

A REVIEW OF LAMINOFORAMINOTOMY FOR THE MANAGEMENT OF LATERAL AND FORAMINAL CERVICAL DISC HERNIATIONS OR SPURS

Nancy E. Epstein, M.D.

Clinical Professor of Neurological Surgery, The Albert Einstein College of Medicine, Bronx, New York and Attending, Department of Neurosurgery, The North Shore Long Island Jewish Health System, Manhasset, New York and New Hyde Park, New York

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BACKGROUND

Anterior versus posterior surgical management of lateral and foraminal cervical disc disease remains controversial. The key hole foraminotomy or laminoforaminotomy allows dorsal resection without the instability encountered with anterior cervical approaches, with more limited morbidity. Unilateral radiculopathy can be addressed with the laminoforaminotomy, while bilateral or multifocal radiculopathy with myelopathy may additionally require a laminectomy or laminoplasty.

METHODS

Selection of patients for laminoforaminotomy should be based upon correlation of clinical findings and neurodiagnostic (MR, CT) studies to ensure that the dorsal approaches will sufficiently address the pathology.

RESULTS

The technical completion of a laminoforaminotomy is reviewed.

CONCLUSIONS

Performing adequate preoperative MR and CT examinations allows for the selection of patients who will benefit from the "key hole" or "laminoforaminotomy" approaches to lateral and foraminal disc disease and/or spur formation. © 2002 by Elsevier Science Inc.

KEY WORDS

Key hole foraminotomy, laminoforaminotomy, cervical radiculopathy, disc herniation, spurs.

Key hole foraminotomy" or "laminoforaminotomy" are the terms used to describe the typical posterior approaches for resecting lateral or foraminal cervical disc herniations or spurs [1,3,6,

9,10,16,18,21]. They may be performed unilaterally at one or more levels, bilaterally at one or more levels (fenestration approach), or in combination with a laminectomy or laminoplasty. The clinical, neurodiagnostic, and technical performance of these procedures, along with the pros and cons of posterior-lateral versus anterior cervical surgery are reviewed (Figs. 1-7).

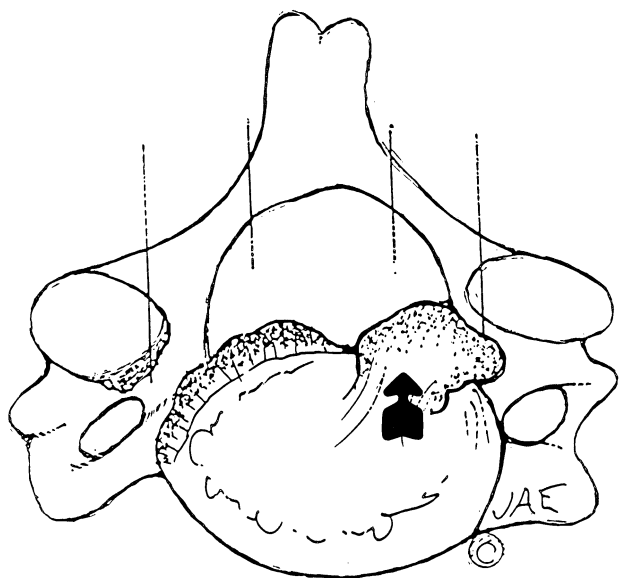
HISTORY

The posterior approach to cervical pathology was originally reported by Mixter and Barr, and the key hole foraminotomy was subsequently popularized by Scoville, Epstein, and Fager, Ducker later coining the term *laminoforaminotomy* [6,9,16,21]. However, despite the lesser intraoperative and postoperative risks compared with anterior approaches, the laminoforaminotomy has lost ground when compared with anterior approaches for the management of lateral and foraminal cervical pathology. The "pros" of the laminoforaminotomy are emphasized here to bring it back into the mainstream of alternatives for the management of lateral and foraminal cervical disc herniations and spurs.

SYMPTOMS AND SIGNS

Patients with lateral or foraminal disc disease or spurs present with radicular symptoms which include pain, numbness, tingling, or weakness in a specific nerve root distribution, and with accompanying radicular motor, reflex, and sensory deficits. In Kumar et al's series of 89 patients undergoing posterior cervical foraminotomy, 50% of patients

Address reprint requests to: Dr Nancy Epstein, Long Island Neurosurgical Assoc. P.C., 410 Lakeville Rd Suite 204, New Hyde Park, NY 11042.
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1 Unilateral foramininal disc (arrow) intruding into the neural foramen resulting in focal ventral nerve root compression. Spurs are evident on the other side.

had significant preoperative motor or sensory deficits [12].

LOCATION

Lateral or foraminal cervical disc herniations or spurs are most frequently located at the C6-C7 level where they produce a C7 nerve root syndrome. Subsequent levels involved, in descending order, include C5-C6 (C6 root deficit), C4-C5 (C5 root deficit), and C7-T1 (C8 root deficit) [6,15].

SURGICAL INDICATIONS

Anterior cervical surgery is generally indicated for the resection of midline or paramedian discs or spurs, while lateral or foraminal pathology may be approached with anterior discectomy with or without fusion, or posteriorly with a laminoforaminotomy [11]. Focal radicular symptoms or signs can be addressed with a unilateral laminoforaminotomy, while bilateral radicular complaints may require a fenestration technique. When myelopathy accompanies multifocal radiculopathy, hemilaminectomy, laminectomy, or laminoplasty may also be warranted [1-4,6-12,15-17,19].

NEURODIAGNOSTIC STUDIES

Adequate preoperative diagnostic testing with both magnetic resonance (MR) and computed tomography (CT) studies is critical when evaluating cervical pathology, to avoid discovering intraoperatively that the pathology is not accessible via the route chosen. Patients undergoing a one-level key hole foraminotomy or laminoforaminotomy present with focal radiculopathy [3,4,12]. MR studies provide an overview of posterior or anterolateral cervical disc disease, including disc herniations, spondylosclerosis, or focal forms of OPLL, but less clearly define lateral and foraminal pathology. Unfortunately, with MR calcification or ossification appear as a hypointense mass often indistinguishable from soft tissue disease. Performing additional CT studies helps differentiate between the two. While noncontrast CT studies may suffice in some cases, the myelo-CT examination may better demonstrate lateral and foraminal root impingement (Fig. 2).

PATHOLOGY

Lateral and foraminal encroachment may be attributed to soft disc herniations, hypertrophied, or ossified posterior longitudinal ligament, degenerative spondylotic changes of the uncovertebral joints, osteophytes arising from the posterior articular facets, or root sleeve fibrosis [6]. Intrusions superimposed on a stenotic spinal canal become symptomatic earlier, and cause greater neurological deficits.

BENEFITS

A major benefit of the laminoforaminotomy versus posterior discectomy with fusion is the preservation of stability, avoiding the need for fusion [14, 20]. Bracing is typically required for patient comfort up to 1 to 2 weeks postoperatively, and pseudarthrosis is not a factor. Additional benefits include the avoidance of postoperative tracheal edema, esophageal dysfunction, and stroke secondary to inadvertent compression of the different posterior structures.

LIMITATIONS

Following laminoforaminotomies, patients typically awaken without pain because of the use of intraoperative steroids. However, they often subsequently complain of radiculopathy that lasts for up to 6 postoperative weeks. Furthermore, if more than



2 Transaxial myelo-CT demonstrating right-sided anterolateral spur formation at the C7-T1 level (arrow).

50% of the facet joint has been compromised, it may become unstable and warrant secondary fusion.

INTRAOPERATIVE MONITORING

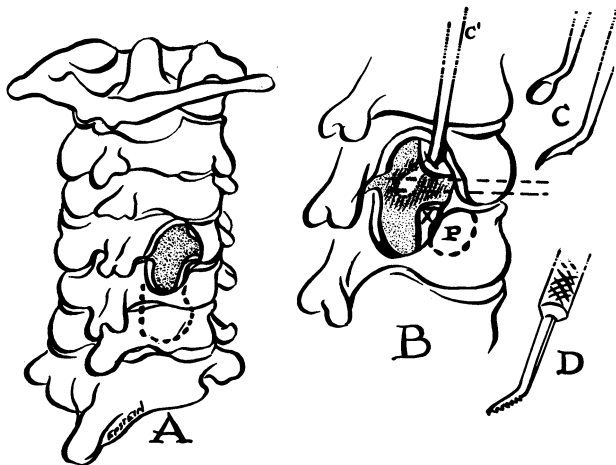
Continuous intraoperative somatosensory evoked potential (SSEP) (median or ulnar and posterior tibial nerves) monitoring can be performed during the entire procedure to assess cord function. However, electromyography (EMG) is performed only during foraminal nerve root dissection once the initial muscle relaxant has “worn off” to signal impending damage to the vulnerable motor root [8]. Other monitoring modalities include arterial lines, end tidal CO₂, EKG, and pulse oximetry. Patients in the sitting position, who are at greater risk for air embolism, are additionally monitored with central venous catheters and doppler devices placed over the right atrium. If air embolism occurs, visible venous bleeding sites should be coagulated, the wound should be packed with a saline soaked lap pad, and air should be aspirated from the right atrium using the central venous catheter. If air persists, the patient must be turned into the left lateral decubitus position to trap air in the right atrium.

ANESTHESIA: INTUBATION

Patients undergoing laminoforaminotomy with or without accompanying laminectomy or laminoplasty undergo fiberoptic nasotracheal or endotracheal intubation while awake. Once intubated, the three pin Mayfield head holder is applied using local anesthesia at the pin sites, and the patient is positioned awake, either prone or sitting, before the induction of anesthesia.

SITTING POSITION

When the sitting position is used, patients are given 1 liter of normal saline before they are slowly raised to the sitting position. Beginning at this point, and continuing throughout the duration of the procedure, the blood pressure must be maintained, avoiding hypotension. If a significant drop in the SSEPs occurs, involving amplitude (50%), latency (10%), or both parameters, hypertension should be artificially induced as these changes reflect “relative hypotension,” or underperfusion of the cord. Once SSEPs have stabilized with the patient remaining neurologically intact, induction may follow.



3 A. Right-sided key hole foraminotomy is illustrated at the C4-C5 level. The dotted line illustrates how a right-sided C5 hemilaminectomy combined with a C6 laminotomy would allow for decompression of pathology at the subjacent level. B. Through the laminoforaminotomy at C4-C5, the lateral aspect of the thecal sac and exiting C5 nerve root may be readily skeletonized. Dissection under the neural structures may be performed with a down-biting curette (C) either above or below the nerve root (X), adjacent to the pedicle. C. Here, the small down-biting curette is illustrated. D. A down-biting rasp may also facilitate spur excision.

PROS AND CONS

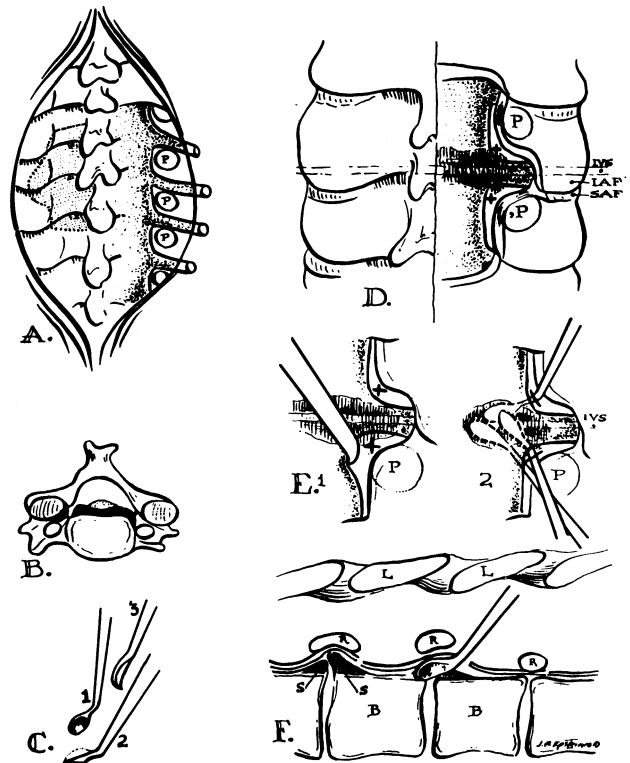
Advantages of the sitting position include decreased operative time, decreased operative blood loss, and a nearly bloodless operative field facilitating dissection and removal of foraminal disc herniations or spurs. Disadvantages include the increased risk of air embolism and intraoperative hypotension, with resultant neurological and cardiovascular complications.

PRONE POSITION

Patients are placed in the prone position using bilateral chest rolls (smaller patients), a Wilson frame (medium sized/large patients), or an extra-large Cloward saddle (largest patients). The three-pin head holder is affixed to the Mayfield head rest, maintaining the neck in a neutral position. The arms are held down at the sides tucked in operative sheets or sleds. SSEPs should again be checked before and after induction to ensure that operative positioning has not compromised neurological function.

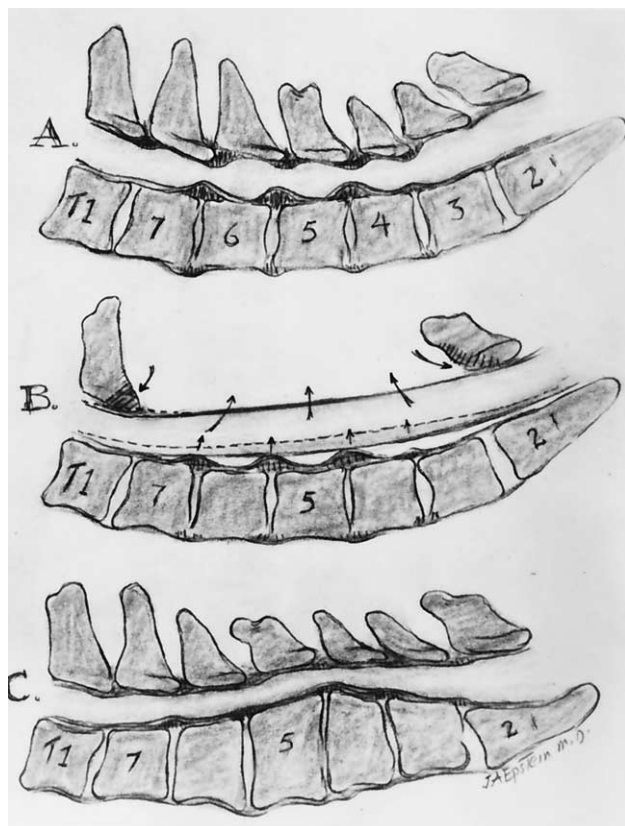
PROS AND CONS

The prone position, although associated with greater overall operative blood loss (average 2 units) and more blood in the operative field, lessens the risk of intraoperative hypotension and air em-



4 A. On the left, a typical laminectomy plus foraminotomy is illustrated. On the right, the thecal sac and horizontal course of the exiting nerve roots are shown, riding just above the inferior pedicles. B. This transaxial image of a cervical segment shows ventral spur formation across the base of the spinal canal bilaterally compressing the proximal neural foramina. A spur on the facet margin is present on the left side. C. Down-biting curettes, used to resect lateral or foraminal discs or spurs, are illustrated. D. For more extensive lateral and foraminal lesions, a full hemilaminectomy of the cephalad and caudad lamina may be required. Additionally, the accompanying medial facetectomy and foraminotomy may require excision of between 25% to 50% of the inferior (IAP) and superior articular facets (SAP) to provide adequate foraminal exposure of the nerve root as it travels just above the inferior pedicle (P). E. (1) To resect a disc or spur, a Penfield elevator or nerve hook has to be introduced lateral to the thecal sac, below the take-off of the involved nerve root. This mobilizes the neural structures, while detethering them from the epidural venous plexus and perineural adhesions. Next, (2) down-biting curettes may be introduced ventrally, medial to the thecal sac, without risking inadvertent dural or neural injury. F. The down-biting curette may be inserted through a small incision made in the posterior longitudinal ligament to remove disc and spur.

bolism. Using the Concorde position (raising the head) allows the blood to better drain out of the operative field, but does slightly increase the risk of air embolism. Fusion is more readily performed in the prone position, and allows for the simultaneous exposure of the iliac crest if autograft is to be used.



5 A. Illustration of diffuse cervical stenosis accompanied by multilevel ventral spur formation. B. The laminectomy can be completed over multiple levels allowing for dorsal cord migration away from ventrally situated osteophytes. This can also be combined with focal laminoforaminotomy for additional disc or foraminal spur excision. Note the undercutting of the laminar margins above and below the site of decompression. C. In the presence of a kyphotic deformity, dorsal decompression will not be successful because the cord remains tethered over ventrally situated disease.

INTRAOPERATIVE RADIOGRAPHY

Intraoperative lateral radiographs, fluoroscopy, fluoronavigation, or stereotactically guided surgery allow for correct documentation of the surgical level(s) to be addressed.

LAMINOFORAMINOTOMY

Once anesthesia has been induced, patients are given 1 gm of methylprednisolone at the time of induction, accompanied by an appropriate dose of an anti-staphylococcal antibiotic. The wound is then infiltrated with 0.5% bupivacaine HCL and 1:200,000 epinephrine (30 cc). The involved spinous processes are directly exposed, and a clamp is

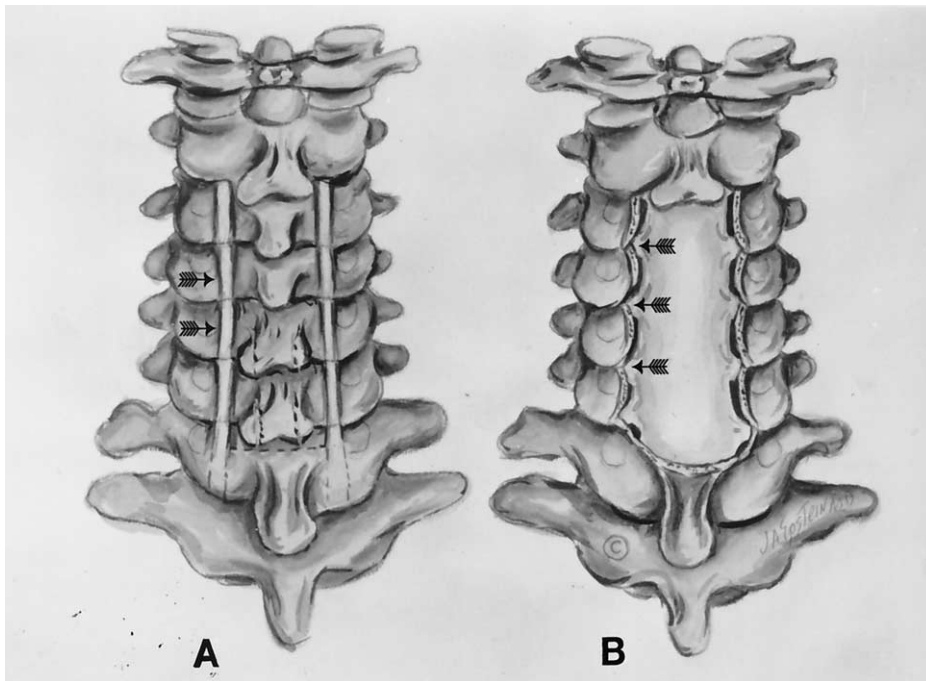
placed on the interspinous ligament for radiographic confirmation. Once the X-ray has been checked, a midline incision may be appropriately extended inferiorly or superiorly. Once a unilateral (laminoforaminotomy) or bilateral exposure (fenestrated approach, laminectomy) has been completed, retractors are applied. During the procedure, the retractors are deliberately released every 20 minutes to prevent muscle necrosis. Once the appropriate levels are skeletonized, a 4 mm low speed diamond bit is used to thin down the dorsal aspect of the lamina, leaving a thin rim of ventral cortex in place. Next, a small rotating (360 degrees) Kerrison rongeur (2 mm) is used to remove the thin rim of residual ventral cortical bone. Rotating upbiting curettes (2 mm) are also used to dissect ligamentous structures away from the lamina and the dura, the ligamentous structures themselves being excised with the small rotating Kerrison punch.

The soft tissue or calcified composition and extent of foraminal pathology dictates how much cephalad and caudad lamina have to be removed. For most foraminal lesions, more cephalad rather than caudad lamina has to be removed. Ebraheim et al noted that a semicircular laminotomy involving the cephalad lamina may be all that is needed for a lateral soft disc intrusion since the disc space itself is located above the leading edge of the caudad lamina [5]. However, for lesions with greater cephalad and caudad extension, more extensive laminotomy or complete hemilaminectomy may be required.

Bilateral foraminal disease at a single level can be managed by the fenestration procedure that includes bilateral laminoforaminotomies separated by the preserved spinous processes, interspinous, and supraspinous ligaments [16]. However, proper exposure should not be compromised by an attempt to minimize the size of the incision and removal of bone. If better visualization and fuller decompression are warranted by either the pathology at hand or technical difficulties incurred by the patient's body habitus (i.e., deep wound), then a laminectomy may prove safer and more expeditious (Figs. 3-7).

FACET RESECTION

The percent of facet resection is based on the extent of foraminal pathology. In Baba et al, 16 nerve roots were adequately exposed with 25% of the facet removed, while 8 patients required a 50% foraminotomy [3]. Therefore, for most lesions, medial facetectomy and foraminotomy involving 25% of the facet joint affords adequate visualization of 4 mm of the proximal foraminal nerve root [3,6,14,



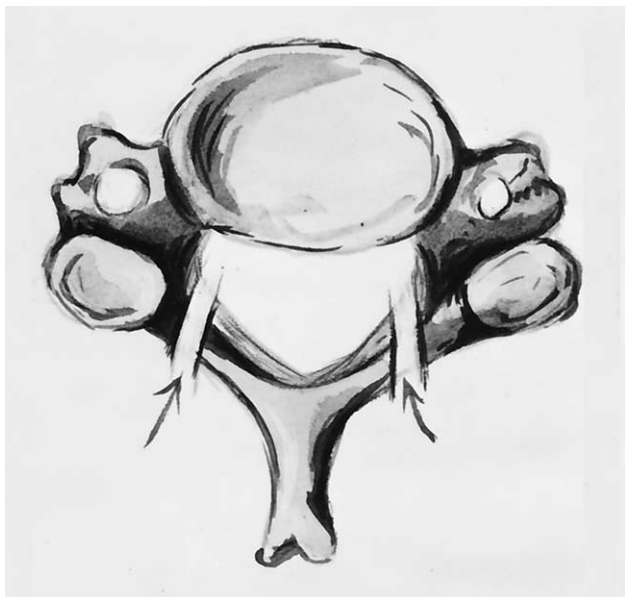
6 A. The laminectomy, illustrated here, is performed by incising linear channels along the lateral margins of the laminae, medial to the facet joints (arrow). Once completed, the laminae can be dissected free, elevated, and removed. B. Once laminectomy for decompression of stenosis is complete, medial facetectomy and foraminotomy can be accomplished at multiple levels. Focally, more extended laminoforaminotomy may be performed (arrows).

15]. However, where disease is more extensive, 50% or more facet resection becomes associated with a higher risk of instability. Technically, removal of

the medial facet joint is completed using a 4-mm diamond burr, and a 2-mm rotating Kerrison rongeur. Dissection and skeletonization of the nerve root under the operating microscope is performed with a small Penfield dissector and nerve hook. When the foramen is extremely tight, a 1- or 2-mm rotating up-biting curette helps remove the thin remaining rim of the medial facet thinned down by a diamond burr.

FORAMINAL ROOT DISSECTION

After the nerve root has been exposed, it is vital to discern whether the dorsal sensory and ventral motor roots are combined in a single dural sleeve, or if the ventral motor root has a separate, thinner, dusky dural investment. This identification is critical to avoid confusing a tethered ventral motor root surrounded by perineural adhesions with the disc herniation itself. Typically, a compressed nerve root is surrounded by an engorged epidural venous plexus that must be coagulated, where feasible, with a bipolar forceps (on a low setting). Alternatively, diffuse bleeding should be controlled with microfibrillar collagen. Now, under EMG monitoring, the root should be gently teased away from the underlying disc or spur using a small Penfield dissector and nerve hook. A major benefit of this dorsal approach is the ability to expose part or virtu-



7 This transaxial figure of a laminectomy shows how the lateral lamina are resected just medial to the facet joints. The extent of dorso-lateral decompression can be readily extended to complete a laminoforaminotomy addressing more focal pathology.

ally all of the root as needed, although more extensive facetectomy may warrant fusion. After gently retracting the root with the Penfield elevator, the underlying periosteum and/or fibers of the posterior longitudinal ligament overlying the lesion are directly incised with an 11-blade knife, large enough to allow a 2 mm down-biting curette to be introduced. The curette is then gently directed laterally and inferiorly away from the cord, this maneuver allowing disc or spur to be delivered into the lateral gutter. While disc tissue may appear occasionally as a free lying fragment, more typically several small fragments measuring 1 to 3 mm in size or punctate fragments of spur may be delivered. Once the root is freed and dissection deemed complete, microfibrillar collagen is placed longitudinally in the lateral gutter, followed by the dorsal application of gelfoam and an epidural drain (Figs. 3 and 4). Routine closure follows, the anesthetic is reversed, and the patient is extubated once awake and alert on the operating room table unless significant risk factors (obesity, asthma, etc.) require delayed extubation. Postoperatively, patients are placed in hard and then soft cervical collars for a total of 2 weeks.

LAMINECTOMY WITH LAMINOFORAMINOTOMY

Laminectomy with laminoforaminotomy may be required in patients with diffuse single or multilevel stenosis accompanied by lateral and foraminal disease [7,8]. The laminectomy is accomplished using a small 4 mm medium-to-low speed diamond burr for excision of the dorsal cortex along both lateral gutters. The residual ventral cortex may be sequentially removed at each level with a 2-mm rotating Kerrison punch. Medial facetectomy and foraminotomy can be performed at the necessary levels, and may include a focal extensive laminoforaminotomy to address a specific disc herniation or spur (Figs. 4 and 6).

LAMINOPLASTY WITH FORAMINOTOMY

Laminoplasty can also be combined with foraminotomy for decompression of myelopathy in addition to significant focal radiculopathy. In Baba et al, 17 patients with significantly myeloradiculopathy had laminoplasty with laminoforaminotomy successfully completed [2].

BIOMECHANICAL CONSIDERATIONS

The extent of facet resection required during laminoforaminotomy is typically 25%, and rarely

exceeds 50% [3,14,20]. Zdeblick et al performed successive 25%, 50%, 75%, and 100% facetectomy in an *in vitro* model to evaluate the impact of progressive facet resection on instability; significant segmental hypermobility occurred with greater than 50% facet resection [20]. Chen et al also found that the laminoforaminotomy was "less destabilizing" to the cervical spine than the anterior discectomy performed with or without fusion [3].

OUTCOMES

A 96% incidence of good to excellent outcomes have followed laminoforaminotomy performed for radiculopathy [1,2,4,9,10,12,15,18,19]. In Kumar et al's series, excellent to good outcomes were achieved in 95.5% of 89 patients with lateral and foraminal disease [12]. In Tomaras et al's patients who were not receiving Workers Compensation benefits, 92.8% of patients achieved good to excellent outcomes [18]. Good results were similarly reported in 94% of 54 patients in Woertgen et al's series, poor prognostic factors including longstanding preoperative complaints and long-term preoperative neurological deficits [18]. Davis, using Prolo's Functional Economic Outcome rating Scale, documented a somewhat lower 86% good outcome rate for similar procedures [4]. However, as in Baba et al's series, where myelopathy accompanied radiculopathy and warranted laminoplasty in addition to laminoforaminotomy, good to excellent outcome rates dropped to 76% [2].

INTRAOPERATIVE COMPLICATIONS

A 2.2% or greater intraoperative complication rate may be observed in patients undergoing laminoforaminotomy [12]. Complications may include excessive blood loss in obese patients having surgery in the prone position. Alternatively, "relative hypotension" may occur in patients operated on in the sitting position, resulting in cord or brain ischemia. Cerebrospinal fluid fistula with loss of dural tamponade and increased epidural bleeding may occur either prone or sitting, although in the latter position, the head may fill with air resulting in pneumocephalus or bilateral subdural formation. Vertebral artery injury, although possible, is rare. SSEP and EMG monitoring help limit cord and root injuries. MR and CT studies combined should allow the surgeon to judiciously select patients for a laminoforaminotomy approach; however, if this exposure

should prove insufficient, the surgeon should return anteriorly.

REOPERATION RATE FOLLOWING LAMINOFORAMINOTOMY

Major causes of failure reported in 6% to 6.7% of patients undergoing laminoforaminotomy include the wrong diagnosis, the wrong side and level, the wrong patient, and the wrong surgeon [4,12].

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COMMENTARY

The controversy that should not be. Anterior vs. posterior. Both approaches to the cervical spine have their place, and their indications nicely overlap. Dr Epstein discusses some of the virtues of multiple posterior surgical procedures applicable to the cervical spine. Many reasons are provided and appropriately explained. Two are less well-appreciated and worthy of mention: intraoperative and postoperative risks are reduced, and preservation of stability is greater than with the anterior approach without a fusion.

The sitting position has advantages that outweigh the risks of air embolization and hypotension. The operative time is decreased. The blood loss is minimized, and there is less obscuration of the operative field.

The use of somatosensory evoked potentials and EMGs is recommended. CT may supplement the MRI when there is a question of a hypointense mass that may indicate calcification or ossification rather than soft tissue disease.

History and experience establish, and this article re-emphasizes, the various surgical techniques available using the posterior cervical approach in