

# Minimally Invasive Foraminotomy of the Cervical Spine: Improving Technique and Expanding Indications

Laura A. Snyder, MD  
Justin C. Clark, MD  
Luis M. Tumialán, MD

*The minimally invasive foraminotomy allows surgeons to treat multiple pathologies with minimal muscle dissection and less disruption of the native spine. Pathologies that have traditionally been treated with fusion can be safely and effectively treated with minimally invasive and motion-preserving techniques. The smaller exposure used with the minimally invasive foraminotomy results in reduced blood loss, shorter operative times, and faster patient recovery compared with traditional open surgical techniques.*

**Key Words:** cervical spine, foraminotomy, minimally invasive surgery

**Abbreviations Used:** MR, magnetic resonance imaging

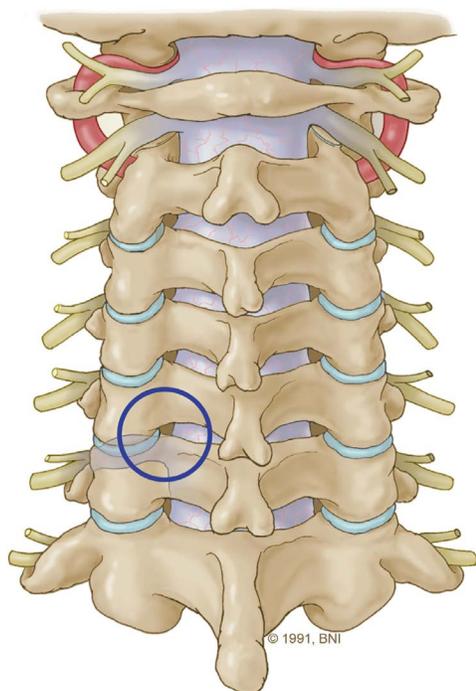
*Division of Neurological Surgery, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, Arizona*

The rise of minimally invasive techniques has returned the posterior cervical foraminotomy to the armamentarium of the spine surgeon. The morbidity associated with a midline exposure, especially with the complex insertion patterns of the posterior cervical musculature, has been difficult to reconcile with the well-tolerated anterior cervical approach. However, the development of minimally invasive techniques for posterior cervical foraminotomies not only has reversed the decreasing trend of posterior cervical approaches, but also has steadily expanded our capacity to address a variety of pathologies in the posterior cervical spine. In this report, we describe the minimally invasive technique for posterior cervical foraminotomy and laminectomy. The application of this technique in three distinct clinical scenarios is presented.

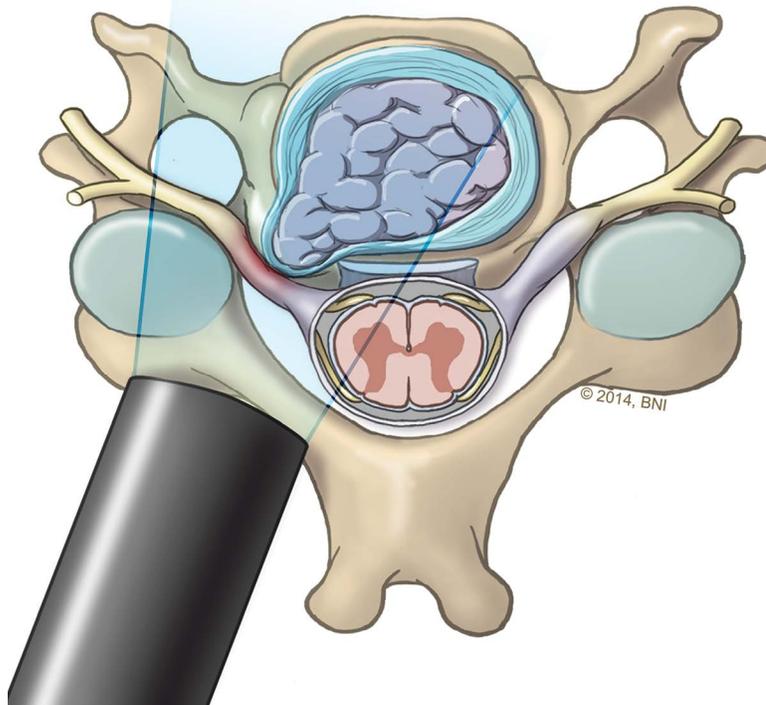
## Anatomy

The limited 14-mm-diameter field of view in minimally invasive foraminotomies has the potential to be disorienting, even to surgeons familiar with posterior cervical approaches. Reviewing the anatomy within the context of a minimally invasive approach is of value, before reviewing the operative technique. Thus, we describe the anatomy for standard lesions at C3 or below.

The posterior cervical spine is protected by multiple layers of muscle with their investing fascia. From superficial to deep, these muscles include the trapezius, erector spinae, semispinalis capitis, and semispinalis cervicis muscles. The



**Figure 1.** Posterior cervical spine showing the amount of bone removal needed (*blue circle*) for a posterior cervical foraminotomy.



**Figure 2.** Axial view of the docking site of the tubular retractor in the posterior cervical spine that allows access to decompress nerve roots.

disruption of these multiple layers of muscles and their complex insertion patterns may contribute to painful muscle spasms that are common after open approaches.<sup>1,3,4</sup> In the minimally invasive foraminotomy, this pain is mitigated by a focal dilatation through these muscles.

The spinous processes in the midline are formed by the union of the bilateral lamina. Laterally, the lamina intersects the pedicle to form the lateral mass. The inferior portion of the superior lateral mass and the superior portion of the inferior lateral mass create the superior and inferior processes or facets. The superior facet often overhangs the superior one-third of the inferior facet. The superior articular process makes up the posterior wall of the foramen.

The foramen is bound superiorly and inferiorly by the pedicle. Nerve roots in the cervical spine exit the foramen just above their named pedicle (i.e., the C6 nerve root exits above the C6 pedicle). Thus, the C6 pedicle

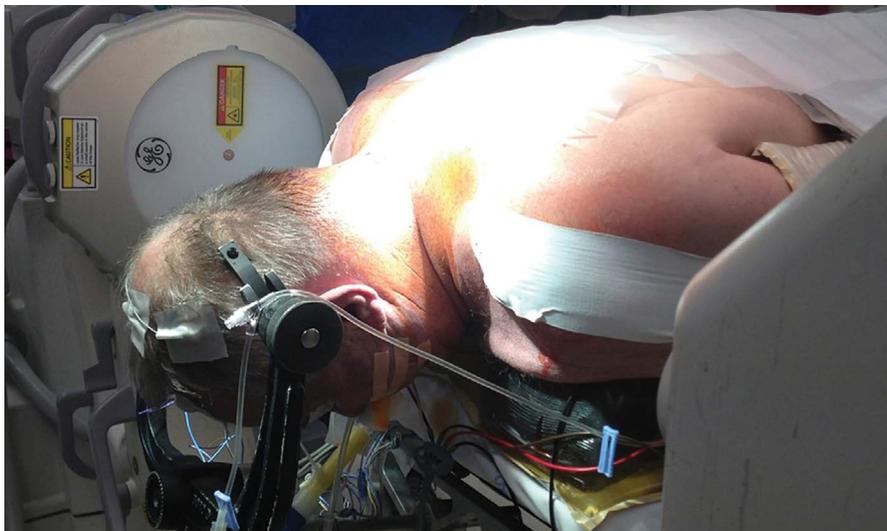
forms the floor of the foramen for the C6 nerve root and the C5 pedicle forms the roof. The nerve root lies in the inferior one-third portion of the foramina, while the superior portion is filled with fat and veins.<sup>1</sup> The ventral or motor roots emerge from the dura mater more caudally than the dorsal or sensory roots, and the ventral roots course along the caudal border of the dorsal roots within the intervertebral foramina.<sup>3</sup>

The anterior boundary of the foramen is formed by the disc space (C5–6 disc in this case) and the lateral unciniate process. Compression of the nerve roots typically occurs anteriorly from disc herniation or uncal vertebral joint osteophyte complexes. Thus, more often the ventral root is affected. The posterior wall is formed by the superior articular process of the like-numbered segment (i.e., the posterior wall of the C6 nerve root is made up of the superior articular process of C6). Arthropathy of the facet may also be a source

of compression of the nerve root, often the dorsal root.

Knowledge of the foraminal dimensions allows one to feel comfortable that tubular retractor access will provide adequate exposure. The intrapedicular distance ranges from 10 to 14 mm, depending on the disc height, but on average is no more than 12 mm. The distance from the lateral aspect of the disc space to the medial aspect of the superior articular process usually measures from 8 to 10 mm. The rostral-caudal exposure should be from pedicle to pedicle, a distance of at least 12 mm. The medial-lateral exposure should be from the medial aspect of the pedicle to the middle of the lateral mass-facet complex, a distance of at least 10 mm. Thus, a well-positioned 14- or 16-mm diameter tubular access port can adequately provide the surface area needed for a comprehensive decompression of the nerve root (Figs. 1 and 2).

The vertebral artery enters the transverse foramen of C6 and ascends



**Figure 3.** Patients are positioned prone with their heads secured in a radiolucent Mayfield head holder.

through the transverse foramina to C2. In this region, the vertebral artery lies just ventral to the ventral rami of cervical nerves C6 to C2 and is surrounded by a venous plexus and sympathetic nerve fibers. Thus, venturing anterior to the cervical nerve root in the posterior cervical foraminotomy may result in injury to the vertebral artery. Encountering significant venous bleeding in this approach may indicate increasing proximity to the vertebral artery.

### Patient Positioning

At our institution, a patient undergoing a minimally invasive posterior cervical foraminotomy or laminectomy is placed prone on an operating table with chest rolls. The head is slightly flexed in a Mayfield head holder (Fig. 3). The chest rolls must be high enough on the chest to maintain a slight neck flexion. If positioned too low, the cervical spine will be extended. There should be no tilt to the head when the Mayfield head holder is in final position. Any tilt may prevent lining up the facets on the lateral fluoroscopic image. This is essential for ideal planning of the incision and positioning of the tubular access port. Furthermore, every attempt should be made to keep the anatomy directly orthogonal to the line of sight through the

tube. This makes the anatomy at a given depth consistent and predictable during dissection. After positioning, the patient is placed in a reverse Trendelenburg position, and the knees are flexed to prevent the patient from sliding down the bed while their head is fixed in the head holder. The shoulders are taped down to facilitate visualization of the level.

Some authors have recommended that this procedure be performed with the patient in a sitting position. The putative benefit is that the seated position decreases epidural venous pressure and thereby the potential for bleeding. In our experience, this bleeding, although frustrating at times, can be mitigated by placing the patient in a reverse Trendelenburg position to decrease epidural venous pressure. The sitting position, while conceptually advantageous, is typically met with significant resistance by anesthesiologists at centers where it is not routinely performed.

### Surgical Technique

A perfect lateral fluoroscopic image should be obtained to plan the incision. The goal on lateral fluoroscopy should be to dock onto the inferomedial edge of the rostral lateral mass of the foramen of interest. Initial localization of the target level of the lesion to the desired

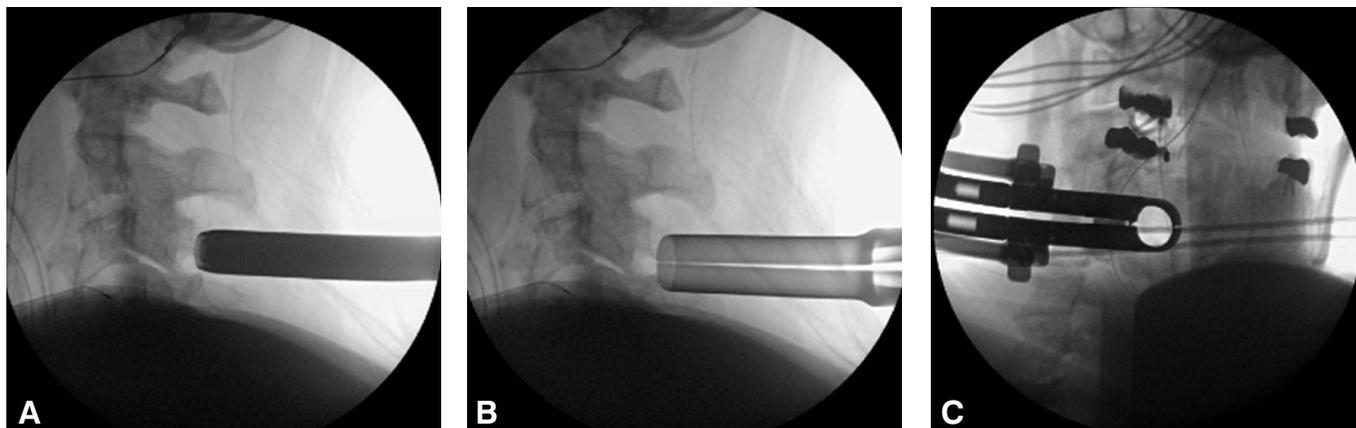


**Figure 4.** (A) Initial localization of the C3-C4 facet docking site with fluoroscopy allows (B) a small incision to be planned that is only slightly larger than the size of the desired tube to be used.

facet on a lateral fluoroscopic image (Fig. 4A) allows one to plan the incision the size of the tube to be used (Fig. 4B). An incision 1.5 cm off the midline spinous process will bring the initial dilator to the facet laminar junction, which is the medial to lateral aim of docking, but should there be any question, anterior-posterior fluoroscopy can be used to verify this trajectory.

Depending on the size of the lesion and the size of the retractor, incision and dilation can proceed over this area. After the incision is made, the superficial fascia, which can be tough, is usually opened with monopolar cautery. In general, we believe that use of a Kirschner wire in the cervical spine is ill advised, as the wire may inadvertently pass intralaminarly into the spinal cord.

The tubular muscle dilators are



**Figure 5.** Sequentially larger tubes are used to dilate the muscle until the final retractor is locked into place. Placement of the dilators and final retractor in correct position is verified by lateral and anterior-posterior fluoroscopy.

placed sequentially in line with the diameter of the desired retractor, with each retractor docking onto bone before the next dilator is placed. Not properly docking to bone will cause muscle to creep into the field with larger dilators. After a retractor of the desired size is placed, the retractor tube can be held in place by an arm that attaches to the side of the bed. The location of dilators and retractors should be verified with lateral fluoroscopy and anterior-posterior fluoroscopy as needed (Fig. 5). Slight changes in tube trajectory can be made while still holding the retractor to the bone so that no muscle enters into the field. The retractor system is then locked to the side of the bed using a stabilizing arm (Fig. 6).

Visualization into the tube is performed with a microscope, and the bed can be turned to help gain a more comfortable working angle. Starting laterally over the bone of the facet junction, one can safely clean away muscle in the field, as the superior facet overlying the inferior facet will protect the nerve root in the foramen. Monopolar cautery and pituitary rongeurs allow visualization of the bony landmarks. For orientation purposes, it is important to visualize the medial one-third of the rostral and caudal lateral mass, and the lateral one-third of the rostral and caudal lamina of interest. For procedures such as minimally invasive posterior cervical foraminotomies and discectomies, much of the



**Figure 6.** The retractor is locked into the correct position using an arm that attaches to the side of the bed.

procedure will occur in this view. For procedures that address intradural lesions or lesions extending further to the other side, the tube can be angled more medially. However, it may be beneficial to clear off the ligamentum flavum and other tissue overlying the lateral aspect of the cord with the known bony landmarks before adjusting the tube.

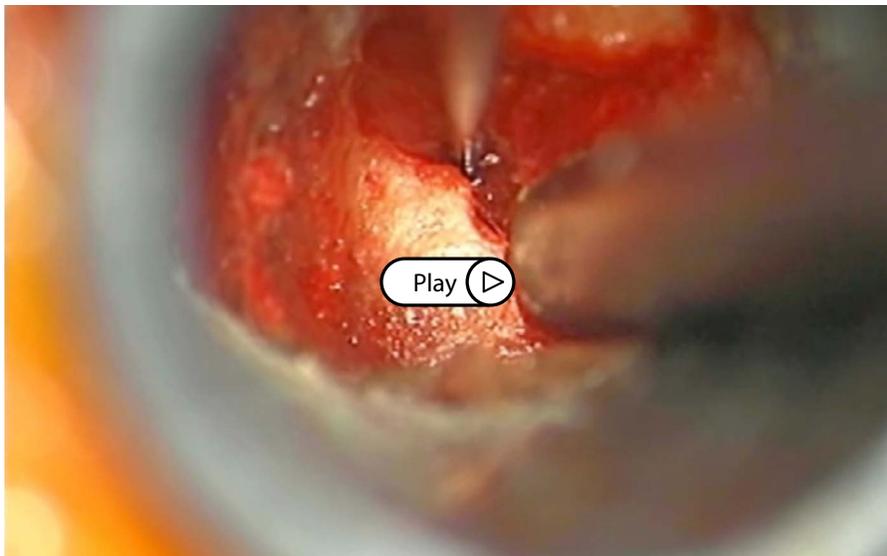
The ligamentum flavum and tissue over the spinal cord can be removed by detaching it laterally using a small

angled curette at the undersurface of the inferior edge of the rostral lamina. One can then use a combination of a ball-tipped probe, a curette, and Kerrison rongeurs to further remove the ligamentum flavum and tissue. As further dissection and relative anatomy will depend on the pathology being treated, we expand upon our description of this technique by presenting a series of cases that demonstrate how this approach can be used and modified for different indications.

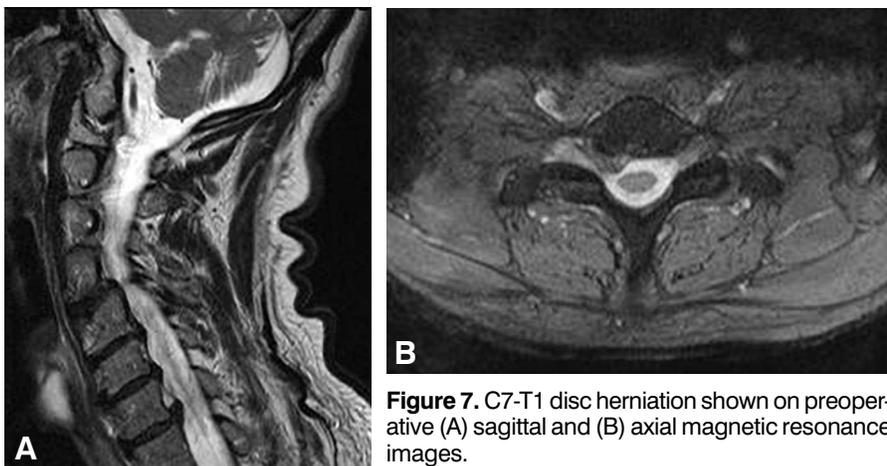
### Case 1: Posterior Cervical Foraminotomy and Discectomy

A 58-year-old man presented with increasing right arm pain and tingling in his fingers. Magnetic resonance (MR) imaging of the cervical spine demonstrated a disc herniation at C7-T1 (Fig. 7). The patient had no neck pain, and dynamic cervical radiographs showed no instability at this level. Surgical options for management of this clinical scenario include a C7-T1 anterior cervical discectomy and fusion or a minimally invasive posterior cervical foraminotomy with discectomy. Given the absence of spinal cord compression and axial neck pain, we decided that the patient was a candidate for a motion-preserving approach.

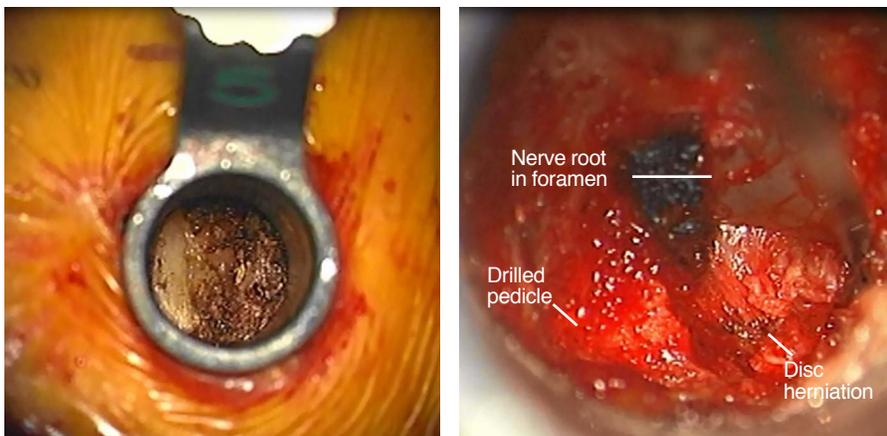
The retractor tube was centered over the medial edge of the facet (Fig. 8,



**Video 1.** Minimally invasive foraminotomy performed for nerve root decompression in a patient with a disc herniation at C7-T1. <https://www.barrowneuro.org/Foraminotomy1>



**Figure 7.** C7-T1 disc herniation shown on preoperative (A) sagittal and (B) axial magnetic resonance images.



**Figure 8.** Initial exposure for foraminotomy and discectomy.

**Figure 9.** Visualization of disc herniation through tube.

Video 1), allowing access to the beginning of the foramen, the pedicle, and the axilla of the nerve root. At this location, the disc causing compression can be safely accessed. A small-angled curette was used to detach the ligamentum flavum from the undersurface of the inferior edge of the rostral lamina. When the lamina-facet junction was identified and the ligamentum flavum was dissected away from the inferior edge of the superior lamina and facet, a drill and Kerrison rongeurs were used to create a small laminotomy, allowing visualization of the lateral border of the cervical dura and the proximal exiting cervical nerve root. In some cases, the lamina may be oriented in a vertical fashion, which makes it difficult to remove with Kerrison rongeurs alone.

The drill and Kerrison rongeurs were used to create a medial facetectomy to extend the exposure of the exiting cervical nerve root. If present, osteophyte fragments overlying the foramen can be manipulated and fractured by using angled curettes. Removal of the dorsal bone overlying the root exiting in the foramen may be all that is required for nerve root decompression in a posterior cervical foraminotomy. The adequacy of decompression can be assessed by palpating around the root along its course with a small nerve hook and by freeing any tethering of the nerve root. One should be able to feel freedom of the nerve root on the superior side of the pedicle and as it starts to traverse the lateral side of the pedicle.

If imaging demonstrates ventral compression, access to the ventral space without retraction of the nerve root or cord can be improved by drilling the superomedial quadrant of the pedicle, providing further access to the axilla of the nerve root. A nerve hook entered into this space can be used to palpate the ventral foramen and identify remaining osteophytes or disc fragments. Cervical instability after surgery can be avoided by preserving at least 50% of the facet complex during the bony decompression. During drilling of the

superomedial quadrant of the pedicle, careful attention must be paid to drill only the volume necessary to allow a nerve hook access behind the cervical nerve root (Fig. 9). A No. 11 blade can be used to incise the disc annulus, and disc fragments can be teased out with the use of a nerve hook and micropituitary forceps. Osteophyte fragments causing compression ventrally can be tamped down with down-angled curettes. As a final check, the nerve hook should be used to palpate all sides of the nerve root and out of the foramen just lateral to the pedicle to ensure that no element of compression has been missed.

For this patient, when the surgeon was comfortable that all possible decompression had been performed, hemostasis was achieved and antibiotic irrigation was performed, and the retractor was removed slowly to identify any further bleeding sites. The fascia and skin were closed with buried sutures. In these cases, as the incision is small and the muscle dissection minimal, patients usually have a quick recovery (Fig. 10). This patient returned home on the day of surgery. He returned to clinic 2 weeks later with no arm pain.

cancer and the possible need for post-operative radiation.

The tube was centered over the interlaminar space just medial to the facet (Video 2). The inferior portion of the lamina above and the superior portion of the lamina below were drilled away to provide visualization of the pathology. A combination of drilling to thin the bone and the use of Kerrison rongeurs was used to further expose the lesion. Dissection of the soft tissue from the bone with an angled curette

can facilitate safe use of the Kerrison rongeurs.

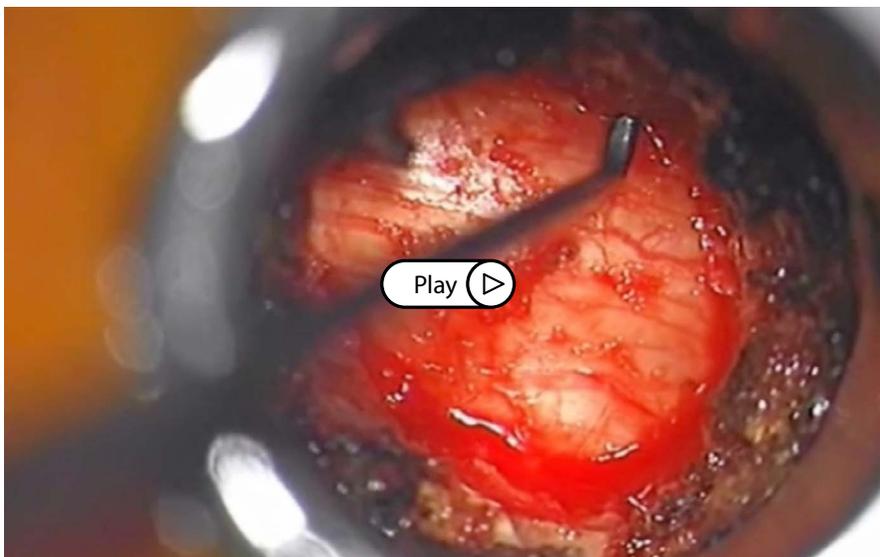
In this case, the fibers of the ligamentum flavum had already been partially separated by the tumor itself. Portions of the ligamentum flavum and then the hemorrhagic metastatic lesion were removed carefully with a micropituitary forceps and Kerrison rongeurs (Fig. 11), allowing visualization of the dura beneath. The plane between the dura and tumor was further expanded using a ball-tipped probe and a nerve hook,



**Figure 10.** A 2-cm incision with minimal muscle dissection allows a quick recovery.

## Case 2: Cervical Metastatic Tumor Resection

A 62-year-old woman with a history of breast cancer presented with acutely increasing neck pain and difficulty walking. MR imaging of the cervical spine demonstrated what appeared to be an extradural hemorrhagic metastatic lesion causing compression of the spinal cord. Given her overt signs of myelopathy and rapidly declining ambulatory status, urgent decompression was mandated. Surgical options included a traditional midline approach for a complete laminectomy and decompression, or a minimally invasive laminectomy with preservation of the posterior tension band. A minimally invasive approach was selected, given the patient's history of breast



**Video 2.** A minimally invasive laminectomy performed to resect an extradural hemorrhagic metastatic lesion that caused compression of the spinal cord in a patient with a history of breast cancer. <https://www.barrowneuro.org/Foraminotomy2>

and additional tumor was removed. If necessary at this point, the retractor tube could be aimed more medially as well as superiorly and inferiorly to further drill the laminar bone and expose more tumor.

After the hemorrhagic metastasis was completely removed and the spinal cord was decompressed, hemostasis was then achieved and the surgical site was irrigated with an antibiotic solution. The minimal access port was removed and the incision was closed in a multi-layered fashion. For this patient, intraop-

erative pathologic findings confirmed metastatic breast cancer and radiation began immediately. The rich supply of blood to the muscles surrounding a transmuscular minimally invasive approach and the small size of the incision avoid the constraints inherent in the traditional midline approach. In the traditional approach, the use of radiation is typically deferred until the incision has completely healed. In this case, the patient returned home on postoperative day 1 with complete resolution of her myelopathy.

### Case 3: Synovial Cyst Resection

A 68-year-old man presented after experiencing neck pain, bilateral arm numbness and tingling, and difficulty walking for two months. MR imaging demonstrated compression of his spinal cord posteriorly at C3 and C4 by ligamentous hypertrophy and a synovial cyst (Fig. 12). Surgical options for management included a traditional midline approach with complete C3-C4 laminectomies for resection of the synovial cyst. The concern with this approach

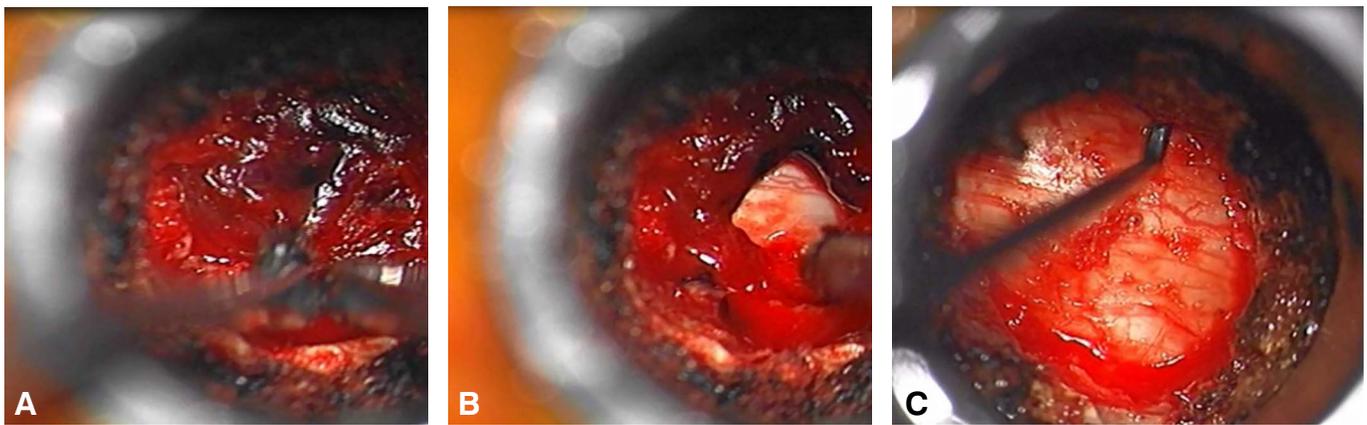


Figure 11. Intraoperative photos demonstrate progress of minimally invasive laminectomy for cervical metastatic tumor resection.

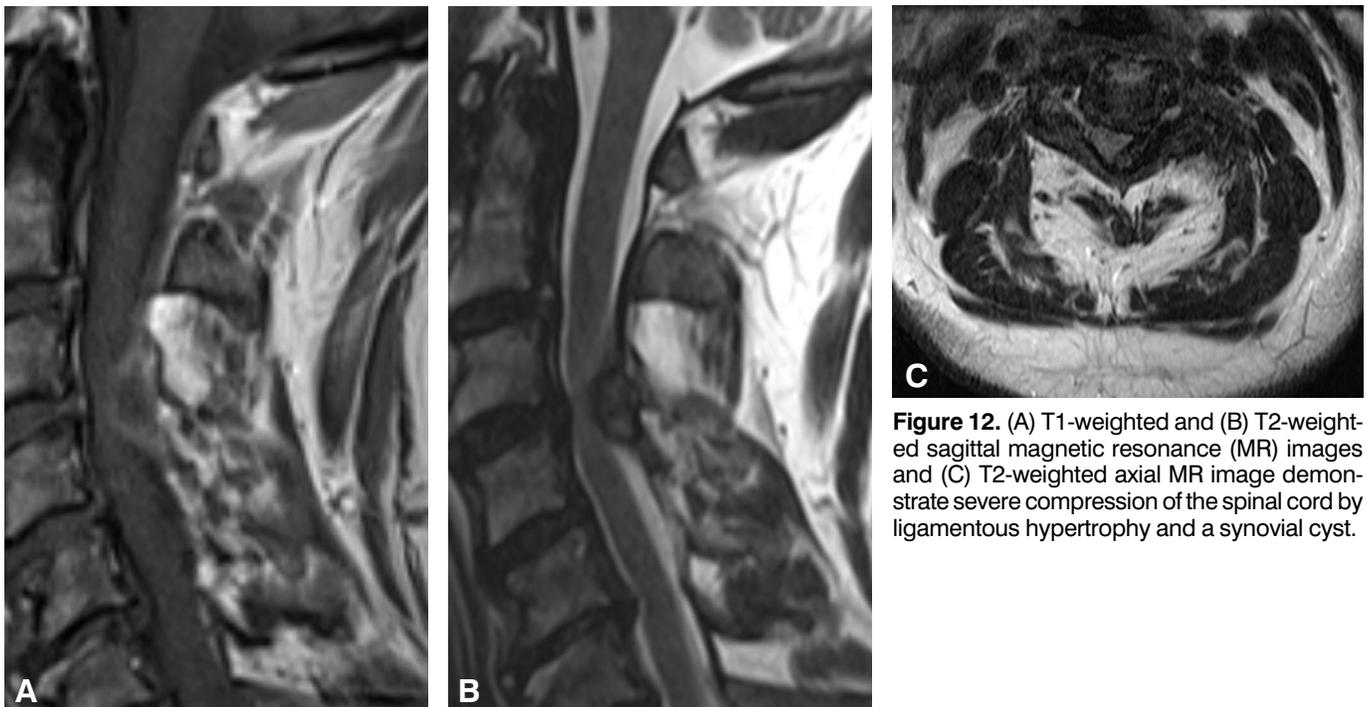


Figure 12. (A) T1-weighted and (B) T2-weighted sagittal magnetic resonance (MR) images and (C) T2-weighted axial MR image demonstrate severe compression of the spinal cord by ligamentous hypertrophy and a synovial cyst.

was that disruption of the posterior tension band could mandate an instrumented fusion. In light of this, a minimally invasive laminectomy was chosen.

The tube was centered over the intralaminar space rather than the medial edge of the facet to access the synovial cyst and ligamentous hypertrophy causing compression (Video 3). A small-angled curette was used to detach ligamentum flavum from the undersurface of the inferior edge of the rostral lamina. The inferior portion of the lamina of C3 and the superior portion of C4 were drilled away to provide visualization and access to the entire pathology.

The fibers of the ligamentum flavum were carefully separated in a cranial-caudal direction by use of a No. 4 Penfield dissector. After the plane between the ligamentum flavum and the dura was identified, an angled curette and a ball-tipped probe were used to detach the ligamentum flavum from the dura. With the space created, Kerrison rongeurs were used to further remove the ligamentum flavum. Dissection of the synovial cyst away from the dura requires identifying its borders by slowly establishing a plane over the top of the dura. This can be done with the assistance of a No. 4 Penfield dissector, an angled curette, or a ball-tipped probe, or by using microscissors to divide any dural attachments.

After the compression was removed, closure was performed as described in Cases 1 and 2. This patient was admitted due to his history of coronary artery disease, but he returned home on postoperative day 2 without complication. As early as postoperative day 2, he felt that his hand sensation had improved and, on examination, he showed bilateral improvement in his grip strength.

### Complication Avoidance

In the minimally invasive foraminotomy, sequential dilation using tubular retractors prevents trauma to the muscles and the posterior cervical tissue, which is often a result in an open approach. Traditionally, an open approach

requires an incision long enough to expose and visualize the lateral facet complex. To achieve this amount of visualization and muscular retraction at the desired region, one must mobilize muscles above and below the desired region. The paraspinal muscles are stripped from the spinous process, lamina, facet capsule, and their ligamentous attachments to the midline. This mobilization of muscle can cause increased postoperative pain as well as increased dead space, which in turn can increase the likelihood of a hematoma or pseudomeningocele in cases of cerebrospinal fluid leak.<sup>4</sup> In contrast, the minimally invasive foraminotomy approach can avoid these common complications.

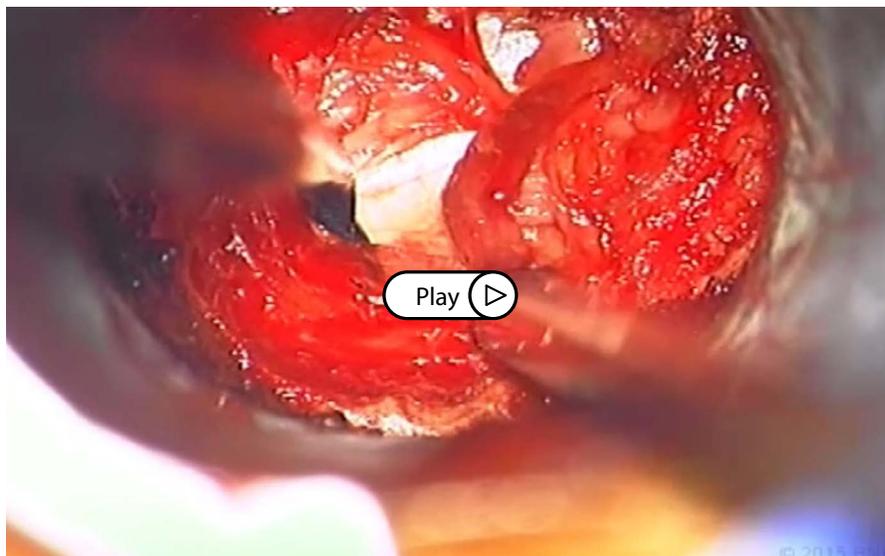
Although minimally invasive spine surgery can spare some of the complications that are associated with open posterior cervical approaches, the practicing neurosurgeon must be cognizant of possible complications. As the rate of infection is directly proportional to the size of the incision and the time of the procedure, minimally invasive surgery minimizes the risk of infection due to the small incisions and less time spent in dissection. However, infections are still possible, so antibiotic irrigation should

occur frequently. Durotomies can be repaired primarily or with muscle, fat, or Gelfoam (Pfizer, Inc., New York, NY) over the tear and the application of a dural sealant such as DuraSeal (Confluent Surgical, Inc., Waltham, MA). As dilation of the muscle does not create a significant dead space, pseudomeningoceles are less likely to form.

### Outcomes

Patients who are treated with minimally invasive cervical techniques have demonstrated good outcomes. In our experience, these patients often return home the day of surgery in the case of a discectomy or within the first 2 postoperative days for more complex pathologies. Patients usually see an improvement of their symptoms by discharge, with continued improvement over time. They usually can return to light work duties in 3 to 4 weeks and can have narcotic pain medication discontinued by 5 to 6 weeks after surgery.

Long-term improved outcomes have been demonstrated by Skovrlj et al.<sup>6</sup> in 70 patients who underwent posterior cervical foraminotomies and microdiscectomies through minimally invasive techniques. With a mean fol-



**Video 3.** Minimally invasive foraminotomy performed for decompression of the spinal cord by removing symptomatic ligamentous hypertrophy and a synovial cyst at C3 and C4. <https://www.barrowneuro.org/Foraminotomy3>

low-up of 32.1 months, there were 3 complications (1 cerebrospinal fluid leak, 1 postoperative wound hematoma, and 1 radiculitis), none of which required a second procedure. Visual analog scale and Neck Disability Index scores improved significantly for these patients.<sup>6</sup> Although no large series have been published for synovial cysts and extradural cervical tumors, case reports and small series have also demonstrated good long-term outcomes at other centers.<sup>2,5</sup>

## Conclusion

We have described the minimally invasive posterior cervical technique for decompressing the spinal cord and the cervical nerve roots from 3 different pathologies. This technique is a reliable method for treating patients and results in shorter postoperative recovery and minimal complications compared with open surgery. As surgeons' comfort with the minimally invasive skill set increases, we believe this technique will continue to be safely generalized to other pathologies with equally excellent clinical outcomes.

---

## References

1. Epstein NE: A review of laminoforaminotomy for the management of lateral and foraminal cervical disc herniations or spurs. **Surg Neurol** 57:226-233; discussion 233-224, 2002
2. Hung LK, Zhao X: Relationship of cervical spinal rootlets and the inferior vertebral notch. **Clin Orthop Relat Res** 409:131-137, 2003
3. Russell SM, Benjamin V: Posterior surgical approach to the cervical neural foramen for intervertebral disc disease. **Neurosurgery** 54:662-665; discussion 665-666, 2004
4. Shiraishi T, Kato M, Yato Y, Ueda S, Aoyama R, Yamane J, et al: New techniques for exposure of posterior cervical spine through intermuscular planes and their surgical application. **Spine (Phila Pa 1976)** 37:E286-296, 2012
5. Sihvonen T, Herno A, Paljarvi L, Airaksinen O, Partanen J, Tapaninaho A: Local denervation atrophy of paraspinal muscles in postoperative failed back syndrome. **Spine (Phila Pa 1976)** 18:575-581, 1993
6. Skovrlj B, Gologorsky Y, Haque R, Fessler RG, Qureshi SA: Complications, outcomes, and need for fusion after minimally invasive posterior cervical foraminotomy and microdiscectomy. **Spine J** 14(10): 2405-2411, 2014