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Minimally Invasive Lumbar Discectomy and Foraminotomy

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Traditional microsurgical discectomy, initially described by Caspar [1] and Yaşargil [2], has survived the test of time and remains the "gold standard" for the management of radicular symptoms related to lumbar disc herniations. Since the early 1960s, however, a number of authors have described less invasive approaches for managing lumbar disc pathologies. Such techniques as chymopapain nucleolysis [3], percutaneous lumbar nucleotomy [4], automated disc removal [5], endoscopy [6], laser nucleolysis [7], and intradiscal electrothermy [8] have been developed and reported with varying success. None of these approaches, however, have achieved widespread acceptance as a mainstay of treatment for these patients.

The most promising recent advance has been the microendoscopic discectomy (MED) system that was first described in 1997 by Foley and Smith [9]. The MED approach uses minimal access surgical techniques (MASTs) to allow direct visualization of the nerve root to ensure adequate decompression. At the same time, this approach is thought to minimize tissue trauma, thereby enabling patients to recover from surgery and return to work faster than with traditional "open" approaches.

The most widely applied technique (Fig. 1) uses the METRx system (Medtronic, Memphis, Tennessee). This system consists of a series of tubular dilators that progressively dilate the paraspinal musculature until a 16- or 18-mm working portal is placed. A number of instruments specifically designed for working in a restricted space facilitate nerve root exposure and decompression. The METRx system, similar to open microdiscectomy (MD), enables the surgeon to treat a variety of scenarios, such as disc protrusions, contained herniations, sequestered fragments, and lateral recess stenosis as well as other bone and ligamentous compression, that cannot all be addressed using the other percutaneous methods mentioned previously. Furthermore, the system has been modified so as to enable the use of the endoscope or the microscope depending on the surgeon's training and comfort. The microscope adds a degree of comfort to surgeons because it provides a much more familiar three-dimensional image of the operative field. With experience, however, surgeons can acquire the same comfort with the endoscopic approach and benefit from the enhanced visualization outside the working portal gained by the 30° camera as well as the positioning advantages afforded during other procedures, such as microendoscopic decompression of stenosis and cervical foraminotomy.

This article discusses the surgical techniques, pitfalls, and clinical outcomes for microendoscopic lumbar discectomy and foraminotomy.

Surgical technique

Initial approach

During the informed consent process, patients are counseled that the operation is performed on

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Fig. 1. The METRx system (Medtronic, Memphis, Tennessee) equipment used for MED. (*A*) K-wire and dilating tubes are on the right, the endoscope is in the center, and the flexible arm and table attachment are on the left. (*B*) Midas Rex Legend Stylus drill (Fort Worth, Texas). (*C*) Video display equipment. (*D*) Operating instruments.

an outpatient basis. The rare exceptions mandating an overnight stay include persistent nausea and/or vomiting or an intraoperative cerebrospinal fluid (CSF) leak. The patient is brought to the operating room (Fig. 2), and after induction of general anesthesia, he or she is positioned prone on a radiolucent Wilson frame (OSI, Union City, California). This frame maintains the lumbar spine in a flexed position, improving interlaminar exposure while providing a degree of abdominal relaxation to reduce epidural venous engorgement. Attention is given to the final patient positioning to ensure that all pressure points are adequately protected and padded. Appropriate antibiotics are given intravenously before the procedure. The fluoroscopy unit is then brought in to ensure adequate visualization of the planned surgical site and to mark out the incision. As with any surgical procedure, optimal room use is essential. We prefer to stand ipsilateral to the operative site and have the endoscopic monitor and the fluoroscopy unit on the contralateral side. The scrub nurse and instruments are positioned near the patient's feet (see Fig. 2).

The surgical site is then prepared and draped in the usual sterile fashion. The flexible arm assembly is solidly attached to the operative table. The endoscopic camera is assembled, focused, and white-balanced. There are a number of cameras that can attach to the endoscope, and adapters are provided with the setup. It is essential that the surgeon confirms before surgery that the camera

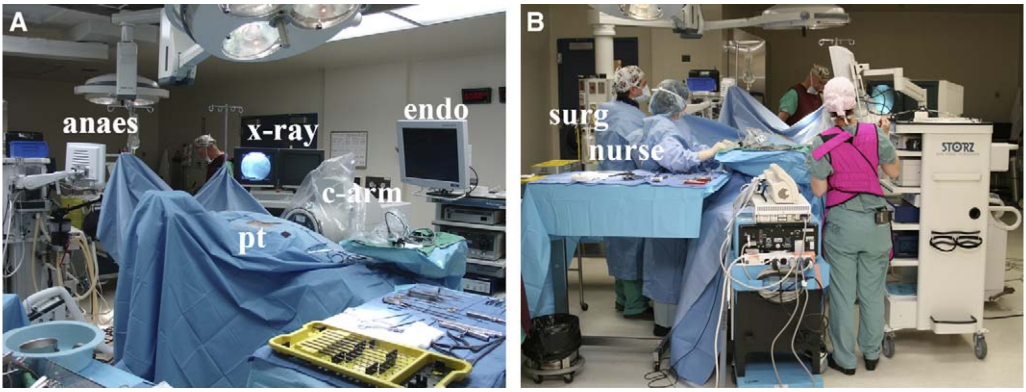

Fig. 2. (*A, B*) Orthogonal views of the operating room setup for MED. The patient (pt) is positioned prone on a radiolucent frame. The surgeon (surg) stands on the patient's symptomatic side, along with the scrub nurse (nurse). The anesthesia team (anaes) is positioned at the patient's head for easy access to the endotracheal tube if needed. The fluoroscopy unit (c-arm) is brought in opposite the surgeon. The video display for the endoscope (endo) and the fluoroscopy unit (x-ray) is also positioned opposite the surgeon and in easy view.

system to be used provides adequate images to perform the procedure. Secondary suction is applied to the aspiration port on the endoscope assembly. Caution should be used to avoid resting the light source, or the endoscope once assembled with it, on any combustible materials, because ignition may occur and cause injury to the patient. Before use, the endoscope is cleaned and antifogging solution is applied to the distal tip. It may be necessary to repeat this set at intervals during the case.

Initial dilatation

The incision is placed 15 mm off the midline on the symptomatic side, and the trajectory is confirmed by visualizing a K-wire with fluoroscopy. The site is infiltrated with local anesthetic, and the skin is sharply incised to the level of the subcutaneous tissue. To accommodate an 18-mm diameter working portal and avoid pressure injury to the skin, a 20-mm incision is typically required. The K-wire has a sharp end and a blunt end. The sharp end is effective at penetrating the lumbar fascia; however, the blunt end is safer when probing near the thecal sac. The K-wire is directed through the incision toward the affected disc space using fluoroscopy to modify the trajectory. A gentle medial angle is used to target the inferior lamina of the rostral vertebral body. Too sharp of a medial angle may inadvertently lead the K-wire to the contralateral side, particularly in thick patients. The lumbar fascia provides noticeable resistance to passage of the K-wire; however, once penetrated, the wire passes easily to the level of the lamina. Fluoroscopy is routinely used to confirm the location of the K-wire and to avoid its placement within the interlaminar space. Once firmly docked on the lamina and confirmed with fluoroscopy, sequential dilatation may proceed.

While maintaining downward pressure to avoid migration of the K-wire, the initial dilator is placed over it and advanced to the lamina using a twisting motion. This facilitates the dilation without requiring excessive downward force. Fluoroscopy confirms that the dilator has not passed into the interlaminar space. Once firmly docked, the K-wire can be removed. This dilator can then be used to palpate the margins of the lamina, providing orientation to the surgeon and elevating the residual musculature subperiosteally. With the initial dilator held in the ideal location, the sequential dilators are placed in succession. Firm downward pressure on each docked dilator ensures that the dilators do not migrate dorsally, which lessens the effectiveness of the dilatation procedure. After the five dilators are in place, the final dilatation is achieved using the working portal. Once satisfactory positioning on the lamina has been confirmed with fluoroscopy, the working portal is attached to the flexible arm opposite the surgeon and the dilators are removed.

Endoscope insertion

The endoscope is inserted into the tubular retractor and secured using the locking mechanism on the ring attachment. The endoscope may be positioned anywhere along the periphery of the working tube; however, it is usually placed on the medial aspect (12 o'clock) and adjusted during the procedure depending on the working needs of the surgeon. Adjusting the depth of the endoscope within the working tube increases or reduces the magnification. Contact with muscle or bone debris blurs the image and may be cleaned with irrigation or removal. When working through a tubular system, such as the METRx system, it is essential that the surgeon remain oriented during the procedure. The image position may be adjusted by turning the gold ring on the endoscope. Orientation on the monitor is according to the surgeon's preference; however, we prefer the convention of placing the medial edge at 12 o'clock and the lateral margin at 6 o'clock.

Once the endoscope is in position, the residual muscle overlying the lamina is removed. An electrocautery pen is passed around the perimeter of the working channel to free the muscle and expose the lamina. Once detached, a pituitary rongeur easily removes this tissue. It is essential to remove all the muscle to maximize surgical visualization and working space. The interlaminar space is then identified, and the ligamentous attachments are released with a cup-curette. The remainder of the procedure proceeds similar to traditional MD.

Discectomy

A high-speed burr or a Kerrison rongeur is used to remove the lamina and expose the ligamentum flavum further to its origin (Fig. 3A, B). This is detached with an angled cup-curette and reflected caudally (Fig. 3C). The Kerrison rongeur is then used to remove the ligament and expose the nerve root (Fig. 3D, E). The dissection is continued laterally, removing approximately 2 to 3 mm of the medial facet to ensure adequate access to the lateral recess and minimizing the need for root retraction. The nerve root is followed distally along its course, removing ligamentum and any bony compression. The caudal pedicle is identified, and the foramen is palpated with a ball-tipped probe. A foraminotomy can be performed at this time in the standard fashion. If a large herniated fragment is present, the foraminotomy may be performed more easily after the fragment has been removed and the nerve root is more relaxed.

The lateral margin of the root is identified and dissected from the surrounding tissue using blunt dissection. Any epidural veins are cauterized and divided. The root is reflected medially using the suction nerve root retractor as an efficient means to maintain its position and maximize working space within the tube. Any identified free fragments are loosened and removed with a pituitary rongeur. The annulus is inspected for any defects; if present, they are used as an entrance into the disc space. If the offending lesion is a contained disc herniation, a horizontal linear incision is made in the annulus and the fragment is removed (Fig. 3F). We favor an approach in which we excise only the portion of the disc that is compressing the nerve. Although we probe the disc space for any free fragments, we do not routinely perform a radical discectomy.

Once the discectomy is completed, we palpate beneath the root and thecal sac to ensure that there are no further retained fragments. If located, they are removed directly or delivered back into the disc space with a down-going curette for removal with a pituitary rongeur. If significant osteophytes are present, the compression exerted can be relieved with a curette and a mallet.

During the course of decompression, it is frequently necessary to adjust the angle of the working portal to maximize visualization. This technique is referred to as ''wanding.'' When making these adjustments, the wheel on the flexible arm is loosened and the tube is moved and then retightened. It is important to maintain downward pressure on the working tube when altering its position, because the muscle may creep around the edges and obscure the view. The reluctance of the surgeon to adjust the position of the working portal leads to restricted access to pathologic findings and is a common cause for inadequate decompression during the procedure. Wanding effectively enables access from pedicle to pedicle and ensures maximal working space by centering the pathologic findings within the portal.

Lateral foraminotomy

If the preoperative imaging and clinical features are suggestive of a purely foraminal source of compression, a lateral approach may be considered. The approach is also useful for addressing far lateral disc herniations. This technique preserves the ligamentum flavum and epidural space and may reduce the incidence of postoperative fibrosis around the nerve root. The incision is more lateral than described previously and is centered so that the K-wire and dilators dock on

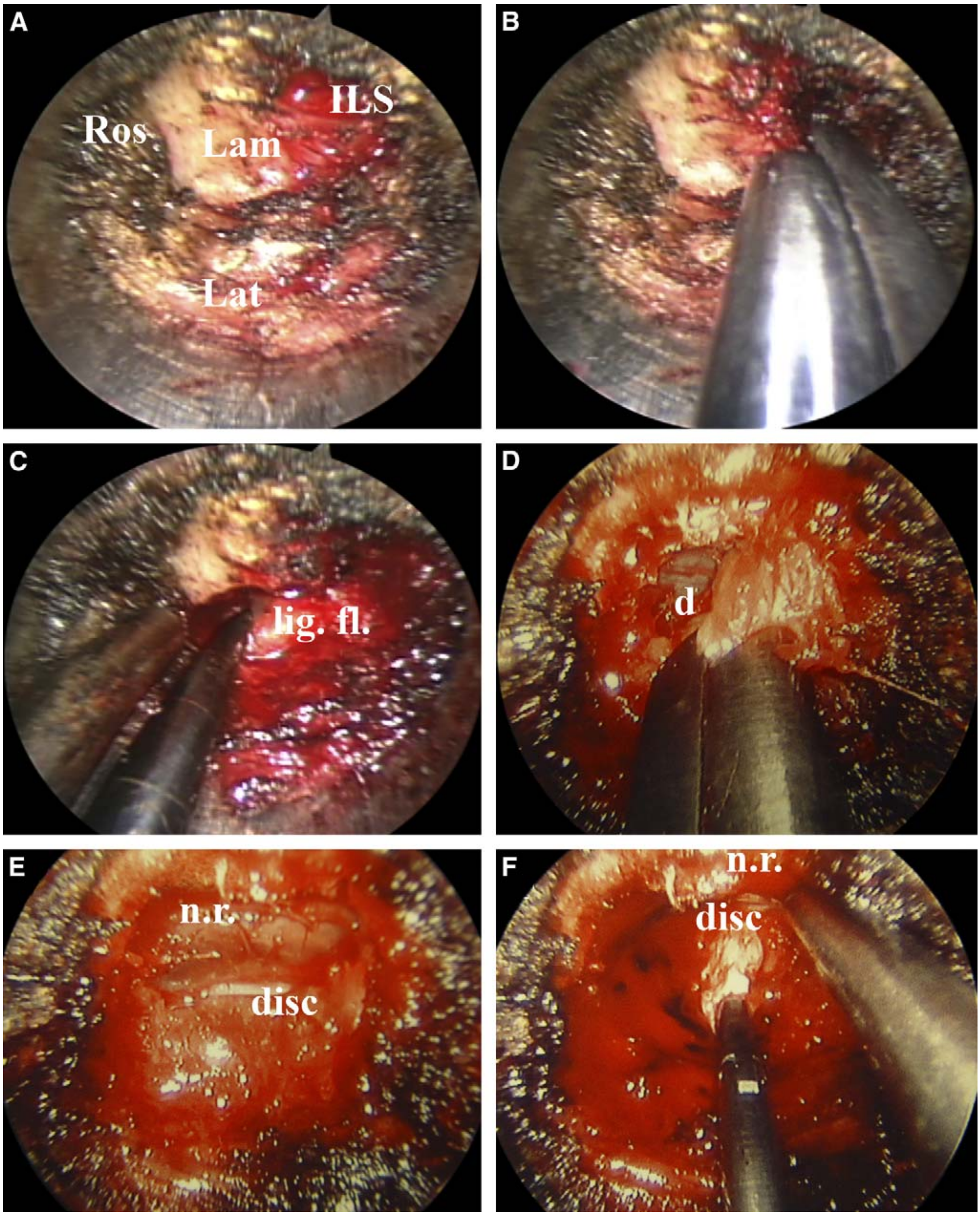

Fig. 3. Intraoperative images illustrating the various steps in MED. (*A*) Initial exposure after placement of working tube. ILS, interlaminar space; Lam, lamina; Lat, lateral; Ros, rostral (this orientation is maintained throughout the figure). (*B*) Kerrison rongeur is used to remove the lamina. (*C*) After adequate exposure of the ligamentum flavum (lig. fl.), it is detached from the lamina and reflected caudally using a cup-curette. (*D*) Ligamentum flavum is then removed to reveal the dura (d). (*E*) Nerve root (n.r.) can then be identified, as is the offending lesion (disc). (*F*) Nerve root is retracted, and a small linear annulotomy enables removal of the disc fragment (disc).

the inferior aspect of the medial transverse process. Sequential dilatation and muscle removal reveal the transverse process and enable identification of the inferior margin. The intertransverse ligaments and muscles are released and reflected caudally. The nerve is identified within a layer of fat coursing across the field. The inferior margin of the transverse process can also be followed medially, where the pedicle can be palpated beneath it. Using both of these approaches, the foramen can be identified. A Kerrison rongeur is used to enlarge the foramen, and a ball-tipped probe is used to ensure adequate decompression.

Closure

Once satisfactory decompression has been achieved, the disc space and operative field are irrigated with saline solution and the tubular retractor is slowly removed. Any bleeding vessels in the muscle are controlled with bipolar cautery. The fascia is closed with a single 00 absorbable suture. The subcutaneous tissue is reapproximated with inverted 000 sutures, and a running 0000 stitch is used on the skin. The wound is cleansed, and Steri-Strips (3M Health Care, St. Paul, Minnesota) and a sterile bandage are placed.

After surgery, the patient is brought to the postanesthetic care unit and observed until discharge. Standard instructions and follow-up are the same as for the patient undergoing MD.

Pitfalls and complications

MED continues to be adopted by an increasing number of spinal surgeons. As with any new procedure, there is a "learning curve" that reflects surgeons' comfort and proficiency related to the number of cases performed [10,11]. It has been theorized that with experience, blood loss, operative time, and overall satisfaction improve. The factors that have the greatest impact on surgeon comfort are the restricted working space and the use of the endoscope. The latter probably requires the most adjustment. Surgeons are generally accustomed to the high-resolution three-dimensional visibility afforded by an operating microscope. The two-dimensional images viewed through the endoscope mandate an advanced knowledge of the anatomic relations within the surgical field. Disorientation and a feeling of "being lost" often lead the inexperienced surgeon to conversion to an open procedure [11]. Nowitzke [11] published a formal assessment of the learning curve for his first 35 MED cases. His training consisted of a case observation and 2 days of laboratory experience. Most of the complications and conversion to open procedures occurred in the first 10 patients. He observed that as his experience grew, he was applying the procedure to more complex cases without a concomitant increase in complications. Analysis of the surgical times suggested that the asymptote, the steady state observed after early learning of a new task, was reached after approximately 30 cases. During this period, surgeons may benefit from mentoring and should expect an increase in operative times compared with the open microdiscectomies they are used to performing.

Many of the other complications of MED are similar to those of open MD. Patients should be counseled as to the risks of bleeding, infection, nerve root injury, and CSF leak. CSF leaks tend to occur more frequently during the early part of the learning curve. The clinical effect seems to be more benign with a muscle-splitting technique compared with the traditional midline approach. It is, however, often difficult to close a durotomy primarily through a 16- or 18-mm tube. For large defects, primary repair should be attempted. For the more common, small, pinhole leak, however, sealing the defect with fibrin glue is often sufficient. The patients are kept recumbent overnight and then allowed to mobilize as tolerated. The use of a lumbar drain is rarely necessary.

Wrong-level surgery is a possible complication, and as with any other spinal operation, the surgeon must be vigilant in verifying the levels. Use of fluoroscopy during the initial localization is essential. During the dilation phase, there may be a tendency for the tubes to migrate rostrally along a "steep" lamina. This tends to occur more often at the L5 level; although the initial K-wire was docked at the L5 to S1 space, the sequential dilators gradually migrate rostrally and end up at the L4 to L5 space. Judicious use of fluoroscopy during the procedure avoids these complications.

Adequate visualization through the endoscope is essential to performing MED safely. Blood and bone dust can frequently obscure the optics and necessitate removal and cleaning of the distal tip. This incidence can be reduced by keeping the camera retracted in the working portal during the initial bony removal and then advancing it for the decompression when higher magnification is required.

Clinical outcomes

All new tests and procedures must be scrutinized against existing gold standard procedures before they can be professed as superior. In the case of radiculopathy attributable to lumbar disc disease, the gold standard procedure is the microscopic discectomy [12]. The presumed benefits of MASTs are less tissue damage, shorter hospital stays, and faster return to work. Accomplishing these goals cannot be at the expense of maintaining long-term benefits of the procedure. Although there have been no large, randomized, controlled studies comparing MD and MED, a number of case series and clinical reports provide some insight on its efficacy and reduced invasiveness.

Schick and coworkers [13] used intraoperative electromyographic (EMG) recordings to examine the difference in nerve root irritation between microscopic discectomy and MED. They randomly assigned 30 patients to each group. The electrical recordings were taken bilaterally from four muscles corresponding to the affected root and one muscle from an adjacent root. The EMG findings recorded at various stages during the procedures suggested that the mechanical stimulation present during MED was statistically less than with MD. The clinical significance of this finding is unclear, however, because both groups reported clinical improvement in their pain.

Muramatsu and colleagues [14] compared the postoperative imaging findings in a group of patients undergoing MED or open discectomy using Love's technique in an attempt to compare the invasiveness of the two procedures. They compared serial pre- and postoperative enhanced MRI scans for differences in nerve root intensity, muscular enhancement, and cauda equina configuration. This nonrandomized study enrolled 25 patients in the MED group and 15 patients in the Love's technique group. They observed an equal increase in nerve root enhancement after surgery in the MED and Love's technique groups. Furthermore, there was no difference in the configuration of the cauda equina with either approach. Although all patients in the MED group displayed muscular changes at 4 weeks, these findings were not as widespread, being restricted only to the surgical corridor, and resolved faster than those seen in the open cases. These authors concluded "that MED is appreciably less invasive than Love's method."

Two independent groups have examined the systemic inflammatory responses for MED and traditional procedures to investigate further the claim that MED is less invasive. Sasaoka and colleagues [15] compared patients undergoing MED, MD, or open laminotomy for radicular decompression. They found that although clinical outcomes were similar at last follow-up, the MED and MD groups had less blood loss and a dampened rise in C-reactive protein and interleukin (IL)-6 and IL-10 compared with the open group. Furthermore, at the 24-hour time point, IL-6 values measured for the MED group were statistically lower than those observed in the MD and open groups. Huang and coworkers [16] randomized patients with symptomatic lumbar disc herniations who had failed conservative management to MED or open discectomy. Concentrations of tumor necrosis factor-1 (TNF-1), IL-1β, and IL-8 were low and not different between the groups. Similar to the findings of Sasaoka and colleagues [15], however, the concentrations of IL-6 and C-reactive protein were statistically lower in the MED group. Despite a slightly longer operative time in the MED group, these patients had statistically smaller incisions, less blood loss, and shorter hospital stays. Clinical outcomes using visual analog pain scores and the modified MacNab criteria were equivalent at 18 months between the two groups.

There is a growing body of literature suggesting that MED affords at least equivalent clinical outcomes to traditional open or microscopic discectomy up to and beyond a year [13,15–20]. The equivalence of these two treatments should not be surprising, however, because the extent of neural decompression should be the same with either approach. Where MED is showing benefit is in the early postoperative period because of the less destructive approach. Shorter hospital stays are routinely reported, as are lower analgesic requirements [20] and faster return to work times [17,18]. Palmer [17] noted that almost three quarters of his cohort of 135 patients had returned to work by 5 weeks after surgery. He also reported that the MED approach reduced his hospital's costs by 18% compared with MD. Nevertheless, many of these studies are matched, consecutive, or uncontrolled prospective cohorts yielding class II data. A large, randomized, multicenter study comparing MED with MD has yet to be reported.

Summary

MED is a safe and effective approach for managing patients with compressive radiculopathies who have failed conservative treatments. As experience with the technique increases, so does the surgeon's comfort level. Isaacs and colleagues [21] and Le and coworkers [22] have reported success and safety in using the MED technique for recurrent disc herniations. Any surgeon considering adopting MASTs for their spinal practice should first adopt and become comfortable with the MED approach. This approach is the least "foreign" and provides a forum to master the "learning curve." Once achieved, the surgeon can then expand the indications and applications of MASTs as evidenced throughout this issue.

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