70 Percutaneous and Minimally Invasive Approaches to Decompression and Arthrodesis of the Cervical Spine

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SUMMARY OF KEY POINTS

- Minimally invasive (MIS) cervical options include both anterior and posterior approaches with the decision on approach requiring a full understanding of the clinical picture and the risks and benefits of each approach.
- MIS approaches to the cervical spine have been shown to have clinical outcomes that are comparable to traditional open approaches, with a reduction in length of hospital stay and narcotics use and an earlier time to mobilization.
- Posterior approaches avoid the anterior approach–related laryngopharyngeal complications and include MIS foraminotomy/laminectomy/discectomy and even lateral mass fusion.
- Indications for MIS laminotomy/foraminotomy/discectomy include unilateral radiculopathy from lateral disc herniations or foraminal stenosis (single-level or multilevel), without instability, significant kyphosis, or severe axial neck pain or persistent or recurrent root symptoms following anterior cervical discectomy and fusion.
- Anterior MIS approaches include anterior cervical foraminotomy (microsurgical and endoscopic), percutaneous procedures for discectomy with or without stabilization/fusion, and annuloplasty.
- An anterior approach is generally most appropriate in cases of same-level bilateral radiculopathy, central disc herniation, symptomatic uncinate spurs, significant kyphosis, and in the presence of severe axial neck pain.
- Percutaneous annuloplasty or nucleoplasty has not yet been widely adopted due to the natural history of isolated soft disc herniations causing radiculopathy.

Degenerative disease of the cervical spine can cause compression of neural elements through disc herniation, ligament and facet joint hypertrophy, and the formation of vertebral body end plate osteophytes. The effects of these changes can be exacerbated by a congenitally narrow spinal canal, segmental instability, and deformity. These dynamic processes can contribute to radiculopathy, myelopathy, or both, depending on the degree to which nerve roots or the spinal cord are affected. Many patients with radiculopathy or stable myelopathy can be managed with appropriate nonoperative measures, whereas those who remain symptomatic have multiple surgical options available for decompression. Surgical decompression is indicated for selected patients with neurologic signs and symptoms of radiculopathy or myelopathy with corresponding radiographic evidence of neural compression. The cervical spine can be decompressed through either an anterior or a posterior approach, each of which has relative advantages and disadvantages. Anterior cervical discectomy and fusion are considered by many to remain the gold standards for treatment of cervical radiculopathy, myelopathy, or myeloradiculopathy, but motion-preserving techniques including disc replacement and posterior cervical foraminotomy and minimally invasive techniques have become increasingly popular alternatives. When approaching a patient the choice of approach is sometimes relatively clear, and often the problem can be addressed from either direction, with the ultimate decision balancing the risks and benefits of each method. The minimally invasive and percutaneous techniques have been shown to preserve healthy tissues, better maintain intact spine biomechanics, shorten hospital stays, cause less postoperative pain, enable faster patient mobilization, reduce complications, minimize operative blood loss, and possibly even lead to reduced hospital costs as a result. This chapter discusses these different techniques (anterior and posterior approaches) with descriptions of the procedures and outcomes.

POSTERIOR MINIMALLY INVASIVE APPROACHES FOR THE CERVICAL SPINE

Posterior decompressive procedures are fundamental tools in the surgical treatment of symptomatic cervical degenerative spine disease.[1-5] Even as anterior cervical procedures have gained prominence, posterior cervical laminoforaminotomy still provides symptomatic relief in 92% to 97% of patients with radiculopathy from foraminal stenosis or lateral herniated discs.[3,6] Similarly, dorsal cervical decompression for cervical stenosis achieves neurologic improvement in 62.5% to 83% of myelopathic patients undergoing either laminectomy or laminoplasty.[4,7-9] Moreover, these operations avoid the approach complications related to anterior approaches to the cervical spine, namely, esophageal injury, vascular injury, recurrent laryngeal nerve paralysis, dysphagia, and accelerated degeneration of adjacent motion segments after fusion.[9-12]

However, open dorsal approaches to the cervical spine require extensive subperiosteal stripping of the paraspinal musculature that leads to increased postoperative pain, spasm, dysfunction; can lead to muscular ischemia; and can be persistently disabling in 18% to 60% of patients.[4,10,13-15] Furthermore, preoperative loss of lordosis and long segment decompressions increase the risk for postoperative sagittal plane deformity,[15-19] a complication that frequently prompts instrumented arthrodesis at the time of laminectomy. Employing these extensive posterior fusion techniques increases operative risks, time, and blood loss; exacerbates early postoperative pain; and potentially contributes to adjacent-level degeneration.

The fundamental tenet of minimal access techniques is reduction of approach-related morbidity through minimization of tissue disruption. To that end, the advent of muscle-splitting tubular retractor systems and the use of endoscopic technology or the microscope have allowed for the application of minimally invasive (MIS) techniques to dorsal cervical decompressive procedures[14,15,20-36] and fixation.[37-41]

Spurling, Scoville, and Frykholm were the first to describe the open cervical foraminal decompression between 1944 and 1947.[42-44] In 1983, Williams reported the first microsurgical technique for dorsal cervical foraminotomy,[45] and several minimally invasive dorsal cervical techniques were described subsequently.[20-41] To avoid confusion and to simplify the description of all these techniques, we divide them into two main approaches: (1) the minimally invasive midline cervical approach and (2) the minimally invasive paramedian (transtubular or transmuscular) cervical approach. An endoscope, microscope, or loupes and a headlight can be used with either approach. These approaches are used to perform MIS laminotomy/foraminotomy/discectomy, laminectomy, laminoplasty,[35,36] and lateral mass fixation.[37-41]

Indications

The operative indications for minimally invasive laminotomy/foraminotomy/discectomy are (1) unilateral single-root (Fig. 70-1) or multiple-root cervical radiculopathy from lateral disc herniations or foraminal stenosis (single-level or multilevel), without instability, significant kyphosis, or severe axial neck pain; (2) persistent or recurrent root symptoms following anterior cervical discectomy and fusion; (3) cervical disc disease in patients for whom anterior approaches are relatively contraindicated (e.g., ventral neck infection, tracheostomy, prior irradiation); and (4) cervicothoracic disc herniation and radiculopathy, to avoid ventral approach potential complications and when the anterior approach is less desirable (short neck or others). An anterior approach is generally most appropriate in cases of same-level bilateral radiculopathy, central disc herniation, uncinate spurs, significant kyphosis, and severe axial neck pain.

Most patients who are candidates for a noninstrumented, dorsal cervical decompression are also candidates for MIS posterior cervical decompression: myelopathy or myeloradiculopathy, spinal cord compression from one to three adjacent cervical levels, and a lordotic cervical spine (Fig. 70-2). Contraindications include loss of the normal cervical lordosis, severe ventral disease (disease that extends for more than three levels), and segmental instability.

MIS lateral mass screw insertion technique can be used to treat segmental instability after decompression or also for

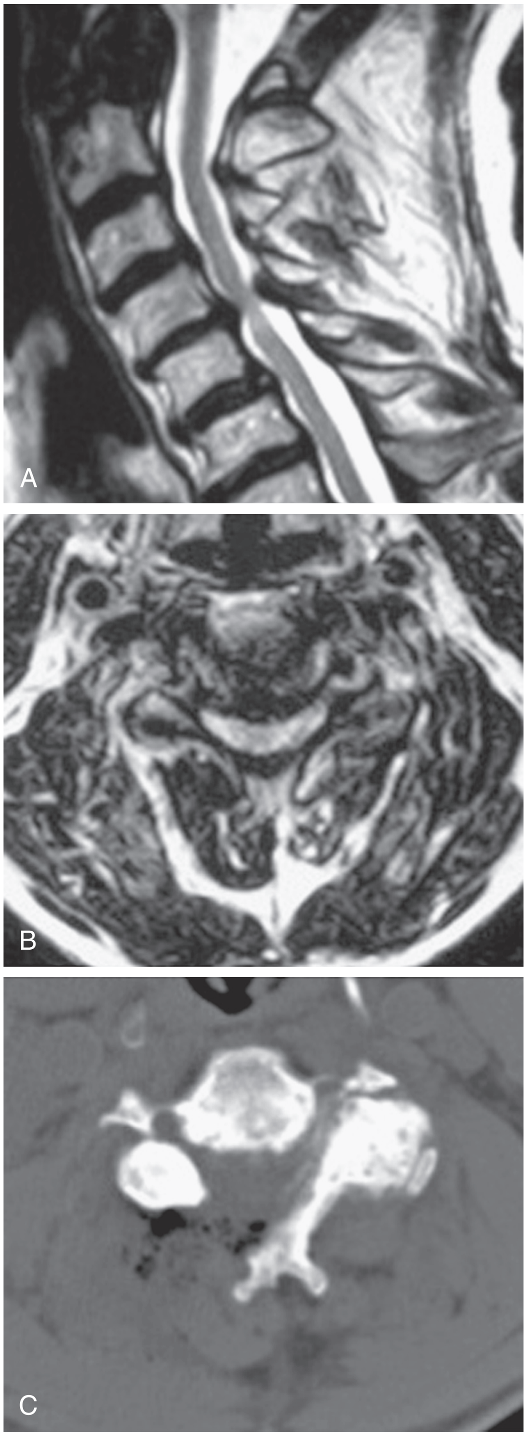

Figure 70-2. An 80-year-old male presented with chronic myelopathy from cervical stenosis and underwent right-sided approach for C4-5 microendoscopic decompression for stenosis. **A,** Sagittal T2-weighted MRI demonstrates focal C4-5 spondylotic stenosis with signal change in the spinal cord. **B,** Axial T2-weighted MRI reveals severe focal compression at C4-5. **C,** Postoperative axial CT image shows typical extent of bony resection required to achieve adequate decompression of the spinal cord. Note the preservation of the dorsal spinous process and contralateral lamina and facet. Also note the minimal impact on paraspinal soft tissues on the approach side (postoperative air is seen on the approach side and at the site of the laminotomy).

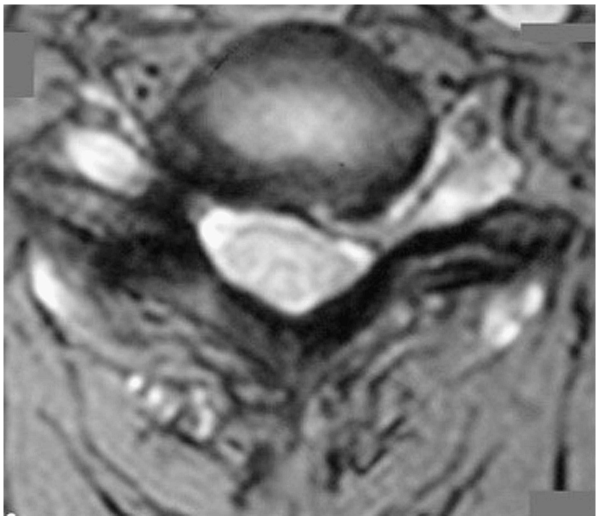

Figure 70-1. Axial T2-weighted cervical spine MRI demonstrates laterally herniated disc to the left with resultant effacement of the lateral thecal sac and compression of the exiting nerve root.

cases of facet dislocation, or even to augment previous ventral fusion techniques.[15,37,38,40] Minimally invasive cervical laminoplasty has also been described via a cadaveric feasibility study, which found the technique to be challenging.[35]

Preoperative Evaluation

The preoperative radiographic evaluation follows a detailed history and physical examination and should include magnetic resonance imaging (MRI) or postmyelographic computed tomography (CT), in addition to anteroposterior (AP), lateral, and dynamic cervical radiographs. Electromyography (EMG) and nerve conduction studies (NCS) may also assist to confirm the localization of radicular compression. Selective nerve root blocks can also be a useful additional therapeutic and diagnostic tool. All patients with pure radiculopathy who go on to surgery have failed a trial of conservative therapy, which includes oral medications, physical therapy, or steroid injections. Cervical spondylotic myelopathy patients undergo a careful analysis of their disease progression, physical examination, radiographic studies, and comorbidities. All patients are carefully counseled regarding the risks, benefits, and alternatives to surgery.

OPERATIVE SETUP

General endotracheal anesthesia is induced on a standard electric operating table. A neurophysiologic monitoring array with capabilities for somatosensory-evoked potentials (SSEPs), motor-evoked potentials (MEPs), and free-running EMG is put in place. In cases of myelopathy, a fiberoptic intubation may be elected, and evoked potentials are compared before and after positioning to identify positioning-related cord ischemia. Maintenance of normotension to avoid spinal cord hypoperfusion is best directed with continuous blood pressure measurements afforded by an arterial line. Measures to detect and treat air embolism, such as a precordial Doppler and a central line, are options but have not yet proved necessary. Given the small exposure, the risk of air embolism is low. A urinary catheter is generally not necessary for one- or two-level procedures. Routine perioperative antibiotics are administered. Relaxants are minimized after induction to allow for effective neurophysiologic monitoring.

Posterior cervical approaches might be performed with the patient in the prone or sitting position. With the prone position, the head is held with a Mayfield pin holder or a well-padded horseshoe-shaped headrest, with slight flexion. The operating table is tilted in a reverse Trendelenburg position to ensure that the cervical spine is parallel to the floor. The senior author prefers the sitting position (Fig. 70-3) because it confers the advantages of decreased epidural bleeding, decreased pooling of blood in the operative field, decreased anesthesia time, and gravity-dependent positioning of the shoulders for better lateral fluoroscopic images. The table is turned 180 degrees relative to the anesthesiologist. The patient's head is fixed in a Mayfield head holder. The table is manipulated to place the patient in a semisitting position with the head flexed and the neck straight and perpendicular to the floor.

Midline Approach

A 3-cm skin incision is made in the dorsal midline with the disc space centered on the incision. Larger incisions extending over several segments may be necessary for multilevel disease. The operative level(s) and entry point are confirmed on lateral fluoroscopy. The superficial fascia is incised in the midline to the level of the ligamentum nuchae. The ligamentum nuchae is incised just off the midline ipsilateral to the site of interest.

Figure 70-3. Sitting position with C-arm in place.

Care should be taken to avoid penetration into the erector spinae muscles, by staying along the margin of the bloodless deep fascia. After reaching the spinous processes of the site of interest, paraspinous muscles are dissected from the spinous processes, laminae, and facet joint, using a monopolar cautery or subperiosteal dissection with a Cobb. A self-retaining retractor is placed to reflect the paraspinous muscles from the interlaminar space of interest. The remaining steps are performed under microscopic magnification or using loops and an endoscope.

Paramedian Approach

The operative level(s) and entry point are confirmed on lateral fluoroscopy with a K-wire. A 1.8-cm longitudinal incision is marked out approximately 1.5 cm off the midline on the operative side and injected with local anesthetic. For two-level procedures, the incision should be placed midway between the targeted levels. Once an optimal trajectory is established, the fascia is incised with a scalpel to accommodate dilators. A Metz scissors is used to bluntly dissect to the facets to enable "force-free" insertion of the tissue dilators. The fascia is retracted, and the smallest dilator is placed through the posterior cervical musculature under fluoroscopic guidance and docked at the facet at the level of interest. A slightly lateral trajectory is advised to avoid the spinal canal and ensure contact with the lateral mass. Successive tubular muscle dilators are carefully and gently inserted, remembering that the axial forces that are routinely applied during muscle dilation in the lumbar spine are hazardous in the cervical spine. After dilation, the final tubular retractor is placed and secured over the junction of the lamina and the facet with a table-mounted flexible retractor arm and the dilators are removed. The following steps are performed under microscopic magnification or using loupes or an endoscope. The endoscope is inserted and attached to the tubular retractor (Fig. 70-4). Monopolar cautery and pituitary rongeurs are used to clear the remaining soft tissue off of the lateral mass and lamina of interest, taking care to start the dissection over solid bone laterally.

Laminotomy/Foraminotomy/Discectomy

The medial facet/interlaminar space junction is identified. Using a high-speed drill, a partial laminotomy-facetectomy is performed beginning at the medial facet/interlaminar space and going laterally, without exceeding 50% facet removal, to maintain biomechanical integrity. The dorsolateral portion of the superior lamina and the medial part of the inferior articular facet are removed first. This will permit the removal of the lateral corner of the inferior lamina and the medial part of the

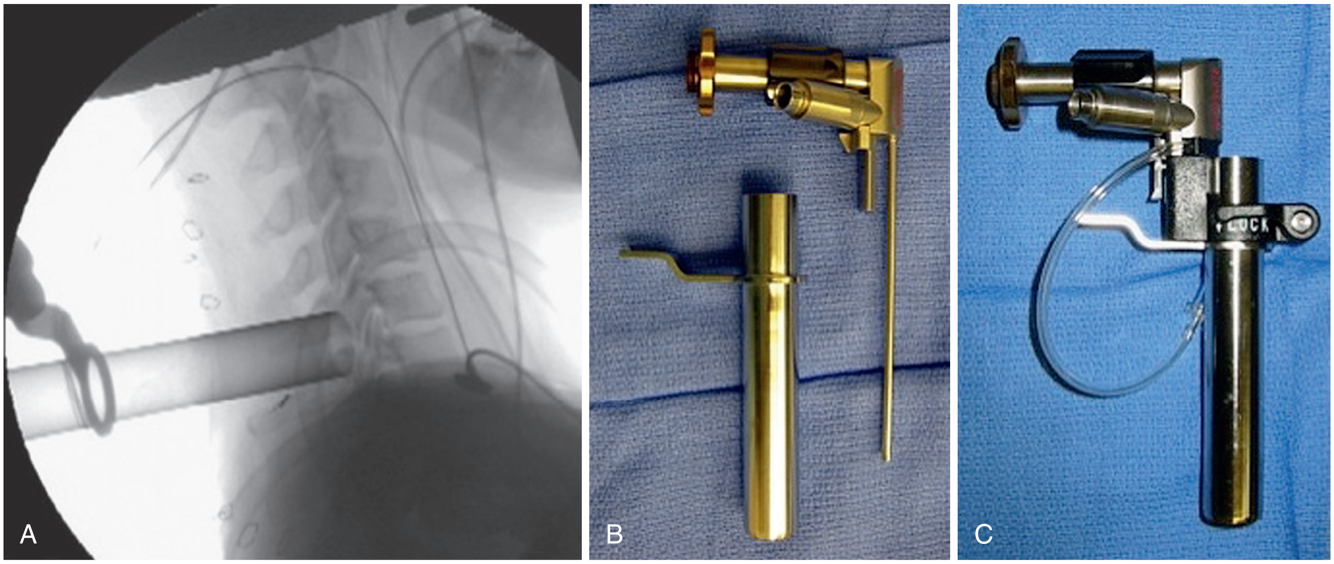

Figure 70-4. A, Fluoroscopic control verifying the right placement of the table-mounted retractor after removal of the dilators. **B,** The endoscope and the retractor separately. **C,** The endoscope mounted on the tubular retractor.

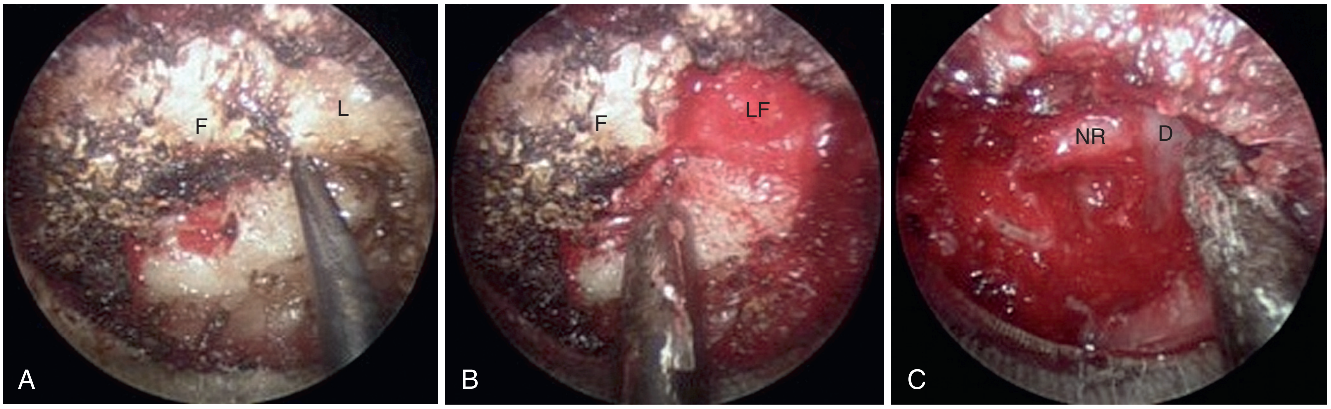

Figure 70-5. Intraoperative endoscopic photographs during left-sided cervical microendoscopic foraminotomy. In all photos, rostral is to the top and medial is to the right. **A,** Initial exposure reveals lateral edge of lamina (L) joining the medial facet (F) with fine up-going curette inserted under caudal edge of laminofacet junction. **B,** After initial laminotomy, the ligamentum flavum (LF) is seen with adjacent facet (F). **C,** After foraminotomy, the lateral edge of dura (D) and decompressed nerve root (NR) in the proximal foramen are revealed.

superior articular facet, exposing the medial border of the caudal pedicle. The nerve root is located directly above the caudal pedicle and anterior to the superior articular facet. The ligamentum flavum can be removed medially after the foraminotomy to expose the lateral edge of the dura and proximal portion of the nerve root. Progressive lateral dissection can then proceed along the root as it enters the foramen. The venous plexus overlying the nerve root should be carefully coagulated with bipolar cautery and incised. With the root well visualized, a fine-angled dissector can be used to palpate ventrally to the nerve root for osteophytes or disc fragments. Should an osteophyte be present, a down-angled curette may be used to tamp the material further ventrally into the disc space or fragment it for subsequent removal. In the case of a soft disc herniation, a nerve hook may be passed ventrally and inferiorly to the root to gently tease the fragment away from the nerve for ultimate removal with a pituitary rongeur. In either case, additional drilling of the superomedial quadrant of the caudal pedicle allows greater access to the ventral pathology and obviates the need for excessive nerve root retraction superiorly (Fig. 70-5).

DECOMPRESSION FOR STENOSIS

In this case, ipsilateral laminotomy of the levels of interest is performed and the ligamentum flavum is left in place to protect the dura. The tube is then angled about 45 degrees off the midline such that the tube is oriented to visualize the contralateral side. A plane between the ligament and undersurface of the spinous process is gently dissected with a fine curette. The drill with guard sleeve extended is then used to progressively drill the undersurface of the spinous process and contralateral lamina all the way to the contralateral facet. This initial decompression allows greater working space within which to remove hypertrophied ligament while avoiding downward pressure on the dura and spinal cord. Dissection and removal of the ligamentum flavum with curettes and Kerrison rongeurs may now proceed safely. Any compressive elements of the contralateral facet or the superior edge of the caudal lamina may also be drilled off or removed with Kerrison rongeurs at this time because their impact on the dura is more apparent with the ligament removed. After gently confirming decompression over to the contralateral foramen with

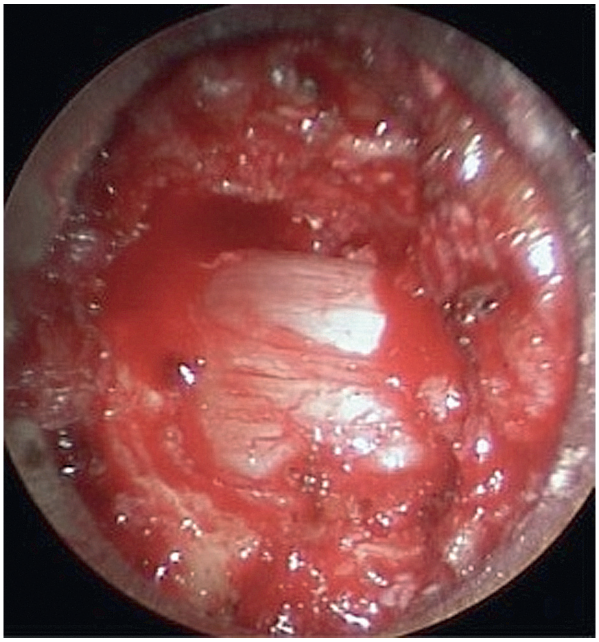

Figure 70-6. Intraoperative endoscopic photograph during right-sided approach. The dura is completely decompressed in this image, following removal of offending bone and ligament. Rostral is to the right and lateral is to the bottom.

a fine probe, the tube is returned to its original position to complete the ipsilateral removal of ligament and bone. This should then reveal completely decompressed and pulsatile dura (Fig. 70-6). If indicated, ipsilateral foraminotomy, as described earlier, also may be performed at this time.

Lateral Mass Fixation

After exposure of the facet joint, a hand drill is used to create a pilot hole with a 2.5-mm drill and a 14-mm stopping length. Care is taken to avoid disruption to facet capsules that are not to be fused. The tubular retractor should be angled 15 degrees cephalad for optimal screw placement. The starting point is 1 mm medial to the midpoint of the lateral mass in the medial-lateral plane and in the middle of the lateral mass in the cephalad-caudad plane, and the trajectory will be 15 degrees cephalad and 30 degrees lateral and parallel to the facet joint. It is important to visualize both the medial and lateral extent of the lateral mass to ensure a proper entry point and trajectory. Polyaxial screws 3.5 mm in diameter are inserted after tapping, and a rod is fixed with setscrews. The retractor can be angled and adjusted to reach each level to be fused. The screws are inserted on the side of the decompression and foraminotomy through the same incision used to approach the pathology.

Closure and Postoperative Care

Local anesthetic is injected into the fascia and muscles surrounding the incision. The wound is closed using one or two absorbable stitches for the fascia, two or three inverted stitches for the subcutaneous layer, and a running subcuticular stitch and Dermabond for the skin. After awaking from general anesthesia, the patient is brought to the postanesthesia care unit and mobilized as early as possible. No collar is necessary. The patient can be discharged the same or next day if medically stable.

Outcomes and Results

Favorable outcomes were reported in the literature for posterior cervical foraminotomy with a range between 75% and 100%.[1,3,10,45-53] Krupp and colleagues separated the outcomes by soft, hard, and mixed pathology, with favorable outcomes of 98%, 84%, and 91%, respectively.[46] Jodicke and colleagues reported a significantly better outcome for soft discs compared to hard discs in early follow-up, but no difference was found at long-term follow-up.[48]

The reports of minimally invasive, microscopic, and microendoscopic posterior cervical foraminotomy have demonstrated equivalent efficacy to the open technique, but the blood loss, length of stay, and postoperative pain medication usage were reduced with the minimally invasive techniques.[10,14,22,23,27,28,49] Fessler and Khoo prospectively used cervical microendoscopic posterior foraminotomy in 25 patients and compared the results with another 26 patients treated via open cervical laminoforaminotomy.[10] The microendoscopic group had a lower overall operative time (115 versus 171 minutes), less blood loss (138 versus 246 mL), shorter postoperative hospital stay (20 versus 68 hours), and fewer postoperative narcotic medications (11 versus 40 equivalents) when compared with the open technique group.

Ruetten and associates conducted a prospective, randomized, controlled study with lateral cervical herniations, operated either in a full endoscopic posterior foraminotomy (89 patients) or conventional microsurgical anterior technique with fusion/plating (86 patients), with 2 years of follow-up.[22] There was no significant difference between the groups in the clinical outcome, revision, or complication rates. Preservation of motion was conserved in the full endoscopic posterior group.

Perez-Cruet and Fessler have reported on five patients undergoing cervical microendoscopic decompression for stenosis at one, two, or three levels.[18] All patients demonstrated improvement in their myelopathy and returned to work with the only complication being one unintended durotomy that sealed spontaneously. Yabuki and colleagues performed endoscopic partial laminectomy in 10 patients with degenerative cervical compressive myelopathy.[30] All patients experienced symptomatic improvement with slight postoperative wound pain. The mean operative duration was 164 ± 35 minutes and the intraoperative blood loss was 45.5 ± 27 mL. Skovrlj and the senior author retrospectively reviewed 70 patients with 95 operated levels, from a prospective cohort who underwent MIS posterior foraminotomy with or without discectomy with average follow-up of 32.1 months.[50] They found a complication rate of 4.3% and 7.1% patients went on to have subsequent anterior cervical discectomy and fusion (ACDF) an average of 44.4 months after the initial surgery. There was a low rate at 0.9% per level per year of adjacent-level disease requiring fusion. Patients had both their neck disability index (NDI) and visual analog scale (VAS) decrease significantly postoperatively, but the NDI improvement decreased gradually with time and the VAS tended to plateau. Liu and colleagues[51] compared posterior MIS laminoforaminotomy to cervical disc arthroplasty in consecutive groups of 52 and 45 patients respectively, with at least a 2-year follow-up and found that both procedures were acceptable alternatives to ACDF in their clinical outcomes. MIS laminoforaminotomy had the benefit of less operative blood loss, decreased operative time, less fluoroscopy time, and shorter hospital stay. Mansfield and coworkers[52] compared the direct costs of MIS posterior cervical foraminotomy to the standard ACDF in 101 patients with cervical radiculopathy. They found that the average cost of ACDF was 89% more than the cost of MIS foraminotomy ($8192 versus $4320).

Assessing MIS lateral mass screw placement, Wang and colleagues retrospectively reviewed 18 patients using the technique.[38] In two cases, the minimally invasive technique was converted to the standard open technique because of the inability to visualize anatomic landmarks on fluoroscopy (bulky shoulders). Successful fusion was documented in all cases, and there were no hardware failures during the minimum 2 years of follow-up. Two patients were lost to follow-up after 6 months.

Complications

The posterior cervical foraminotomy is a safe procedure associated with a low rate of complications (1% to 15%),[1,3,10,14,22,23,27,28,45,49-51] with wound infection and dural tear being most commonly reported. The senior author has no infection to date in his microendoscopic series, and the unintended durotomy rate has dropped from 8% in the initial series of patients[10] to 1.4% in the most recent series.[50] Direct suture repair of durotomy can be difficult through the narrow-diameter tubes or small incisions. Ruban and O'Toole[54] reported their experience treating 53 patients with unintended durotomy through tubular retractors. The defect was first covered with hemostatic gelatin and a cottonoid patty to assess whether it is full or partial thickness, and whether can be primarily repaired or not. Those that are partial thickness or cannot be primarily repaired can be treated with a combination of Gelfoam, muscle graft, and fibrin glue. When primary repair is possible, a watertight closure is complemented with fibrin glue and a non-watertight closure can be augmented again with a combination of muscle, collagen matrix, and fibrin glue. All patients are kept on overnight bed rest (< 24 h) after repair. Primary repair is possible with a modified bayonetted curved needle holder and a bayoneted Chitwood Knot Pusher (Scanlan International) that facilitates tight suture knots through the tubular retractor with interrupted Nurolon (Ethicon) sutures. In their series there were no postoperative CSF cutaneous fistula, pseudomeningocele, or any complications related to the durotomy. Ultimately, the small opening and relative lack of dead space after minimally invasive procedures have made the incidence of postoperative pseudomeningoceles and CSF-cutaneous fistulae negligible.

Potential neurologic complications include radicular injury from manipulation within the tight foramen or direct mechanical spinal cord injury during dilation or decompression. Vertebral artery injury can be avoided by early detection of dark venous bleeding from the venous plexus surrounding the artery that may arise from accidental dilation lateral to the facet or during overly aggressive dissection laterally in the foramen. This type of bleeding can typically be controlled by packing with Gelfoam or another hemostatic product.

Postoperative muscular pain and spasm from subperiosteal dissection are minimized with the transmuscular microscopic and microendoscopic techniques.

ANTERIOR MINIMALLY INVASIVE APPROACHES FOR THE CERVICAL SPINE

Anterior cervical discectomy and fusion (ACDF) was first described by Smith and Robinson and then by Cloward in the 1950s.[55-57] Orozco Delclos introduced anterior plating in 1970 as adjunctive treatment in cervical fractures.[58] Since then, several types of plates and grafts have been developed. ACDF has now developed as a standard procedure in the treatment of cervical radiculomyelopathy. It is described as a safe and efficacious procedure with good fusion rates. However, several problems can occur, mainly because of access complications and adjacent segment degeneration as a disadvantage of fusion. Hilibrand and colleagues postulated that up to 25% of the patients who undergo a ventral cervical fusion could require treatment for degenerative changes of the adjacent segments within 10 years.[59] With the fascination of minimally invasive techniques and the intent to preserve motion and prevent adjacent segment disease, several anterior alternative approaches have been reported: (1) anterior cervical foraminotomy (microsurgical and endoscopic); (2) percutaneous ventral cervical procedures for discectomy, annuloplasty, and stabilization/fusion; and (3) cervical arthroplasty. The final approach is not discussed in this chapter.

Anterior Cervical Foraminotomy (Microsurgical and Endoscopic)

Anterior approaches to the neuroforamen have continued to evolve since Verbiest's description in 1968, describing a ventrolateral approach to the cervical neuroforamen, which involved sectioning of the longus colli muscle, exposure of the transverse process, mobilization of the vertebral artery, and performing discectomy with and without fusion.[60] In 1976, Hakuba described the transuncodiscal approach. In his approach, the vertebral artery was not displaced, and a complete discectomy was performed with and without fusion.[61] In 1989, Snyder and Bernhardt published a new anterior cervical fractional interspace decompression technique, which consisted of a 6-mm-wide cylindric bur hole in the lateral third of the intervertebral disc, and fragmentectomy. They reported minimal disc space collapse and a 4% rate of spontaneous fusion.[62] In 1996, Jho described the anterior cervical foraminotomy with resection of the uncus process, lateral portion of the rostral end plate, and lateral portion of the intervertebral disc. This technique required cutting of the longus colli muscle and exposure of the vertebral artery along its medial surface.[63] In 2002, Saringer proposed a modification of Jho's technique by preserving a thin piece of cortical bone of the lateral wall of the uncinate process, avoiding exposure of the vertebral artery,[64] and he added the endoscope to his procedure in 2003.[65] Again in 2002, Jho reported an upper vertebral transcorporeal foraminotomy technique. The hole in this technique was drilled at the most lateral and inferior 4 to 5 mm of the upper vertebral body.[66] The cartilage end plate was exposed and entered in its posterior third. In 2007, Choi and associates described a modification of the upper vertebral transcorporeal Jho's approach, made by drilling the hole more medially, to avoid cutting the longus colli muscle and exposing the vertebral artery.[67] The evolution of this technique has led to (1) having less disc disruption, (2) avoiding exposure of the vertebral artery, and (3) avoiding cutting the longus colli muscle, which could injure the sympathetic chain.

Indications and Contraindications

This procedure is indicated in patients with unilateral radicular symptoms, at single or multiple levels, due to a dorsolateral soft-herniated disc or uncovertebral osteophytes. Contraindications include bilateral radiculopathy, instability, central herniated disc, severe spinal canal stenosis, instability, and severe axial pain.

Preoperative Evaluation

History taking and the physical examination should confirm the unilateral radicular pain, with absence of significant neck pain. Standard anteroposterior, lateral, oblique, and flexion/extension radiographs help to visualize the bony anatomy, especially the uncovertebral joints and the foramens, and rule out instability. MRI evaluation is sufficient most of the time to visualize the herniated disc or osteophytic compression in the foramen. Vertebral artery anatomy and possible variations or anomalies should be reviewed to avoid access injury and possible catastrophic complications. Sometimes, a thin-slice CT scan is requested if better bony anatomy details are necessary.

Surgical Technique

The initial steps for this technique are similar to the open ventral cervical approach. It is performed under general anesthesia and on a standard operating room table. The patient is positioned supine with the head in neutral position and slight extension. A roll is placed between the shoulders. The shoulders are taped with down longitudinal traction to allow visualization of the lower cervical levels if necessary. Fluoroscopy is used to mark the transverse 3- to 4-cm skin incision at the side of the radiculopathy, with one third of it lateral and two thirds medial to the medial border of the sternocleidomastoid muscle. Preparation and draping are done as usual.

After the skin incision, the platysma muscle is sectioned along the same line. The superficial cervical fascia is opened medial to the sternocleidomastoid muscle and blunt dissection is directed deeply to the spinal column, with the vascular structures retracted laterally and the trachea and esophagus medially. The prevertebral fascia is opened, and the anterior parts of the vertebral bodies with intervertebral discs and longus colli muscles are exposed. The level of concern is again checked with fluoroscopy. As mentioned earlier, several techniques and modifications have been reported. These can be divided into two main approaches: (1) the transuncal approach and (2) the transcorporeal approach.

Transuncal Approach. The medial border of the longus colli muscle is cut perpendicularly and retracted or excised to expose the medial aspect of the transverse process and the uncinate process of the lower vertebrae. Care should be taken when exposing the C6-7 level because the vertebral artery lies between the transverse process of C7 and the longus colli muscle. The next steps are performed under microscopic magnification or using the endoscope as described by Saringer in his 2003 technique modification.[65] According to Jho, in his first description,[63] the uncinate process is undertaken with a 2-mm high-speed drill, leaving a thin dorsolateral rim of cortical bone that limits the vertebral artery laterally and the nerve root dorsally. The thin cortical bone is removed with a curette and a Kerrison rongeur. The posterior longitudinal ligament is exposed, which covers the nerve root posteriorly. At this point, the foraminotomy is completed and the uncovertebral osteophyte is removed. In case of a herniated disc, the posterior longitudinal ligament should be excised with a curette and Kerrison rongeur and the disc fragment removed. Epidural bleeding could be troublesome and should be controlled with bipolar cauterization or by application of Gelfoam and cottonoid. Saringer, in his microscopic[64] and endoscopic[65] techniques (Figs. 70-7 and 70-8), described two essential modifications to Jho's transuncal approach: (1) leaving the lateral cortical rim of the uncinate process to protect the vertebral artery and (2) extending the foraminotomy by removing more bone from the caudal dorsolateral aspect of the rostral vertebrae.

Transcorporeal Approach. In his technique modification of the transcorporeal approach, Jho described drilling a hole through the ventral caudolateral portion of the caudal or rostral vertebrae[66] that extends dorsally to reach the dorsal portion of the uncinate process. Only this dorsal portion is removed. The uncovertebral osteophyte is removed, and, as described earlier, the posterior longitudinal ligament should be opened if a disc fragment has to be removed. This approach reduced the disc disruption comparatively with the transuncal approach. Choi and colleagues more recently described a modification of this technique made by starting the hole more medially on the upper vertebrae to avoid cutting the longus colli muscle and its related possible complications.[67] They also stated that a transcorporeal approach through the inferior vertebrae could be feasible, especially for the upper cervical levels (Fig. 70-9). Due to the anatomy at the C3-4 level, entry through the caudal vertebral body was preferred by Jho and entry through the rostral vertebral body preferred for the other levels.

Once the decompression is completed, the platysma is closed as usual with 3-0 absorbable sutures. The skin is closed

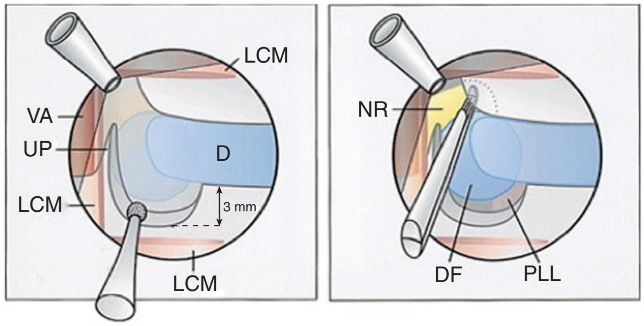

Figure 70-7. *Left*, Under the endoscope, the medial portion of the longus colli muscle (LCM) is excised and the lateral portion of the disc (D) and the uncus process (UP) are exposed. The UP is drilled up. A thin piece of the lateral wall of the UP is left, serving as a landmark and protective layer for the underlying vertebral artery (VA). Periosteum covers the nerve root, disc fragments, and lateral portion of the posterior longitudinal ligament (PLL). The intervertebral disc is maintained in its form. The VA is intentionally not exposed. *Right*, The periosteum and cartilaginous and degenerative fibrous tissue between the tip of the UP and the rostral end plate and osteophytes at the dorsolateral cephalad end plate are removed using a 1- or 2-mm thin-foot Kerrison rongeur. Disc fragments (DF), parts of the nerve root (NR), and lateral parts of the PLL are exposed. *(Modified from Saringer WF, Reddy B, Nöbauer-Huhmann I, et al: Endoscopic anterior cervical foraminotomy for unilateral radiculopathy: anatomical morphometric analysis and preliminary clinical experience.* J Neurosurg *98(Suppl 2):171–180, 2003.)*

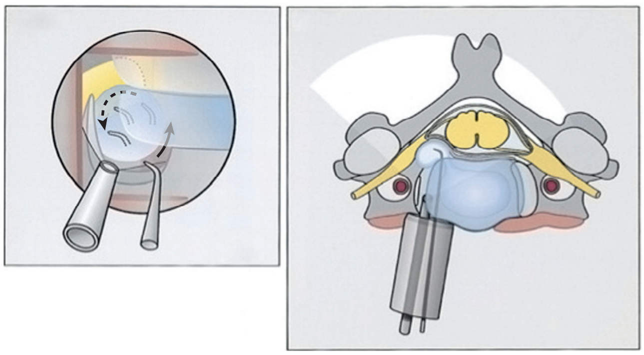

Figure 70-8. *Left* and *right*, Transtubular and axial depiction of the last step of the operation shown in Figure 70-7. To improve visualization, the endoscope is positioned with its tip inside the drilled canal. Herniated disc fragments are mobilized with a microhook. *(Modified from Saringer WF, Reddy B, Nöbauer-Huhmann I, et al: Endoscopic anterior cervical foraminotomy for unilateral radiculopathy: anatomical morphometric analysis and preliminary clinical experience.* J Neurosurg *98(Suppl 2):171–180, 2003.)*

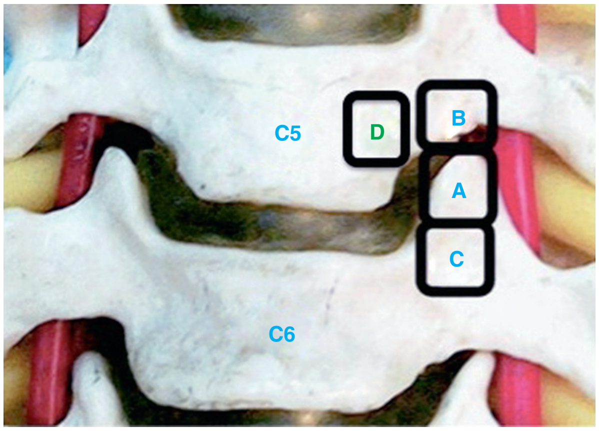

Figure 70-9. Photograph of a cervical spine model demonstrating bone entry sites. A, Transuncal approach as originally described by Jho. **B,** Upper transcorporeal approach as described by Jho. **C,** Lower transcorporeal approach. **D,** Upper transcorporeal approach as described by Choi and colleagues.

with a subcuticular suture and Dermabond. No cervical collar is necessary postoperatively, and activity is advanced as tolerated.

Outcomes and Results

The microscopic or endoscopic anterior cervical foraminotomy for unilateral cervical radiculopathy has been shown to be an effective and safe procedure. Johnson and coworkers reported their series of 21 patients operated on by Jho's original technique (transuncal) and followed between 6 and 36 months.[68] Nineteen patients (91%) had improved or resolved radicular symptoms, and two (9%) had persistent radicular symptoms necessitating further surgery. No patients had evidence of instability or loss of disc height on lateral radiographs at 3 months postoperation. Saringer and colleagues reported in 2002 his results of 34 patients operated on with microscopic uncoforaminotomy.[64] The follow-up period varied from 2 to 17 months with a mean of 8.2 months. The large majority (97%) of patients were pleased with the results of their operation. The relief of neck pain and radicular pain in the affected dermatome was immediate in all patients. Motor weakness and sensory deficit improved dramatically immediately after the operation and improved to normal in the majority of patients within 3 to 6 months. One of the patients had a repeat herniation on the second postoperative day but recovered completely after reoperation and continued to do well at the 6-month follow-up. In 2003, Saringer and associates reported their results from 16 patients operated on with endoscopic uncoforaminotomy.[65] During a mean follow-up period of 13.8 months, an average absolute improvement of 44% ($P > .05$) in the neck disability index score and of 96% ($P > .05$) in the visual analog scale score for radicular pain (compared with the preoperative score) was observed In a large series, Kim reviewed a single surgeon experience of 97 transuncal procedures in 85 patients based on Jho's original approach.[69] Indications for operation included spondylosis, disc herniation, and a mix of the two. Follow-up occurred at a minimum of 3 years, and both patient recorded outcomes and radiographic parameters were evaluated. It was found that 90.3 % of patients achieved an excellent or good outcome, with improvement in VAS and NDI. Disc height was decreased by a mean of 1 mm, which was found to be positively correlated with intraoperative disc invasion, thus defining the importance of avoiding disc space violation making the foraminotomy only as large as required to remove the compressive lesion.

Hacker and Miller are the only researchers to report a significant number of poor outcomes (poor 35% and fair 13%) and a high reoperation rate (30%).[70]

Jho and colleagues reported their results for 104 patients in which they progressed from a transuncal to transcorporeal approach.[66] Specifically they used the transuncal approach for the first on third of their reported cohort, excepting the C34 level, the lower vertebral transcorporeal approach for cases at C34 and the remaining two thirds of patients had the upper vertebral transcorporeal approach. Ninety-nine percent experienced excellent or good results. One patient developed discitis, which resulted in bony fusion. All other patients maintained their motion segments. They concluded that the transition from transuncal to transcorporeal was a natural progression in cases to better decompress the foramen due to the nature of the cephalad curvature of the disc space in the region. Choi and colleagues reported their results from 20 patients operated on by their transcorporeal technique.[67] The maximum follow-up was 1 year. All patients experienced immediate postoperative relief of their radicular symptoms and recovery of their neurologic symptoms. The percentage change in disc height was only 6% from the baseline value, but the difference was statistically significant ($P = .005$). They noted that the loss in disc height seemed to stabilize after 3 months postoperation.

Hong and associates compared the results of the transuncal approach (40 patients) and the transcorporeal approach (20 patients).[71] The mean follow-up period was 9.5 months. They analyzed postoperative changes of disc height, the spinal instability, the average length of hospital stay, the degree of patients' satisfaction, and complications from each approach. They also stated that the transcorporeal approach is a better surgical technique than the transuncal approach, considering the preservation of disc height, spinal stability, length of hospital stay, degree of satisfaction, and complications.

Complications

Possible complications are mostly the same as for a standard anterior cervical approach. As in some of these techniques when the longus colli muscle is cut, risk of injury of the sympathetic chain could be higher. This outcome is true especially at the lower cervical levels, where the sympathetic chain becomes more medial on the longus colli muscle. Jho reported 2 transient Horner syndromes in his 104-patient series.[66] With Choi's technique, this complication could be avoided. Injury of the vertebral artery is another concern of these techniques. Meticulous review of the anatomy of the vertebral artery on the imaging studies and good knowledge of the anatomy of this region should help to avoid this complication. Adjacent segment degeneration, and loss of cervical stability due to removal of the uncovertebral joint is another concern. This relates to the high reoperation rate reported after the procedure by Hacker and Miller,[70] who postulated that resection of the uncovertebral joint combined with degenerative disc disease lead to hypermobility and pain. On the contrary, Kim[69] did not find that the extent of uncovertebral joint resection led to hypermobility, but that disc violation and loss of disc height were associated with changes in stability.

Percutaneous Ventral Cervical Procedures for Discectomy, Nucleoplasty, and Stabilization

In 1963 to 1964, Smith introduced the chemonucleolysis with chymopapain to treat herniated discs.[72,73] In 1975, Hijikata developed the percutaneous lumbar discectomy and reported

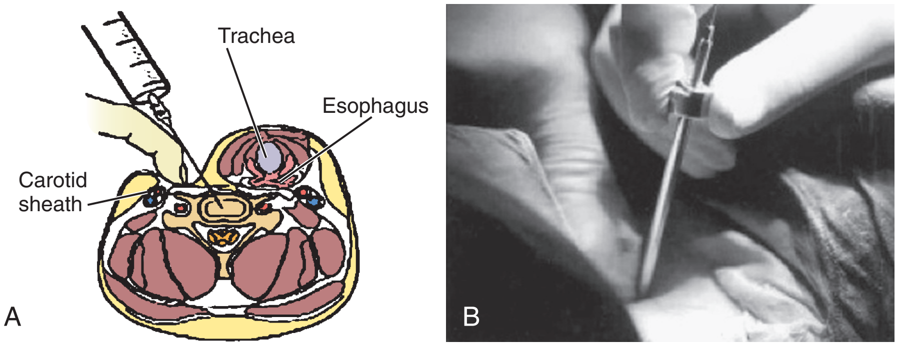

Figure 70-10. Illustration of needle insertion (**A**) and intraoperative view of serial dilation (**B**). The tracheoesophagus is displaced medially, and the carotid artery is displaced laterally with the surgeon's finger. An 18-gauge spinal needle is then inserted into the disc space under fluoroscopic monitoring, and a percutaneous approach using sequential dilation is performed. *(Modified from Lee SH, Ahn Y, Choi WC, et al: Immediate pain improvement is a useful predictor of long-term favorable outcome after percutaneous laser disc.* Photomed Laser Surg *24:508–513, 2006.)*

his series of 136 cases 12 years later.[74] In 1986, Ascher reported the laser discectomy.[75]

The percutaneous ventral cervical approach was first described by Smith and Nicole in 1957, as the cervical discographic technique for the diagnosis of discogenic pain.[76] Despite its low complication rates (0.16% to 2.48%),[77-79] its use was limited due to the catastrophic consequences that can occur if a complication developed. Although controversies still exist, several reports of related percutaneous cervical discectomy (PCD) procedures have been reported: (1) PCD with chemonucleolysis,[80] (2) automated/coblation PCD,[81-86] (3) PCD with laser,[87-94] (4) PCD with endoscopic combined manual andlaser,[87,94-99] and (5) PCD with stabilization.[87,100]

Indications and Contraindications

Patients who present with new onset of cervicobrachial neuralgia, due mainly to recent soft disc herniation (contained), and who are nonresponsive to conservative treatment and without severe neurologic deficit could be considered for PCD with laser, coblation, or chemonucleolysis. In the same clinical scenario, but with noncontained herniated disc, PCD with endoscopic combined manual and laser is recommended. Percutaneous stabilization is indicated when axial symptoms predominate, in case of angular instability (kyphosis), and when cervicoencephalic pain is reproduced by discography.[87,100]

These procedures are contraindicated in patients with migrated or calcified discs, advanced spondylosis, significant anterior bony spurs that could block the entry into the disc, cervical canal stenosis, myelopathy, or evidence of instability, and in those who had previous neck surgery.[87,96,98]

Surgical Technique

The procedures could be performed under local or general anesthesia. The patient is placed in the supine position, as for a conventional anterior cervical approach. A roll is placed under the shoulders, and the shoulders are taped down for better visualization of the lower cervical levels as needed. Preparation and draping are completed as usual. The choice of the side of approach depends on the surgeon's preference, but an approach contralateral to the side of the lateral herniated disc is preferable. Fluoroscopic guidance is used through the procedure for anatomic orientation. The level of interest is identified with fluoroscopy, using a K-wire. The point of skin entry is at the medial border of the sternocleidomastoid muscle. Firm pressure is applied digitally at this level between the sternocleidomastoid muscle and the trachea, and pointed toward the cervical spine. The larynx and esophagus are displaced medially, and the carotid artery is displaced laterally (Fig. 70-10). The esophagus could be made more prominent with the insertion of a nasogastric tube, and the carotid pulse is augmented with sympathomimetics. After palpation of the anterior cervical spine, an 18-gauge spinal needle is placed in the disc space of concern under fluoroscopic guidance. A guidewire is passed through the spine needle and then removed. A 3- to 5-mm skin incision is made, depending on the procedure and instruments to be used. To assist the placement of the endoscope or the working cannula, 3- to 5-mm dilators are passed through the K-wire. Specific instruments are then used to perform the discectomy, with papain (chemonucleolysis), loop-shaped electrode (automated PCD), laser, microcurette, and microforceps, as well as graft for fixation (Figs. 70-11 to 70-14).

In the case of microendoscopic anterior cervical discectomy and fusion (MACDF), similar to posterior MIS procedures, serial endoscopic dilators are placed over the K-wire, and an 18-mm tubular retractor is placed and held by a flexible arm to the operating room table. The discectomy is carried out through this working channel guided with visualization by the endoscope.

Outcomes, Results, and Complications

Good-to-excellent clinical outcomes were reported in the literature, ranging from 80% to 85% for automated PCD,[82-85] 75% to 94.5% for laser PCD,[90,91,93,94] 80.2% to 94.5% for PCD with manual resection and laser,[95-98] and 86.36% for chemonucleolysis.[80] Predictors of good outcome were found to be radiating arm pain, lateral disc location herniation, and the presence of immediate postoperative pain relief.[95-97] Radiographically, Ahn and colleagues showed a significant decrease in the disc height by 11.2% postprocedure, with maintenance of overall and focal sagittal alignments.[96] There was no segmental instability or spontaneous fusion noted. Interestingly, complication rates were less than 1%, without any catastrophic complications.[80,84,85,90,93,95,98] The most serious complications were infection[85] and postoperative hematoma due to rupture of the inferior thyroid artery,[84] not of any major vessels. Good knowledge of the cervical anatomy, understanding the safety zone of work for each level,[101] and liberal use of fluoroscopic guidance will help to avoid complications in these procedures.

Li and associates compared retrospectively the percutaneous cervical disc nucleoplasty (42 patients) with the percutaneous cervical discectomy (38 patients).[102] The average follow-up was 12 ± 4 to 5 months. There was no significant

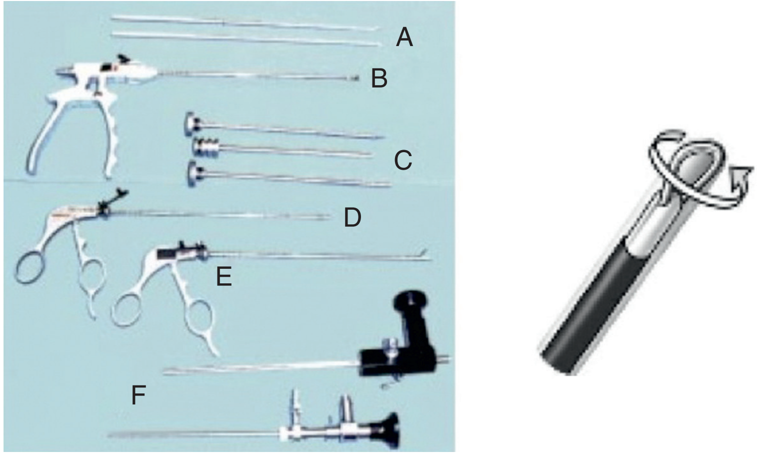

Figure 70-11. Minimally invasive spine surgery instruments. *Left:* **A,** Minicurettes. **B,** Discectome. **C,** Discectomy dilator/cannula/trephine. **D,** Cutter forceps. **E,** Grasper forceps. **F,** Endoscopes. *Right:* Loop-shaped electrode. *(*Left, *Modified from Chiu JC, Clifford TJ, Greenspan M, et al: Percutaneous microdecompressive endoscopic cervical discectomy with laser thermodiskoplasty.* Mt Sinai J Med *67:278–282, 2000.* Right, *Modified from Bonaldi G, Baruzzi F, Facchinetti A, et al: Plasma radio-frequency-based diskectomy for treatment of cervical herniated nucleus pulposus: feasibility, safety, and preliminary clinical results.* AJNR Am J Neuroradiol *27:2104–2111, 2006.)*

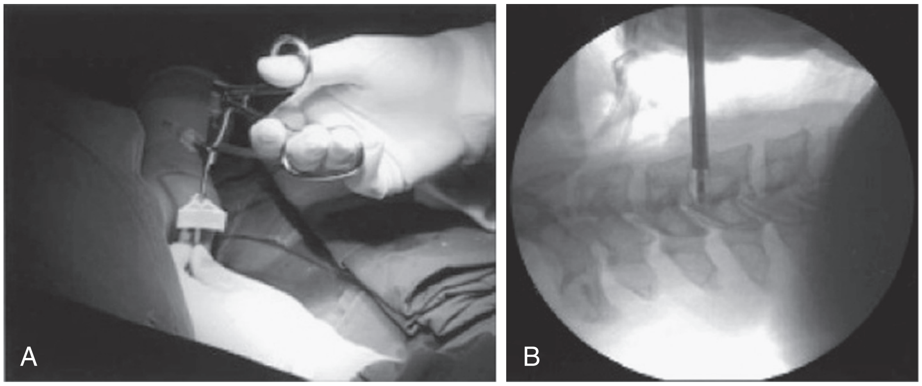

Figure 70-12. Intraoperative view (**A**) and C-arm view (**B**) of manual discectomy using microforceps. *(Modified from Lee SH, Ahn Y, Choi WC, et al: Immediate pain improvement is a useful predictor of long-term favorable outcome after percutaneous laser disc decompression for cervical disc herniation.* Photomed Laser Surg *24:508–513, 2006.)*

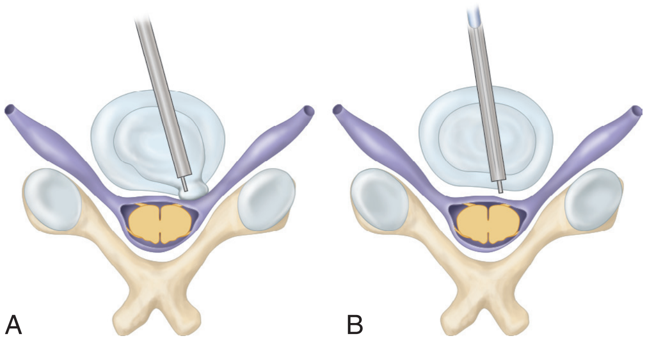

Figure 70-13. Schematic diagram of percutaneous endoscopic cervical discectomy. A, Cross-sectional view through the disc level. The disc fragment is removed by microforceps under high-resolution endoscopic visualization. **B,** Cross-sectional view through the uncovertebral joint level. The side-firing Ho:YAG laser can safely ablate the osteophytes.

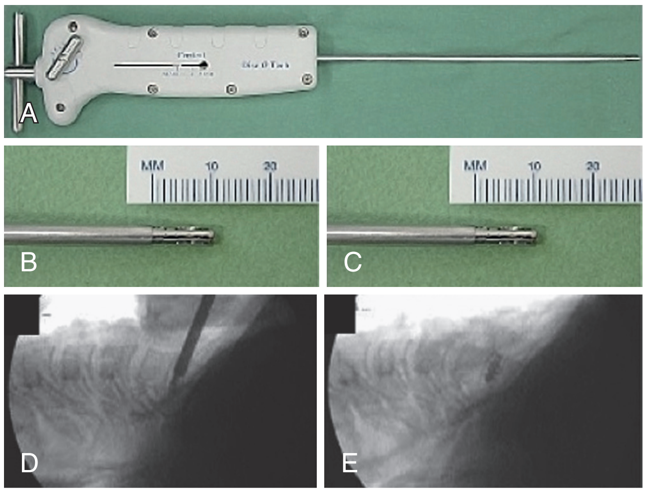

Figure 70-14. The cervical B-Twin with its delivery system (**A**), in its reduced form (**B**) and its expanded form (**C**). After its proper positioning in the cervical disc space (**D**), manual rotating leads to expansion of the implant and then the implant is released from the delivery system (**E**). *(Modified from Lee SH, Lee JH, Choi WC, et al: Anterior minimally invasive approaches for the cervical spine.* Orthop Clin North Am *38:327–337, 2007.)*

difference of the clinical outcomes for the two groups, but operative time was significantly lower for the nucleoplasty group.

Ruetten and coworkers conducted a prospective, randomized, controlled study to compare the results of full-endoscopic anterior cervical discectomy (FACD) (60 patients) with those of ACDF (60 patients) in mediolateral soft disc herniations.[103] Patients were followed for a period of 2 years. Operative time and blood loss were less in the FACD group. There was no significant difference in the clinical outcomes, the progression of preexisting adjacent disc degeneration, or the increase of the postoperative kyphotic angle at the operated segment between the two groups. Revision rates were 6.1% for the ACDF group and 7.4% for the FACD group.

The MACDF approach was described by Tan and colleagues[104] in 36 patients after an endoscopic ACDF feasibility study; the researchers found that C45 and C56 were most amenable to the approach. Yao and associates[105] reported 5-year follow-up data in 67 patients and found excellent or good improvement in 86.6% of patients. Soliman[106] conducted a blinded randomized controlled trial of 70 consecutive patients (35 each group) to traditional ACDF or microendoscopic anterior cervical discectomy with fusion (MACDF) and with an average follow-up of 28 months. They found a statistically significant reduction in the hospital stay and in the amount and duration of postoperative analgesics with MACDF. The incidence of patient-reported laryngopharyngeal complications was significantly higher in the ACDF group. It was reported that all patients had solid fusion at 1-year follow-up save for 1 asymptomatic pseudarthrosis in the MACDF group. Overall 91% of patients reported good to excellent functional outcome in the MACDF group and 94% in the ACDF group. The clinical outcomes of these techniques seem promising but have not yet been widely adopted due to thought that some of the clinical benefit may result from the natural history of disc herniation and cervical radiculopathy. Microendoscopic ACDF also has promising early data with reduction of laryngopharyngeal complications compared with traditional ACDF, but the learning curve and lack of long-term data so far has limited widespread adoption.

SUMMARY

Minimally invasive techniques have gained popularity. Benefits from these approaches include less surgical trauma, preservation of the anatomic structures leading to preservation of spine biomechanics earlier recovery, fewer complications, better cosmesis, and similar or better clinical outcomes to traditional open techniques. More data are being published suggesting that MIS techniques also provide cost benefits on a per case basis. Both ventral and dorsal cervical applications seem promising, with multiple techniques continuing to be developed and refined. Careful patient selection, excellent anatomic knowledge, and technical skills are required to achieve good clinical results while minimizing patient morbidity. Direct comparative studies with open techniques are showing benefits to MIS approaches, and these will be the basis of evidence in using and advancing these techniques.

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