correlate. The angle of the tube can be extreme, in the CC and RL direction. The target (dot on **d**) is the center of the clear triangle formed by the superior margin of iliac wing, the lateral margin of the S1 articular process, and the L5 inferior endplate

Not uncommonly, high iliac crests cover the lateral oblique approach to the disc space, and the triangular window is visible only when the superior articular process of S1 is projected on the lateral third of the S1 endplate; any further obliquity of the X-ray beam brings the iliac crest to obstruct the path from the desired skin entry point to the disc space. Consequently, the entry route has to be less oblique (which means that the entry point in the skin is closer to the midline of the spine, for the needle to pass medially to the iliac crest) or must originate from a more cephalad starting point. With both approaches (more medial and more cephalad), there are instances in which straight instrumentation will not enter the disc correctly. If the trajectory of the needle is not obliquely angled enough, as discussed previously, it might be impossible to position the needle's tip in the desired position in the center of the nucleus pulposus, as it will tend to be too lateral and anterior in the disc. If the trajectory comes from a more cephalad entry point, the needle might still enter the disc, but will not be parallel to the disc endplates, and therefore, it will not advance in the disc space to the center of the nucleus pulposus. If the correct intradiscal position cannot be achieved with a straight cannula, a curved needle can be used. Although some operators might use a curved cannula as the introducing needle alone, this technique is very dependent on personal skills and expertise and might require several attempts to achieve the proper trajectory (Fig. 10.5).

10.3.3 Transdural Posterior Approach

If desired, using an appropriately small caliber needle (21–22 G) and CT guidance, the disc space can be accessed from a posterior transdural approach at the lower lumbar levels, below the position of the conus medullaris. This access is feasible with straight needles when local anatomy permits an axial oblique plane parallel to the disc space passing through the interlaminar space. At certain levels, and in

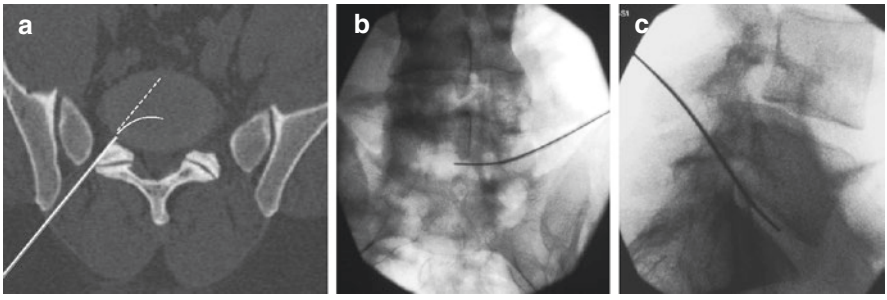

Fig. 10.5 Coaxial curved needle access to the L5–S1 disc. In certain patients, the degree of lateral obliquity of the access to the L5–S1 disc is limited by the iliac crest, as shown by an oblique axial CT view through the disc space (**a**). In such cases, it is possible to reach the center of the nucleus pulposus using a coaxial system; a straight cannula is brought to the annulus, and exchanged with a K-wire; then a curved tip cannula is brought to the annulus along the K-wire; the K-wire is retracted, and the curved tip of the cannula is deployed, advanced, and directed to the center of the nucleus pulposus, as shown on **b**, **c**

certain patients, the oblique plane passing through the disc space corresponds posteriorly to the bony laminae, which would clearly obstruct the needle path. The path of the needle is just lateral to midline where the spinous process is, entering the central canal through the ligamentum flavum, piercing the dura along the posterior and anterior aspect of the dural sac, and thereby entering the disc from the posterior longitudinal ligament. The nerve roots of the cauda equina easily allow this needle access, when performed gently. Although this is a potentially easy and effective access to the center of the nucleus pulposus in selected instances, it carries additional risks of cerebrospinal fluid leak and headache, cerebrospinal fluid infection, and epidural hematoma.

10.3.4 Approach to Cervical Discs

The procedure is performed under fluoroscopy using a C-arm unit, with the patient placed in supine position, and using an anterior approach. The procedure is usually conducted under general anesthesia, although it is also doable under local anesthesia with sedation as necessary, particularly in fragile patients. The head and neck are slightly hyperextended to facilitate access to the cervical discs. For better visualization of the lower cervical discs, it is beneficial to stabilize the shoulders. In these cases, traction is achieved by tying a belt to the patient's wrists, and the belt is fixed to the foot of the table and pulled, if necessary, during the procedure to uncover the lower discs from the shoulders. The entry point for the port cannula is placed off-midline toward the patient's right side in order to make an anterolateral approach. Local anesthetic is administered using a 22-G needle and inserted as deep as the annulus fibrosus; the anesthesia needle is positioned using an extended holder to reduce x-ray exposure to the surgeon's hands (Fig. 10.6). While palpating vital structures away from the surgical pathway (the trachea is pushed across the midline, while the neurovascular bundle, the carotid artery in particular, and sternocleidomastoid muscle are maneuvered laterally and protected manually) (Fig. 10.7), a 18- or 19-G needle is positioned against the anterior surface of the annulus fibrosus. Because the esophagus resides to the left of the midline, a relatively more right-sided approach is deemed safer at the more caudal cervical levels. The C-arm is positioned to gain a lateral view of the surgical field and the needle advanced under fluoroscopic guidance into the disc. The mandrel is withdrawn and the needle is replaced, by means of a guide wire of proper size, by the cannula needed to introduce into the nucleus pulposus the desired device for disc decompression. At the end of the procedure, the cannula is removed and manual compression is applied for a few minutes on the surgical site to favor hemostasis. Alternatively, the surgeon could choose to position the cannula under CT guidance and switch to direct fluoroscopy for the remainder of the procedure. The use of CT allows a better control of the position of the decompressive device, particularly when it must be positioned inside the spinal canal or foramen for treatment of larger herniations (Figs. 10.8 and 10.9).

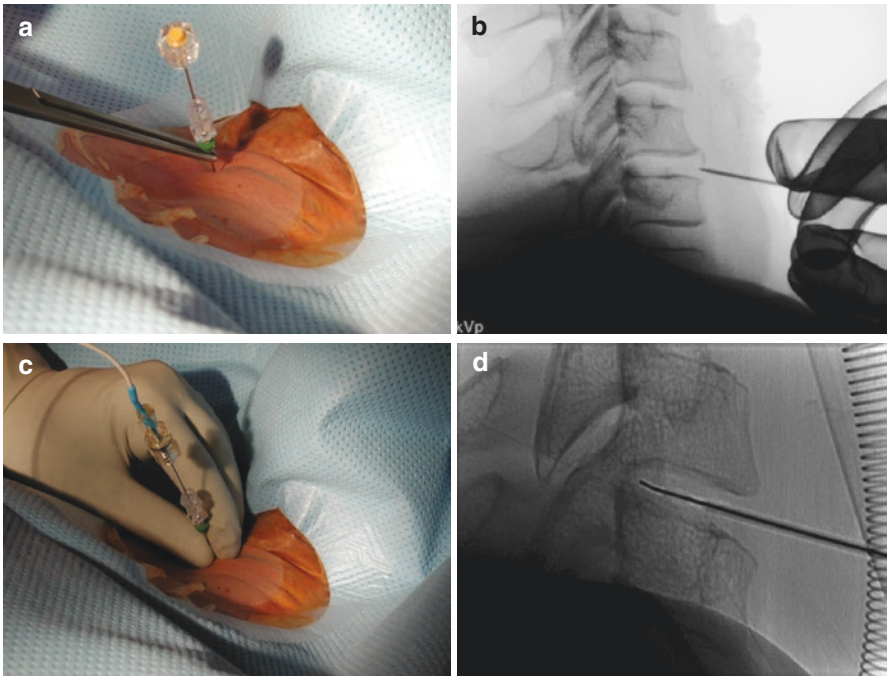

Fig. 10.6 (**a**) The 19-G cannula with an internal mandrel is positioned against the anterior surface of the annulus fibrosus. The cannula is held by surgical forceps to minimize X-ray exposure of the surgeon's hand. (**b**) Cannula placement as observed under fluoroscopy. (**c**, **d**) The cannula is advanced into the disk, and the coblation probe is introduced into the nucleus pulposus via the cannula

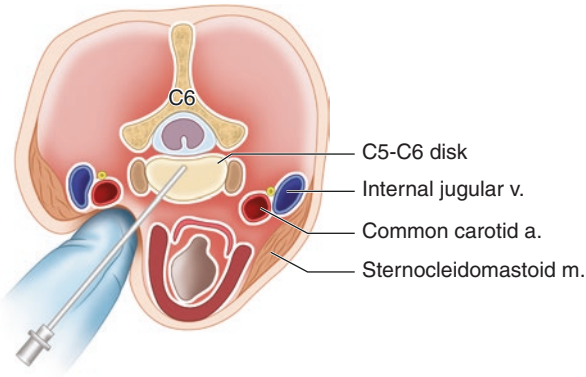

Fig. 10.7 A schematic drawing shows the entry route, with the clinician's fingers pushing the trachea across the midline while protecting the neurovascular bundle

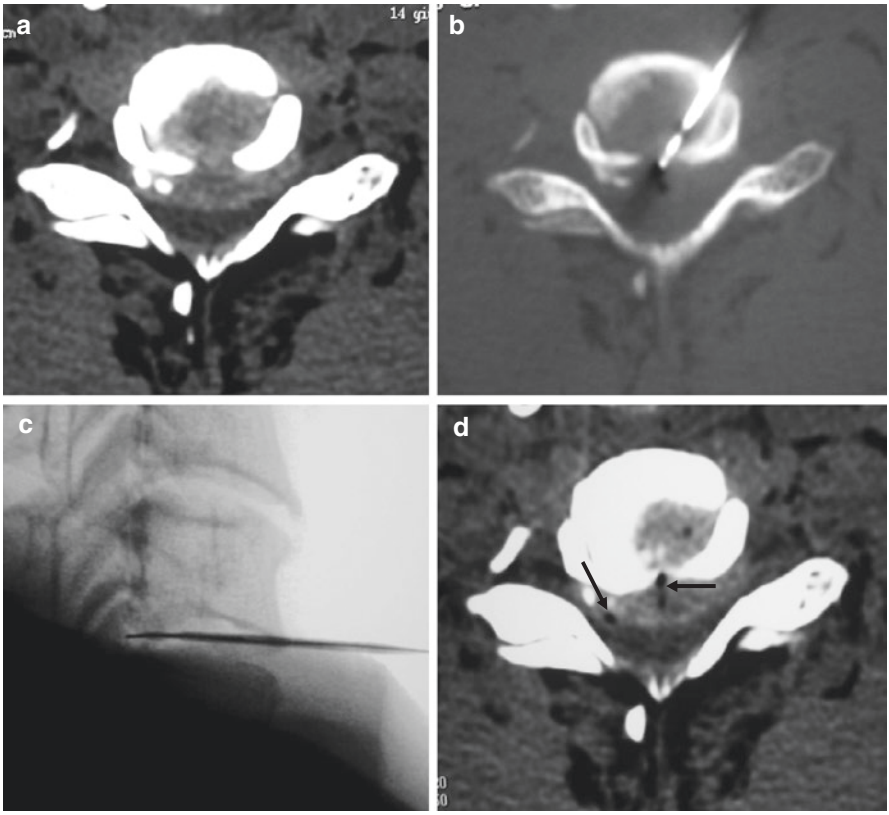

Fig. 10.8 (**a**) Bilateral disk herniation at C6–C7 encroaching the spinal canal. The intervention was conducted under CT guidance for positioning the coblation bipolar probe, switching to direct fluoroscopy during the ablation procedure. This allows activation of the plasma-field energy directly inside the herniation. (**b**, **c**) The active electrode is beyond the posterior limit of the vertebral body, inside the spinal canal. In (**d**) the trajectory of the device and gas from tissue excision (arrows)

10.4 Techniques for Disc Removal with Physical Tools

10.4.1 Mechanical

In 1975, Hijikata [29], in Japan, published his results with a series of patients who underwent lumbar discectomy performed percutaneously. He used specially designed instruments placed through a 5-mm cannula inserted through the lateral annulus. A circular incision was made in the annulus, and the herniated disc material was grasped with modified pituitary-type rongeurs. In his initial published findings, Hijikata reported that approximately 80% of his patients experienced improvement after this procedure. Variations on this method have been subsequently popularized by Kambin [30, 31] in Philadelphia and Suezawa [32] in Switzerland. Using Craig-type biopsy instruments under fluoroscopic control, Kambin inserted a large trocar through the lateral annulus fibrosus, grasped the herniated disc, and removed it. He reported excellent results with no significant complications in 85%

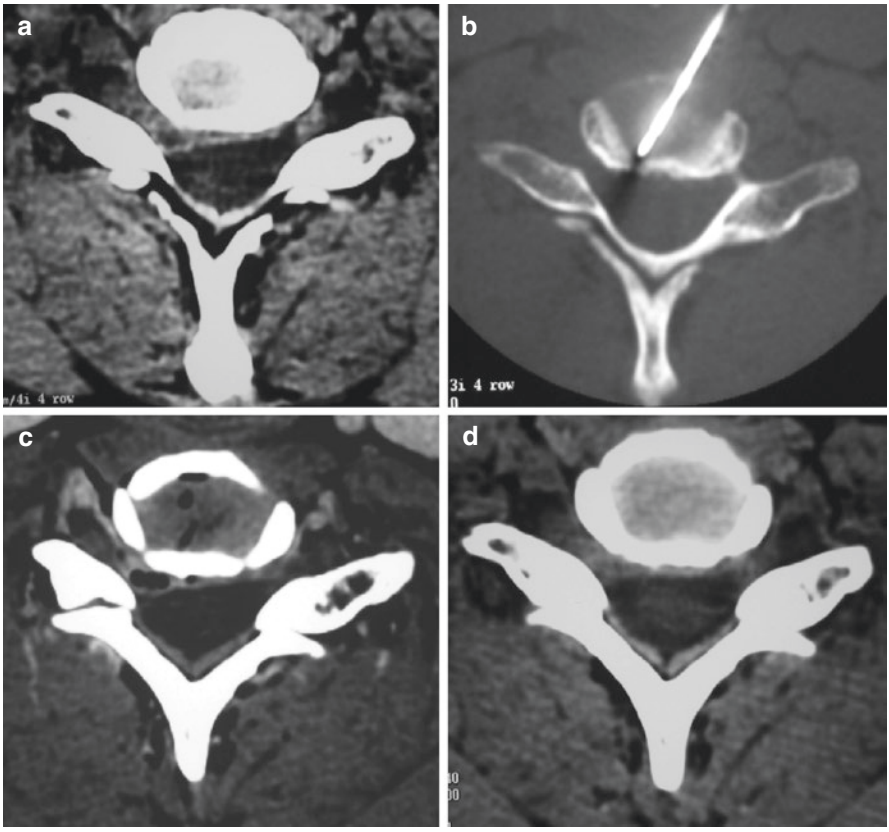

Fig. 10.9 (**a**) Lateral disk herniation compressing the nerve root. (**b**) The cannula and coblation probe are positioned under CT guidance and then safely and precisely directed toward the herniation. (**c**) Note gas from tissue ablation diffusing inside the herniation itself. (**d**) A 4-month CT follow-up shows partial regression of the lesion; the patient reports a definite clinical improvement

of 50 patients. Suezawa used the instruments designed by Hijikata and in addition he inserted a discoscope through a contralateral approach. This was essentially a fiberoptic system used to visualize the disc material being removed. Excellent results were reported in 67% of 47 patients, although the majority of these patients showed complicating factors, such as spinal stenosis.

In another development, Jacobson [33], a neurosurgeon in Miami, designed his own instruments and used a direct lateral approach to remove herniated discs percutaneously in more than 300 patients. With the patient under general anesthesia, a 10- to 11-mm cannula was introduced through the lateral annulus. Using his own patented instruments, Jacobson grasped and removed disc material with overall good results in terms of pain relief. Unfortunately, unacceptable injury of bowel and peripheral nerves occurred. Friedman [8] studied Jacobson's technique in cadavers and demonstrated that the anatomical variations were such, that an unacceptably high rate of morbidity and potential mortality could be expected with this technique. Friedman therefore recommended against its use.

After surveying the previous techniques and assessing their potential problems, Gary Onik working with engineers from Surgical Dynamics, Inc., designed his own instruments for lumbar discectomy in 1984 and introduced it in clinical practice in 1985 [34–37]. The technique was called "automated" percutaneous lumbar discectomy because it involves a mechanical probe, the Nucleotome, which removes the nucleus pulposus by a "suction and cutting" action (Fig. 10.10). The device is now manufactured by Clarus Medical, LLC. The probe tip, excluding the handle, is 20.2 cm long and has an outer diameter of 2.2 mm. The negative pressure for aspiration is generated by the vacuum-generating console. A vacuum is created that draws nuclear material into the side port, which is located a few millimeters proximal to the distal tip of the probe. The cutting blade for fragmentation of nucleus pulposus aspirated through the port works with a reciprocal, not rotatory motion. This type of movement is a safety feature because the "guillotine" blade is contained within the

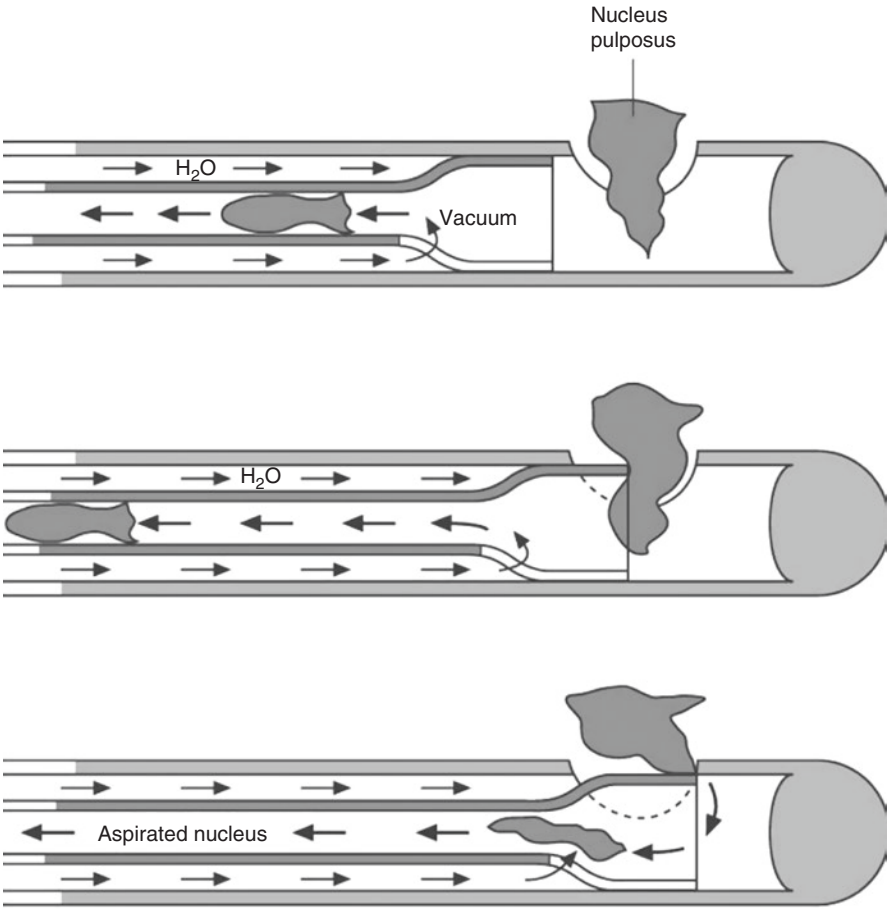

Fig. 10.10 Onik's nucleotome mechanical aspiration probe, with its blunt, rounded tip. Internal irrigation and cutting functions are incorporated. The aspirated nucleus pulposus enters the side port and is resected by a pneumatically driven "guillotine blade," which has a reciprocal not rotary movement

probe. Consequently, only the nuclear material that is drawn into the port can be cut. The material aspirated from the inner disc and exiting through the metallic probe is ultimately deposited into a filter in a disposable collection bottle. The extracted nucleus pulposus is thus available for quantitative and macroscopic qualitative evaluation, or even for histology examination. A sequence of devices is used for introduction of the probe inside the disc, the last one being a cannula, straight with an outer diameter of 2.8 mm, or a curved one, with an outer diameter of 3.8 mm, better suited for access to the L5–S1 disc space, when the direct path from the skin is covered by the iliac crest. The reason for a larger diameter in the latter is that it is internally coated by a Teflon layer, which reduces friction and favors the sliding of the flexible but straight probe. APLD as proposed by Onik has lost the favor of most operators and discussion of the reasons of that falls beyond the limits of this chapter. One of the authors (GB) of this chapter has developed a large experience with very good results, depending on a strict and wise selection of patients, and still uses it in few, very selected cases [17]. In any case, Onik's remains the percutaneous procedure that removes the largest amounts of nuclear material from within the intervertebral disc. Another advantage, when comparing APLD with physical techniques that blindly destroy the disc (such as laser, RF or coblation), is that the surgeon can verify directly and visually the quantity of disc material removed, as well as its "quality." The extracted nucleus pulposus can be observed as it passes through the transparent tubing that connects to the filter. How much nucleus is taken out and how degenerated it is, are important procedural and prognostic pieces of information. For example, viewing the quantity of removed nuclear tissue and comparing it with the amount that was anticipated to be extracted from interpreting the preoperative imaging provide critical information to determine whether the probe worked in the correct intranuclear location. Observing blood coming from the disc could suggest the presence of unexpected degeneration, or of painful granulation tissue inside the disc, or prompt arrest of the procedure so as not to damage the endplate cartilage. Another important safety feature is that, once the Nucleotome is safely within the disc, it is unable, unlike other devices, to cut its way out of the disc space to cause injury to vital structures.

The notion that Onik's proposal was meritorious is suggested by the recent resurgence of new devices designed to mechanically remove the nucleus pulposus in an "automated" mode by aspiration. Observational studies are available, together with four RCTs [38–41]. In a review published in 2009, the level of evidence for clinical effectiveness of APLD, as determined based on the US Preventive Services Task Force (USPSTF) criteria [42], using five levels, ranging from I to III with three subcategories in level II, is level II-2 for short- and long-term relief [43]. This review was updated in 2013 [44], and the indicated evidence was considered limited for short- and long-term relief. However, APLD does not appear to compare favorably against chymopapain injection and open discectomy [39, 41].

A similar hydraulic aspiration principle is utilized by the SpineJet probe, produced by HydroCision. The disposable SpineJet probe simultaneously cuts and aspirates nucleus; a round atraumatic tip design reduces risks of annular puncture and endplate damage. The SpineJet HydroSurgery system utilizes a reusable power console with foot pedal activation (Fig. 10.11). Both the Nucleotome and the

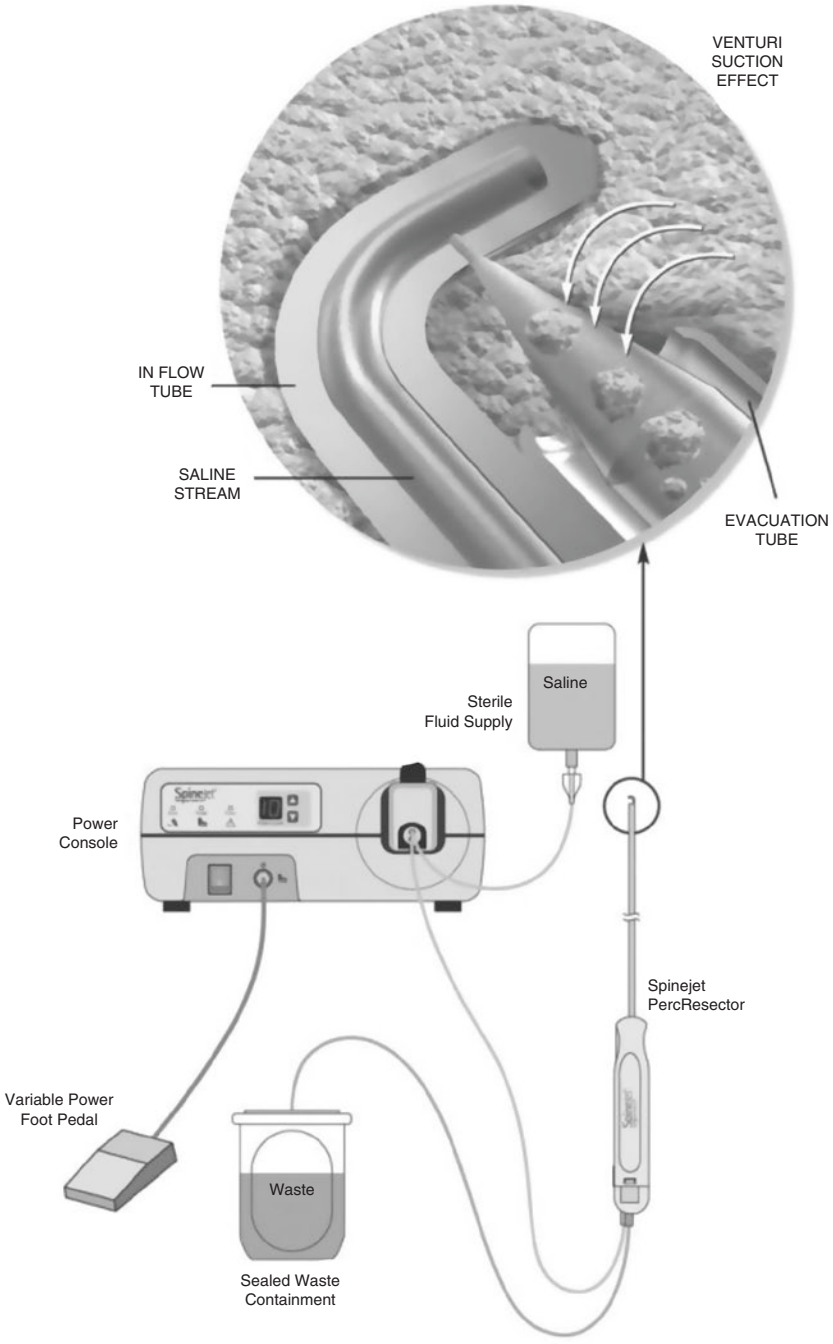

Fig. 10.11 The SpineJet HydroDiscectomy mechanical aspiration system; the nucleus pulposus is fragmented by the high-speed water jet, while a Venturi suction effect aspirates and removes the fragments through the evacuation port and tube

SpineJet are fluid-based systems, that is, the inner disc material is hydrated while the probe's aspiration action is active for tissue removal: consequently, they can, unlike every other system (purely mechanical, thermal, laser, etc.), efficiently ablate tissue regardless of patient's age and disc hydration. Moreover, internal irrigation with sterile saline is a vehicle for easy aspiration, to prevent accumulation of nuclear material and consequent clogging inside the probe.

The Dekompressor, proposed by the Stryker Company in 2003 and now provided by other companies after patent expiration, is a single-use probe, introduced through a 15-mm cannula, intended for percutaneous discectomy in the lumbar, thoracic, and cervical spine. Under fluoroscopic imaging, the Dekompressor utilizes an Archimedes pump principle to remove nucleus material from the disc. The rotating screw blade is spun by a disposable rotational motor (Fig. 10.12). The single-use probe is smaller than Onik's Nucleotome or the SpineJet, with no need for a console or other external control to make it operate properly. It is also cheaper. Unlike the Nucleotome and the SpineJet, the Dekompressor does not entail a hydration of the inner disc to favor tissue removal (purely mechanical extraction), and the quantity of extracted nucleus material is significantly lower. Case series are available [45–49], although no controlled studies have to date been performed. The level of evidence for clinical effectiveness, based on USPSTF criteria [42], is level III for short- and long-term relief [50]. In a new review of 2013 [51], only five studies were considered for inclusion; of those, only three met inclusion criteria. Based on USPSTF criteria, the level of evidence for PDD with Dekompressor is considered limited. Recently Amoretti et al. published a favorable series in patients treated under CT guidance [52].

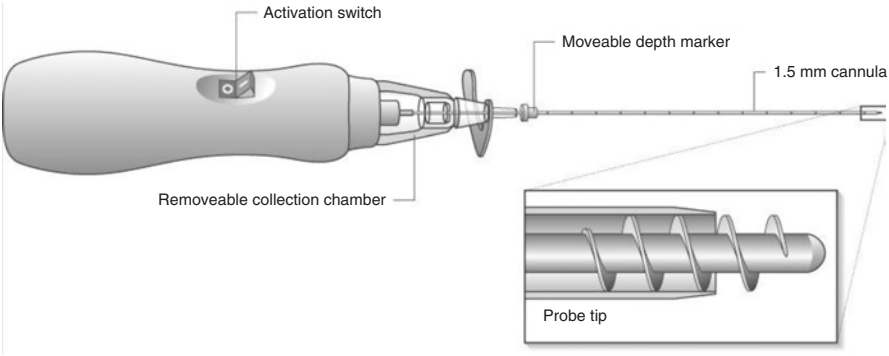

Fig. 10.12 The Stryker Lumbar Dekompressor single-use aspiration probe; the rotating, helical screw blade carves the nucleus pulposus and pushes it inside the cannula and through it up to the clear collection chamber for visual monitoring of the extracted material. Approximately 1 cc of tissue has been removed once the tissue becomes visible at the collection chamber entrance. This material can then be collected and sent for examination

10.4.2 RF Thermal Ablation

The use of thermal energy to modulate and ablate tissue is not new. Electrical current, in one form or another, has been applied to human tissues as a surgical modality for more than 100 years. RF energy occupies a range upon the electromagnetic radiation spectrum. The frequency at which the device operates determines the absorption characteristics and tissue effects. Electrosurgical units based on standard monopolar or bipolar devices generally operate from 200 to 500 kHz, and they are limitedly applied or avoided to prevent unwanted tissue destruction. Devices operating in this frequency range cause the electrode that comes in contact with the tissue to become hot, therefore acting like true heat cautery. RF in the radio wave range (between 1.7 and 4.0 MHz) of the radiation spectrum emits energy that is nonthermal with optimal controlled absorption characteristics of water-rich tissues, with minimal tissue alteration. High-frequency radiosurgery, above 1500 kHz (1.5 MHz), transmits pure radio waves to the tissue without heating the electrode. The heat for this ablation is generated by a natural resistance of the tissue, which comes in the path of the waves released through the electrode tip of the device. The cellular water in the soft tissues gets heated and when the temperature reaches 100 °C, it starts boiling, and produces steam, which results in cellular molecular dissolution of individual tissue cells. The cells exposed to these waves are destroyed whereas the surrounding tissues remain unaffected. This property of radiofrequencies eliminates the possibility of undesired damage to the normal tissues, while improving the surgical precision.

The Disc-FX discectomy system is proposed by elliquence, LLC, formerly Ellman Innovations, LLC, New York. It works in bipolar mode at 1.7 MHz. In particular, the Bipolar Trigger-Flex probe is used to obtain a radio wave energy application both for removal of nucleus material and a modulation of weak collagen fibrils and sealing of annular tears (shrinking or eliminating defects in the annulus) and contributing to depopulating nerve fibers sensitizing the outer annulus due to its smooth thermal effect.

The two different effects in the nucleus (ablation for decompression) and in the annulus (annulus modulation) are obtained by means of two different waveforms generated by an external source; the ablation in the nucleus is achieved using a more aggressive waveform, called “Bipolar Turbo,” the modulation of the annulus using a smoother waveform “called Bipolar Hemo.”

The Bipolar Trigger-Flex probe is flexible and steerable (Fig. 10.13), and consequently can be oriented to operate either in the nucleus or along the posterior annulus. At the same time, the flexible probe allows a more targeted removal of the protruding nucleus, thus relieving tension on the innervated and irritated annulus. The action of the probe on the posterior annulus and its nerve fibers should allow treatments also of patients suffering from purely discogenic back pain.

No RCTs have been published in the literature. Two small observational studies are available [53, 54].

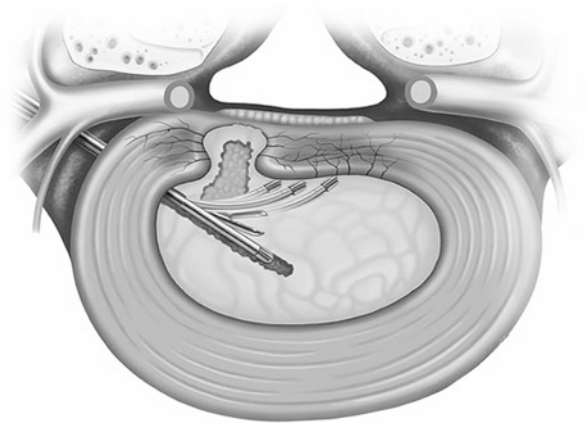

Fig. 10.13 A schematic drawing of the action of the Disc-FX thermal-radiofrequency device; the steerable probe allows topographic nuclear material removal at the site of internal annular disruption and thermal modulation of the nerve fibers in the posterior annulus, using a less aggressive waveform

10.4.3 Coblation

Coblation, or plasma RF-based discectomy, with commercial name Nucleoplasty (ArthroCare, Sunnyvale, CA, now Smith & Nephew), was approved for general use in 1999 and initially used to treat symptomatic contained protrusion in the lumbar spine, subsequently proposed and used also for treatment of cervical herniations. It is a controlled, non-heat-driven, process, which uses radiofrequency energy to excite the electrolytes in a conductive medium. It is conducted by using a bipolar radiofrequency-based device, which functions via a plasma-mediated process [55–57], to perform precise removal of disc tissue. In this process, bipolar voltage pulses at 100 kHz are applied to the active electrode at the distal end of the device, which produces a strong electric field region around the electrode. The electrolytes in the surrounding conductive medium (e.g., sodium ions resident within the nucleus pulposus) respond to the electric fields, and if the voltage is sufficiently large, a localized finely focused plasma field (ionized vapor) is produced between the electrode and adjacent tissue [22, 58]. The plasma field (a layer of only 100–200 μm thick) around the active electrode comprises a complex mixture of gas phase radical chemically reactive and nonreactive molecules and a very small fraction of ionized particles (predominately positive ions and electrons), some of which can break molecular bonds in the adjacent tissue by energetic particle bombardment and chemical reactions. The organic molecules in the disc material (particularly long-chain molecules such as collagen) are thought to be susceptible to fragmentation by the plasma particles, resulting in their conversion into liquid and gaseous products that are subsequently desorbed from the targeted site. Water molecules (which compose a significant fraction of most types of tissue) can be fragmented into excited and ground state hydroxyl radicals and hydrogen atoms. Both of these species are chemically active and can cleave long-chain molecules (e.g., collagen) into smaller fragments that are either more easily liquefied or gasified. Moreover, electrons emitted from the electrodes at the distal end of the device when the voltage is applied can

develop sufficiently high energies not only to cause the water molecules to fragment but also to directly dissociate the chemical bonds in the nearby targeted tissue structures (in our case disc tissue) into smaller fragments [57]. The net result is a reduction of soft-tissue volume and effective excision of the soft tissues within the nucleus. The plasma radiofrequency-based process has been reported to have minimal histopathological effect on tissues immediately adjacent to the treated site [22, 58], particularly annulus, endplates, neural elements, and nerve roots [58]. Because radiofrequency current does not pass directly through tissue during the coblation process, tissue heating is minimal. Most of the heat is consumed in the plasma layer or, in other words, by the ionization process. The temperature is kept below 70 °C (typically between 40 and 70 °C) to minimize tissue damage and avoid tissue charring. Because of the mechanism of action on hydrated nuclear components, tissue ablation and consequently intradiscal decompression are supposedly higher in younger patients and in hydrated, non-advanced degenerated disks [22]. In fact, an exclusion criterion for lumbar nucleoplasty must be considered a disc height less than 50% [59]. Action of coblation on disc tissues and nuclear herniations seems not only mechanical (in terms of tissue removal and intradiscal pressure reduction) but also chemical. Symptoms of herniations are not only a consequence of pressure against the nerve roots, since inflammation may well be a major mechanism in the pathophysiology of radicular pain, mainly as a result of injury or exposure of nervous tissue to nucleus pulposus material [60]. Alterations in cytokine expression potentially associated with the mechanism of pain relief have been observed after plasma radiofrequency-based discectomy [61]. Moreover, coblation appears to effectively degrade the PLA2 activity in the degenerative intervertebral disks in an animal model, and also this might contribute to reduction of inflammation and thus represent a potential mechanism of action of coblation in relieving symptoms of disk herniations [62]. Thus, we could speculate that the final clinical effect of coblation is partially due to reduction of inflammatory response, never observed after mechanical nucleotomy in our experience. This anti-inflammatory mode of action, stimulated by the plasma radiofrequency-based treatment, would be similar to that proposed with treatment of other chronic pathology [63] (Fig. 10.14). The coblation probe is introduced through a very thin, 17 G cannula (Fig. 10.15), probably the narrower among nonchemical procedures, laser excepted. This also allows for bending of the cannula and probe, for access to difficult L5–S1 levels (Fig. 10.5).

A large experience is available, and since 2000, many tenths thousands of patients have been treated using coblation technique for lumbar disco-radicular pain, and many observational studies are available [27, 64–75]. A randomized controlled trial was published in 2010 [76], comprising 90 patients who had sciatica associated with a single-level lumbar contained disc herniation, randomly assigned to receive nucleoplasty or transforaminal injection; nucleoplasty patients had significantly reduced pain and better quality of life scores, and significantly lower likelihood to undergo a secondary surgical procedure. In a review article published in 2009 [77],

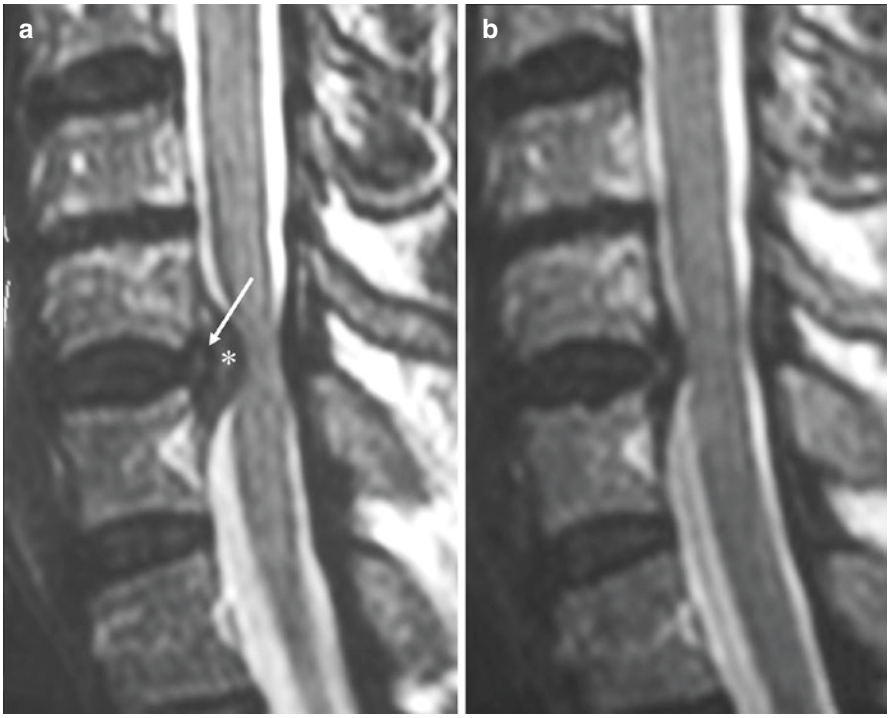

Fig. 10.14 (**a**) 58-year-old female patient. Magnetic resonance imaging shows a contained central disk (C5–C6) herniation. Compression of the spinal cord is also due to a heavy inflammatory reaction swelling the epidural space (asterisk). In (**b**) imaging follow-up at 6-month post-coblation shows almost complete regression of both herniation and inflammatory epidural reaction; spinal cord is no longer compressed; patient is totally asymptomatic

the level of evidence for clinical effectiveness, based on USPSTF criteria [42], was level II-3 in managing predominantly lower limb radicular pain, with no evidence for axial back pain. In an update of 2013 [78], 37 studies were considered for inclusion; based on USPSTF criteria [42], the level of evidence for nucleoplasty was limited to fair in managing radicular pain due to contained disc herniation. In a 2014 systematic review and meta-analysis [79] examining all study data published in clinical trials, conclusions state that nucleoplasty reduces pain in the long term and improves patients' functional mobility, being an effective, low-complication, minimally invasive procedure used to treat disc herniations.

Three randomized controlled trials are available in the literature for cervical nucleoplasty. A study by Nardi et al. [80] showed complete resolution of symptoms in 80% of all cases ($n = 50$) at 60 days after nucleoplasty compared with only 20% in the control group ($n = 20$). Ten percent had no complete amelioration and

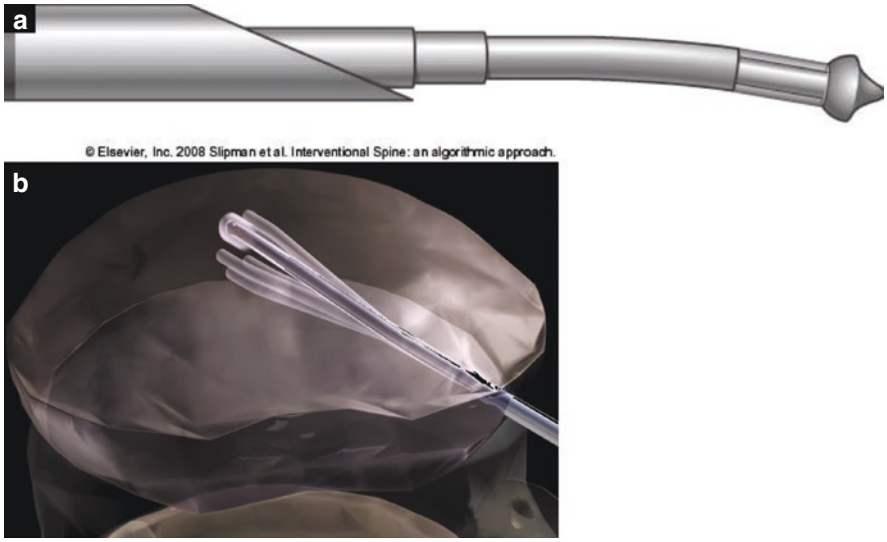

Fig. 10.15 In (**a**) the active tip of the ArthroCare lumbar coblation probe is shown, introduced in the nucleus pulposus through a beveled 17 G needle; the slightly curved tip allows the creation of multiple coblation channels upon rotating the probe at multiple passes (**b**)

remained under clinical FU with a wait-and-see prospective. The remaining 10% without any clinical improvement were treated with alternative traditional methods. No complications were observed during the study. Overall, at a short term, the nucleoplasty group significantly improved from the baseline ($P \leq 0.001$), unlike the control group ($P = 0.172$). Birnbaum [81] compared 26 patients with a conservative care control group ($n = 30$). Nucleoplasty showed lower VAS pain scores compared with conservative treatment at short-, mid-, and long-term FU. The pain scores (VAS) in the nucleoplasty group were 8.8 (preoperatively), 2.0 (3 months), 2.7 (6 months), and 2.3 (24 months), respectively. No complications were observed during the study. Cesaroni et al. [82] compared 62 patients treated with nucleoplasty to a conservative care control group ($n = 58$). The nucleoplasty group had significant lower VAS pain scores at all FU time points ($P < 0.0001$). The Neck Disability Index (NDI) also improved significantly at 6 weeks ($P < 0.0001$) and 1 year FU ($P = 0.005$), and correspondingly, the SF-36 physical component summary (PCS) improved significantly at 6 weeks ($P = 0.004$), 3 months ($P = 0.0237$), and 1 year FU ($P = 0.0003$). No complications were observed during the study. Overall, the statistical analyses favor Nucleoplasty, mainly at short- and long-term FU. This study was appraised to be of high methodological quality [83]. One of the authors (GB) published a prospective study of nucleoplasty for cervical disc herniation [84]. At 2 months, outcomes were good or excellent in 44/55 (80%) patients; the success rate was similar at 6 months, when 44 (85%) patients ($n = 52/55$) had good or excellent results. Seven patients (14%) never showed improvement. One clinically relevant complication (infectious discitis) occurred, which was successfully resolved. Three patients with clinical myelopathy experienced regression of cord

compression symptoms; in two of these patients, MR imaging showed morphological evidence of reduction of cord compression (Fig. 10.14).

A systematic review of cervical nucleoplasty for the herniated disc was published in 2014 and concluded nucleoplasty to be an effective and safe procedure at short-, mid-, and long-term follow-up, with level of evidence moderate [83]. Cervical coblation has been also proposed for treatment of vertigo [85].

10.4.4 Laser

Percutaneous laser disc decompression (PLDD) was introduced by Choy et al. [16, 85] in 1986. By 2002, more than 35,000 PLDDs had been performed [87]. The term laser is an acronym standing for light amplification by the stimulated emission of radiation. Laser is a form of light, and light is made up of electromagnetic energy. Laser energy is formed by energizing an active lasing medium. With the introduction of energy from an outside source, the atoms absorb the energy causing the electrons to rise to a higher excited state. When the electron returns to the normal, non-excited state, the energy initially absorbed is given off as a photon, and the photon bundle has unique properties characteristic to that particular medium. Lasers are generally classified according to the medium they use to produce the laser light. Solid state, gas, liquid, and semiconductor are all common types of lasers. The radiant energy of the laser beam can be transformed into heat energy that produces medical and surgical effects in tissue, such as coagulation, vaporization, or cutting. The total power output of a laser is measured in watts, the power density, measured in watts per square centimeter, and it determines the thermal effect in the target tissue; the energy density (measured in power density × time) of joules per square centimeter indicates the total amount of energy put into a given tissue. The majority of surgical lasers fall in the invisible portion of the electromagnetic radiation spectrum. The absorption characteristic of the medium largely determines the extent of penetration in particular tissue types. Application of any laser requires the surgeon to completely understand the characteristics of the specific laser for safe and effective use. The way in which light interacts with a substance largely depends upon its wavelength. Penetration depth at a certain wavelength is mostly affected by absorption by specific molecules, such as water (the principal component of the nucleus pulposus), hematoproteins, pigments, nucleic acids. As a laser is absorbed by the tissue, several surgical effects take place: at 60 °C protein denaturation and coagulation of blood vessels, near 100 °C evaporation of intracellular water causing shrinkage and tissue loss, beyond this point vaporization will occur. In general, the therapeutic effect of a laser significantly depends on penetration depth, in effect determining whether tissue removal or hemostasis will be predominant. Intradiscal decompression is obtained by shrinkage of the water-rich nucleus pulposus by vaporization. The evaporation of water and the increase in temperature cause protein denaturation and subsequent renaturation, causing a structural change of nucleus pulposus, limiting its capability to attract water [16, 87]. An increase of intradiscal volume of only 1.0 mL causes the intradiscal pressure to rise by as much

312 kPa or 2340 mmHg. On the other hand, a decrease of intradiscal volume causes a disproportionately large decrease of intradiscal pressure. Other beneficial effects of the laser action are postulated, such as shrinkage of collagen fibrils with reduction of disc volume [88, 89] and destruction of nociceptors in the annulus or in the granulation, vascularized tissue growing in degenerated discs. Many types of lasers have been reported in the literature for spine applications [90], including the following: Nd:YAG (whose active medium is a crystal of yttrium, aluminum, and garnet doped with neodymium ions, and whose beam is in the near-infrared) at 1054 nm and at 1320 nm, KTP (a beam generated by a neodymium:YAG laser is directed through a potassium titanyl phosphate crystal to produce a beam in the green visible spectrum) at 531 nm, CO_2 at 10,600 nm, Ho:YAG (YAG doped holmium) laser at 2100 nm, diode (semiconductor) laser at 810–890–940–980 nm. The Ho:YAG laser is better suited for open or endoscopic surgery, under direct visual control, because of the more mechanical effects and risk of endplate damage from energy scattering [91–93]. Yeung, Casper, Chiu, and Knight further report utility of Holmium laser to remodel extradiscal bony architecture during endoscopic spine surgery [93–95]. Nd:YAG at 1054 nm and KTP 532 are the most popular for intradiscal treatments [16, 96–100]. KTP lasers are similar to Nd:YAG lasers in both action and effects [101, 102], as are diode lasers [103]. The latter have the advantage of a much less expensive and less cumbersome power unit. The advantages of the 980 wavelength (peak absorption of water) of the diode laser are maximum absorption for well-hydrated, soft-tissue like the nucleus pulposus, with great thermal effect and consequent efficient shrinking effect [103, 104], with minimal thermal damage of surrounding tissues (particularly the endplates). Absorption by hemoglobin is lower than KTP 532 nm lasers, but they maintain an acceptable haemostatic effect.

The advantage of the laser discectomy is the tiny access port, the tiniest among the different percutaneous discectomy modalities. For the diode laser, the size of the optic fiber is as small as 220 μm, although the best compromise is obtained with the 360-μm probe (too high concentration of the delivered energy for the 220-μm fiber). Such small fiber sizes, which fits coaxially in 21-G cannulas, allow also a transcanalar/transdural approach to the disc, under CT guidance (personal experience) (Fig. 10.16). Nd:YAG laser fibers have usually a diameter of 400–600 μm. A series of pulsed shots with a maximum of 1-s duration (usually between 0.4 and 0.6 s) at no more than 15 W and at 2 s intervals are delivered to the nucleus pulposus. A minimal saline perfusion through the access cannula prevents the tissue temperature getting higher than 100 °C. No more than 1200 J (but better below 1000, usually between 600 and 800) as total dose are administered to the center of the nucleus pulposus, in two to three different positions of the fiber tip, always under fluoroscopic control of the proper position of the device.

The most frequently described complication of PLDD is spondylodiscitis both aseptic and septic [7, 105–110]. The reported frequency of discitis varies from 0% to 1.2% [105, 111–114]. Aseptic discitis is the result of heat damage to either the disc or the adjacent vertebral endplates [115].

Many observational studies report on the laser disc decompression results [7, 16, 86, 93, 97, 101–103, 105, 107, 109, 112, 113, 116–119]. Neuroradiologist Patrick

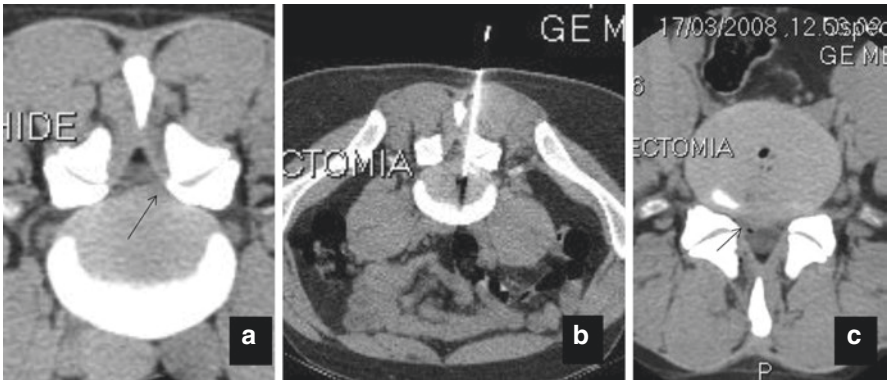

Fig. 10.16 (**a**) Extruded disc compressing the thecal sac and occupying the radicular recess. (**b**) shows the CT-guided coaxial direct insertion of the laser fiber through a 21 G cannula into the herniation, through a translaminar and transdural approach; note in (**c**) the immediate reduction of the size of the herniation, with partial reopening of the radicular recess (arrow) and clear reduction of the mass effect on the thecal sac. Gas bubbles derive from laser tissue vaporization

Brouwer and coworkers published the first RCT on laser disc surgery in February 2015 [120]. They performed a non-inferiority trial comparing laser disc surgery with conventional disc surgery among 115 patients with a disc herniation, and laser disc decompression proved to be non-inferior to open disc surgery. There was a 38% reintervention rate in the laser group over the course of a year compared with a 16% reoperation rate among patients who underwent conventional discectomy. Overall, at 1 year, a strategy of PLDD, followed by surgery if needed, resulted in non-inferior outcomes compared with surgery. Similar results were found at a 2-year follow-up [121], surgery could be avoided in 48% of those patients that were originally candidates for surgery. A cost utility analysis of the same series [122] showed that PLDD, followed by surgery when needed, results in significantly lower 1-year costs than conventional surgery.

Using CT guidance, and thanks to the minimal size of the optical probe, laser has been also proposed for direct treatment of sequestered or migrated disc fragments [104, 123].

10.5 Complications

The main risks associated with these procedures are infection, bleeding, nerve root injury, thecal sac injury, disc endplate injury, injury to the retroperitoneal structures, and colonic perforation. Adherence to a safe technique will dramatically impact the outcome and the probability of realizing a side effect or complication. An incorrect projection means that the cannula and the intradiscal device are actually working away from the place where it is supposed to, not effectively operating on the nucleus or, worse, damaging vital or functionally important structures.

All percutaneous disc procedures harbor a significant risk of disc infection. Absolute contraindication to a disc procedure is local or significant systemic infection. We recommend absolute sterility of the procedure, with particular care in the prep and drape process, strict use of full drape, full gown, gloves, mask, and hat. In addition, we administer the patient an intravenous antibiotic 10 min prior to the procedure for prophylaxis, cefazoline 1 g intravenous, or, in case of allergy to penicillin, ciprofloxacin 400 mg intravenous.

Although there are different policies at different institutions [124], we set our threshold for a safe performance of an intradiscal procedure, to a minimum of 80,000 mm^{-3} platelet count and 1.3 INR. We perform the procedure in patients treated with nonsteroidal anti-inflammatory drugs, including ASA, without special considerations. We recommend withholding the assumption of other anti-aggregants before the procedure, such as clopidogrel (7 days) and ticlopidine (14 days). In case of patients treated with low-molecular-weight heparin (LMWH), we perform the procedure at least 12 h (LMWH prophylaxis regimen) or 24 h (LMWH therapeutic regimen) after the last dose, and we recommend to withhold the LMWH for 24 h after the procedure. Patients treated with unfractionated SQ heparin less than 10,000 units daily can undergo spinal procedures, whereas patients treated with more than 10,000 units daily, and those who receive unfractionated intravenous heparin, can undergo a spinal procedure 4 h after the last dose, provided that the activated partial thromboplastin time is normal, and their heparin can be restarted as early as 1 h after the procedure.

The nerve root is not visualized under fluoroscopy, and this condition could carry the risk of injuring it while approaching the lumbar discs, particularly with the bulkier devices. With the posterolateral paravertebral access to the disc, the needle path is posteromedial to the exiting nerve root. To ensure safe disc access, the needle path has to be lateral but as tangent as possible to the superior articular process of the subjacent vertebral body and with a sufficient degree of obliquity, to avoid the nerve root. Because the radicular pain is a very effective "safety alarm," by no means local anesthesia should be delivered to the region of the neuroforamen. Otherwise, the operator might have the false reassurance of absence of radicular pain while injuring the nerve root. Local anesthetic should be injected to the skin and muscles only, keeping the injection superficial to the articular masses. For the same reason, we strongly recommend the performance of these procedures only under moderate conscious sedation and discourage the use of general anesthesia or heavy sedation. This does not apply to cervical procedures, since the anterior approach to the cervical discs does not cross the path of the roots.

An additional risk at the lumbar levels could be a colonic perforation. A posteriorly placed colon can reside behind the psoas muscle and the spine. For this reason, the preoperative imaging studies, both CT and MRI, must be carefully examined to exclude the presence of such an anatomical condition because bowel in the path of the instruments could be perforated, with the risk of peritoneal or disc infection or local abscess formation.

10.6 Postoperative Care and Follow-up

We routinely perform percutaneous procedures on an outpatient basis. At the conclusion of the procedure, observation is needed for about 2 h before discharging the patient home. Prescriptions are provided for a 2-week supply of a nonsteroidal anti-inflammatory agent and for diazepam at bedtime for 10–15 days.

At the end of the procedure, just before needle or cannula removal, we always inject steroids in the void created inside the disc. After nucleus ablation with physical energies (coblation, RF or laser), aspiration with a 20- to 50-mL syringe is needed before steroids injection, to eliminate the space-occupying gaseous or liquid residues. Injection of steroids is helpful in reducing the risk of an aseptic discitis consequent to inadvertent damage of the endplates, also reducing the back pain in the early post-discectomy period. Steroids have also a mild proteolytic and sclerosing action, which could help further reducing the disc volume in the postoperative period. Steroids and local anesthetics can also be injected, during needle removal, in the foramen, around the compressed nerve root.

Patients can stand and walk the same day of the procedure, and they are encouraged to actively move, stand, and walk on day 3. After percutaneous disc decompression, early activity is not only possible but also useful. It is imperative to avoid muscle atrophy and general deconditioning. Repetitive forward flexion, prolonged car driving, prolonged sitting, and lifting heavy weights are nevertheless prohibited for 3–4 weeks. Limb pain resolution may take weeks, owing to "remodeling" of the disc and regression of inflammation at the surgical site. The concept of disc remodeling must also be clarified to the patient. After decompression, reduction of profiles of the outer disc (annulus) is not immediate and is directly related to the residual tissue resilience, the latter depending on both the age of the patient and the pathologic conditions of the disc. Disc remodeling may be fast, taking hour or days, but also much slower, taking several weeks. Consequently, also nerve root decompression may be expected to take the same time lag, and the patient must be aware of that. A procedure that does not result in substantial relief of pain should not be considered a failure until at least 6 weeks have passed. Progressive return to heavy activities or sports is usually possible at 4–6 weeks. During the convalescence phase, rehabilitation measures applied by experienced physical therapists could be important for a good outcome. The patient must be instructed to recognize the difference between symptoms of a residual herniation and those of a healing process and proper biomechanics. The only noteworthy side effect is the possibility of increased back pain. Most patients with a surgical wound have pain and that applies to percutaneous discectomy. The intradiscal wound is more prominent and painful for mechanical procedure, particularly APLD, requiring a longer time for healing. Injury to skin, muscle, fascia, and annulus will occur, while a correct operative technique usually avoids injury to the endplates. Patients are warned that they may experience new back pain for up to 3–4 weeks. Patients should be encouraged to maintain as much mobility as possible despite the presence of this temporary back pain.

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