Cervical Laminaplasty

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The video that accompanies this article is "Cervical Laminaplasty," available on the *Orthopaedic Knowledge Online Website*, at http://www5.aaos.org/oko/jaaos/surgical.cfm

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Cervical laminaplasty is an extensile approach used to decompress the spinal cord in patients with myelopathy. Tsuji[1] was the first to describe the cervical laminaplasty procedure, in 1982. He reported satisfactory results with this procedure for patients with ossification of the posterior longitudinal ligament (OPLL), spondylosis, and spinal canal stenosis. Since then, there have been many adaptations of the cervical laminaplasty procedure, including dome-shaped laminaplasty, dorsolateral decompression,[2] a double-door procedure with longitudinal splitting of the spinous processes,[3] mini-plate augmentation of the spinal canal,[4] tension-band laminaplasty,[5] use of ceramic laminas,[6] and various modifications of less invasive posterior decompressive procedures.[1,7,8]

Laminaplasty allows for indirect decompression of the spinal cord by opening the lamina on one side, thereby creating a "hinge" joint that allows the spinal cord to float dorsally. Several modified cervical laminaplasty procedures have been described for preserving the posterior elements and reconstructing them more anatomically.[5,8,9] One of the more commonly performed cervical laminaplasty techniques is that described by Hirabayashi et al.[10] This technique involves an open-door laminaplasty, which is hinged on one side, resulting in expansion of the spinal canal. Various techniques have been described for maintaining the lamina in the open position, including the use of sutures, suture anchors, local spinous process autograft, and laminaplasty plates. The other common technique is the so-called French-door approach. With this technique, troughs are made bilaterally in the laminae, just medial to the pedicle. Then the spinous processes are split down the middle, and the two sides of the lamina are opened in a French-door style.[11] Plates and ceramic spacers are two devices used to keep this open.

Cervical laminaplasty has several advantages over anterior decompression and arthrodesis. First, cervical laminaplasty requires no postoperative immobilization. Second, there is no concern about pseudarthrosis, graft extrusion, collapse, or any other graft-related complication. Third, there is no dysphagia, dysphonia, or any other complication related to an anterior approach. There also are some disadvantages of laminaplasty compared with the anterior approach. The incision is longitudinal and, therefore, less cosmetically pleasing. Cervical laminaplasty may not immediately affect neck pain; in some patients, it may initially cause increased pain. Immediate postoperative pain is likely to be greater than for an anterior operation, as laminaplasty requires extensive stripping of the posterior musculature from the dorsal surface of the bone. As with other posterior spine procedures, this generally abates within days to weeks postoperatively.

Cervical laminaplasty also has advantages over cervical laminectomy. The main advantage is that with laminaplasty, a roof is maintained over the spinal cord. Should revision surgery be necessary, it is easier and safer to re-expose the posterior cervical spine after laminaplasty than after laminectomy. Kyphotic deformity of the cervical spine occurs less frequently following laminaplasty than after laminectomy. In their retrospective review of two matched groups of patients treated with either laminectomy or laminaplasty, Heller et al[12] reported objective improvement in patient function. The number of patients reporting subjec-

Figure 1

Preoperative lateral radiograph of cervical stenosis (arrows) in a patient with achondroplasia who presented with severe myopathy. The patient was treated with C3 laminectomy with laminaplasty from C4-T1. She had complete resolution of myelopathy at her first postoperative visit.

tive improvement in strength, dexterity, sensation, pain, and gait tended to be greater in the cervical laminaplasty cohort. No complications were reported in the laminaplasty cohort, whereas 14 complications occurred in nine patients who underwent laminectomy with cervical spine fusion. Shiraishi et al[7] evaluated 43 patients who underwent skip laminectomy and 51 patients who underwent open-door laminaplasty. Skip laminectomy was found to be less invasive than open-door laminaplasty of the posterior extensor mechanism, including the deep extensor muscles.[7] Skip laminectomy was effective in preventing postoperative morbidities often seen after conventional laminectomy and laminaplasty. In addition, it provided adequate decompression of the spinal cord. In a biomechanical study using a goat model, Baisden et al[13] found that laminaplasty was more effective than laminectomy for preserving cervical alignment and preventing postoperative spinal deformities.

Several authors have reported stable, long-term neurologic improvement of cervical myelopathy following laminaplasty.[7,14,15] However, to our knowledge, no prospective, randomized trial has been done that evaluates a direct comparison between laminectomy and laminaplasty. Kawai et al[16] reported that patients with spondylotic myelopathy who were treated with laminaplasty were stable even at 10 years postoperatively. Another group reported on extensive follow-up after French door laminaplasty.[15] The short-term results achieved with laminaplasty were maintained for at least 10 years in 78% of the patients with OPLL and in most of the patients with cervical spondylotic myelopathy.

Takeuchi et al[9] recently compared the results of C4 through C7 laminaplasty with concomitant C3 laminectomy, versus C3 through C7 laminaplasty. The authors concluded that performing the combination procedure of laminaplasty and laminectomy was less invasive (it requires less rostral and caudal dissection) to the cervical posterior musculature than the C3 through C7 laminaplasty. This procedure provided three significant benefits: (1) C3 laminectomy is easier to perform than C3 laminaplasty. (2) C3 laminectomy preserves the semispinalis cervicis insertion into C2. This insertion can be maintained in both French door and open-door laminaplasty. (3) This combined procedure has the same surgical indications as C3 through C7 laminaplasty for management of myelopathy and OPLL.

Laminaplasty is not without potential complications, however, including intrusion into the canal, closure of the lamina, nerve root palsy (particularly at C5), and axial neck pain. Although usually transient, deltoid muscle palsy from a C5 root injury is a debilitating problem; it may not present until up to 20 days postoperatively.[17] Although the exact pathophysiology is not fully understood, deltoid muscle palsy is widely regarded as a stretch injury. Because C5 is at the apex of the lordotic curve and is usually at the center of the laminaplasty, the cord tends to migrate posteriorly at C5 more than at any other level. As the spinal cord migrates posteriorly following decompression, the C5 root gets stretched. The C5 roots tend to be short and less amenable than other roots to being stretched. Another theory is that because the deltoid muscle is singly innervated by the C5 root, C5 palsy is much more noticeable than other root deficits. Transcranial motor-evoked potential monitoring has been recommended to help decrease the incidence of this complication.[18] Fan et al[18] concluded that the clinician should consider intraoperative deltoid and biceps transcranial electrical motor-evoked potential and spontaneous electromyography monitoring whenever there is potential for iatrogenic C5 nerve root injury, thereby allowing the clinician to perform a foraminotomy of C5. Finally, a patient may suffer from axial neck pain following laminaplasty. For this reason, the procedure is contraindicated in the patient with debilitating neck pain. In such a patient, cervical spine fusion is likely to be more suitable than laminaplasty.

Indications

Laminaplasty allows indirect decompression of the spinal cord, with benefits that can last longer than 10 years.[7,14,15] Cervical laminaplasty is indicated for the treatment of multilevel cervical disease, including congenital spinal stenosis, OPLL, and neuromuscular conditions (Figure 1). The ideal patient presents with neutral or lordotic alignment of the cervical spine with no evidence of instability on flexion-extension views, little to no neck pain, and multi-

level cervical disease. A patient who strongly desires to avoid cervical spine fusion and who is not significantly affected by neck pain may benefit from laminaplasty. In addition, laminaplasty has been performed for the management of herniated nucleus pulposus with myelopathy.[12]

One advantage of laminaplasty over laminectomy is that the former allows retention of a bony bridge over the spinal cord, in addition to decreasing the incidence of postlaminectomy kyphosis.[19] In theory, laminaplasty allows preservation of motion segments with fewer postoperative limitations than could be achieved with multilevel anterior decompression and fusion.[20] Posterior laminaplasty enables the surgeon to adequately decompress the nerve roots bilaterally, while allowing indirect decompression of the spinal cord. Adjacent-level disease is also less likely to occur, resulting in a lower incidence of reoperation.

Relative Contraindications

Cervical kyphosis (ie, kyphosis measured between the superior cephalad end plate and the inferior end plate of the caudal level) is the primary contraindication to laminaplasty. Occasionally, a patient with mild, gentle kyphosis with circumferential stenosis who is a poor candidate for or who does not desire fusion surgery, may be adequately treated with laminaplasty. However, in a patient with mild kyphosis, there must be at least some degree of posterior cord compression. In the presence of adequate cerebral spinal fluid behind the cord and anterior compression only, laminaplasty is not likely to be successful. In such a patient, an alternative to anterior decompression is laminaplasty combined with fusion of the posterior elements. This preserves a cover over the cord and provides more bony surface area for the fusion mass.

Debilitating neck pain is another contraindication to laminaplasty. Neck pain has been studied by several authors. In a retrospective study of 72 patients who underwent laminaplasty and 26 who underwent anterior interbody fusion, Hosono et al[21] reported that postoperative axial pain symptoms were present in 60% of patients after laminaplasty and in 19% of patients after anterior fusion. Yoshida et al[22] found that the French door laminaplasty technique had no effect on either the development or resolution of neck or shoulder pain. As long as the patient understands and accepts that the preoperative neck pain may not improve, or may even worsen slightly, neck pain alone is not a contraindication for laminaplasty.

Surgical Technique

Patient Positioning

Before positioning the patient, the surgeon must ensure that the anesthesia providers maintain in-line traction of the cervical spine and that the chin-lift, jaw-thrust maneuver is avoided. Additionally, fiberoptic intubation in an awake patient should be considered to quickly determine whether the process of intubation disturbs the spinal cord.

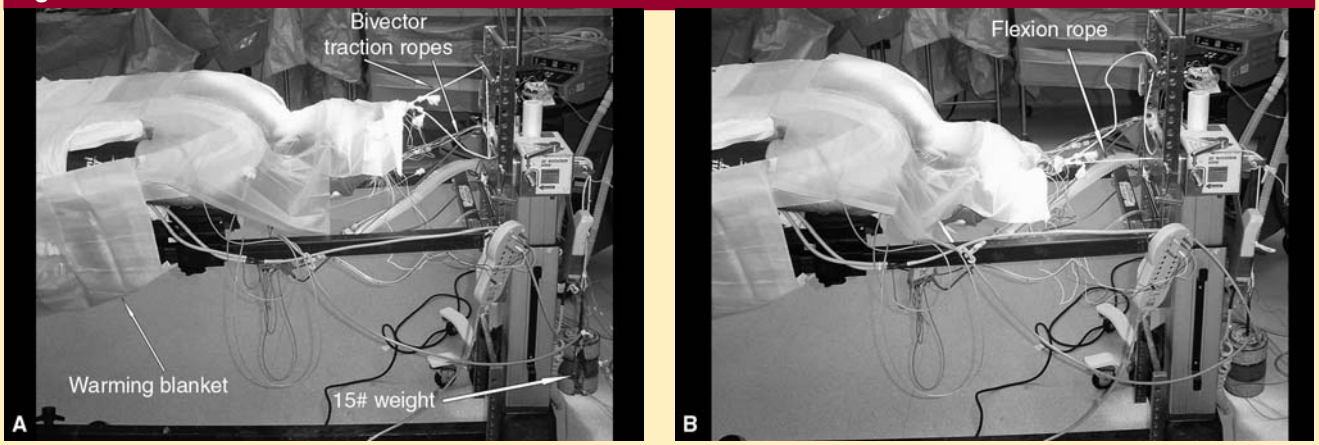
Proper patient positioning is critical to reduce blood loss and improve surgical visualization, while maintaining mean arterial blood pressure ≥80 mm Hg in the patient with myelopathy. An alternative is to use transcranial motor-evoked potential monitoring and observe C5 nerve root abnormalities or irritation before positioning. When there are concerns with monitoring data, a foraminotomy may need to be performed.

We routinely place the patient in Gardner-Wells tong traction and position the patient prone on an open Jackson frame (Orthopaedic Systems, Union City, CA). This versatile table allows for intraoperative alterations in patient positioning. The table is tilted into the reverse Trendelenburg position to distribute blood into the abdomen and legs, thereby facilitating a more physiologic state for the patient. This also provides better visualization in the surgical field. The head of the table is placed in the top rung, and the foot of the bed is placed in the bottom rung. The chest and abdomen are supported on bolsters that allow the abdomen to hang free, and the legs are supported in a sling, with pillow support. The shoulders are taped down on both sides to provide traction, thereby allowing better intraoperative radiographic visualization of the lower cervical spine. Bivector traction is used with the aid of two separate ropes so as to maintain proper neck alignment (Figure 2). One of the ropes is placed in-line and horizontal to the table through a pulley system. The other is placed over a crossbar on the Jackson frame to facilitate placement of the head into extension.[8] The neck is kept in a flexed position during the foraminotomy to open the facet joints. After the laminaplasty is completed, the neck is extended to ensure that there are no bony blocks to full extension. To do this, the anesthesia team switches the weights from the flexion rope to the extension rope while the surgeon holds onto the Gardner-Wells tongs. It is imperative to maintain good coordination and communication with the anesthesia providers during head repositioning because of the risk of dislodgment of the endotracheal tube.

Exposure

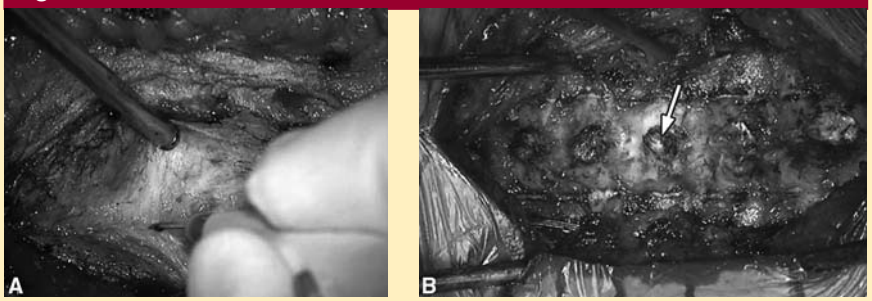
The typical laminaplasty involves exposure and inclusion of all levels from C3 through C7. To perform the five-level laminaplasty, we expose the spine from C2 down to the cranial portion of T1. Care is taken to avoid compromising the rostral and caudal interspinous and supraspinous ligaments. Disruption of the musculature on either side markedly increases blood loss; thus, dissection should be done down the mid-

Figure 2



Reverse Trendelenburg setup with the Jackson frame (Orthopaedic Systems, Union City, CA). Bivector traction technique, with the weight on the extension **(A)** and flexion **(B)** ropes.

Figure 3



A, Dissection along the midline in the avascular plane. When done exactly in the midline, all of the muscles on both sides should be covered by a fascial covering, which can be used to close the wound without grabbing muscle. **B,** Once the spinous processes are exposed (arrow), the midline dissection is continued. All of the soft tissues between the spinous processes are split in the midline, leaving the spinous processes completely denuded of soft tissues.

line between the left and right paraspinal musculatures through the natural avascular plane (Figure 3).

At C2, care is taken to preserve the attachment of the extensor musculature (semispinalis cervicis). By performing a partial or complete laminectomy of C3, it is usually possible to preserve all of this while decompressing the C3 level adequately. When the C2 level needs to be decompressed, one usually can undercut the lamina with a burr rather than doing a C2 laminaplasty. When C2 laminaplasty is necessary, care must be taken to reattach the extensor musculature onto the remaining C2 dorsal elements. When we intend to perform a foraminotomy at C2-3, we release the attachment of the extensors on the caudal half of C2 to expose the facet adequately. Below C2, incision of the interspinous and supraspinous ligaments directly in the midline using a Bovie electrocautery (Bovie Aaron Medical, St. Petersburg, FL) is recommended. All of the soft tissues are reflected to the sides during the exposure such that at the conclusion, only the completely denuded spinous processes and laminae remain.

As the surgeon proceeds out laterally, care must be taken to remain superficial during dissection to preserve the facet capsules. Cobb elevators and electrocautery may be used to dissect over the facet capsules, carrying this out to the lateral aspect of the lateral mass. Further lateral exposure may lacerate the lateral veins, resulting in increased blood loss.

Foraminotomy

We routinely perform bilateral foraminotomy at C4-5 to minimize the risk of C5 nerve palsy. Foraminotomy may be performed at any level with radiographic foraminal stenosis, regardless of symptomatology. This may decrease the incidence of postoperative neck pain, which may be the result of impingement of a stretched root against a tight foramen. In addition, this may result in a decreased likelihood of developing radiculopathy postoperatively. The use of a microscope during cervical spine decompression allows much better visualization and enables two surgeons to work simultaneously.

The cervical neuroforamen is bordered ventrally by the disk and uncovertebral joint. Cranially and caudally, the neuroforamen is bordered by the pedicles. The roof of the foramen

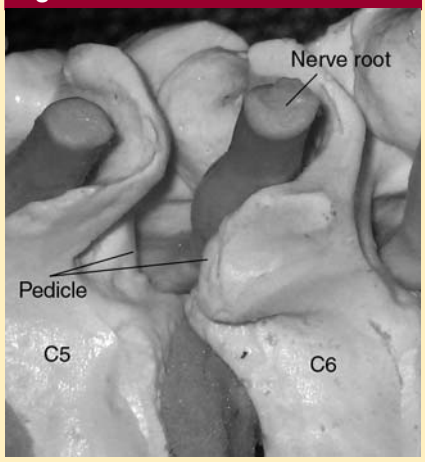
is the superior articular facet of the caudal segment (eg, the superior articular facet of C6 at the C5-6 foramen) (Figure 4). The principle underlying posterior decompression is to unroof the foramen, which allows the nerve root(s) to displace dorsally away from the anterior uncinate spur. Thus, decompression of the neuroforamen is accomplished by resecting all of the superior articular facet that covers the foramen. Because the pedicles form the cranial and caudal borders of the neuroforamen, adequate decompression requires resection of the superior articular facet (the roof of the foramen) to the lateral margin of the pedicles. Any overhang of the superior facet over the caudal pedicle may result in persistent compression. In contrast, resection of the superior facet lateral to the pedicle is unnecessary and may lead to facet instability.

Following exposure, the interlaminar "V" is identified (Figure 5, A) (**video**). This is the point at which the lamina of the cranial segment intersects with the lamina of the caudal segment. A high-speed, 2-mm, acorn-shaped, carbide-tipped cutting burr is used to resect the overlying inferior articular facet. Rarely, the inferior articular facet causes impingement of the root; the inferior articular facet lies dorsal to the superior articular facet. Despite this, approximately 50% (medial-lateral) of the overlying inferior articular facet must be removed to expose the underlying superior articular facet, which is covered by articular cartilage (Figure 5, B). The exposed superior articular facet is then removed with a burr. The simplest way to do this is to make an L-shaped trough (Figure 5, C). The vertical limb of the "L" is made along the lateral border of the pedicle, and the horizontal limb is made just cranial to the pedicle (**video, 2:00**). The cranial border of the superior articular facet should be visualized, whenever possible, by maximally flexing the neck and removing an adequate amount of the inferior facet. Failure to see this cranial border can result in a "sickle-shaped" decompression (Figure 5, D). Copious irrigation (20 mL syringe with a 2-inch, 18-gauge angiocatheter) is used to prevent thermal damage to the surrounding tissues, as well as to aid in visualization. A burr is preferred to Kerrison rongeurs; in a patient with a tight foramen, putting instruments into an already stenotic canal can cause neurologic deficits. Once most of the roof of the foramen has been removed, a 1-mm Kerrison punch may be used to clean up any overhanging bone (Figure 5, E) (**video, 3:55**). At the conclusion of the foraminotomy, the lateral wall of the cranial and caudal pedicles should be readily palpable (Figure 5, F) (**video, 4:40**). There should be no bone overhanging the medial and cranial aspect of the caudal pedicle. For the patient with intraforaminal disk herniation, the nerve root must be manipulated to expose the herniated disk fragment that is ventral to the nerve root. When there is little room for the root to migrate cranially, the surgeon may burr down the cranial 2- to 3-mm of the caudal pedicle. A microscopic right-angle probe may be placed into this space and rotated ventral to the root to sweep any herniated disk fragment out from under the root. Micro pituitary rongeurs are used to remove the disk fragment. After completing the decompression, bleeding surfaces are controlled with a local hemostatic agent, such as powdered thrombin or gelfoam (**video, 5:05**).

Laminaplasty

Using the Hirabayashi technique, we typically open the laminaplasty on the side with greater compression or with greater symptoms; the hinge side remains a bit less decompressed. After performing the necessary foraminotomies, the lamina is osteotomized completely on one side using a 2-mm, carbide-tipped, acorn-shaped burr to create the open door (Figure 6) (**video, 5:30**).

Figure 4

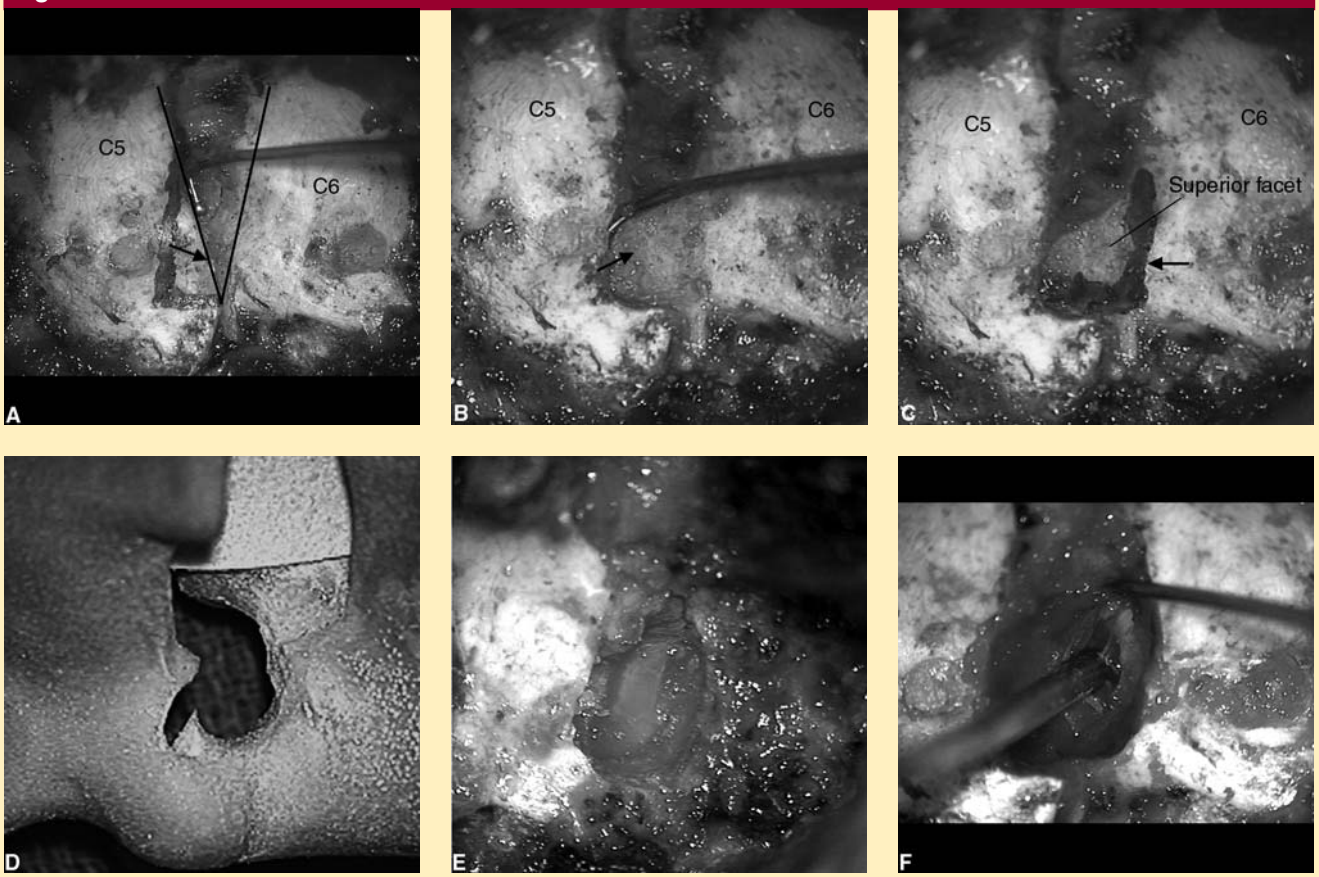


Posterior element anatomy. Note the boundaries of the foramen (pedicles cranial and caudal) and the nerve root exiting at the C5-6 level.

We perform our osteotomy at the lamina-facet junction and routinely score the dorsal cortex with the burr before proceeding with the osteotomy. The cut is made just medial to the pedicles, which are identified during the foraminal decompressions. This location is usually at the junction between the lamina and the lateral mass. A high-speed burr is used with constant irrigation to allow better visualization and avoid thermal necrosis. The microscope allows excellent visualization such that one can distinguish between bone, the ligamentum flavum, and the dura (**video, 6:10**). This in turn allows the surgeon to rapidly cut through the lamina without lacerating the dura underneath.

Once the lamina has been completely cut on one side, the ligamentum flavum is detached on that side, as well as above and below the levels to be decompressed (**video, 7:15**). This must be done thoroughly to ensure that the ligamentum does not prevent the opening of the lamina. At this point, epidural veins are often lacerated; these may bleed profusely. Bipolar electrocautery and lo-

Figure 5



A, The interlaminar "V," the point at which the decompression is begun (arrow). **B,** Approximately 50% of the inferior articular facet is removed to expose the underlying superior articular facet (arrow). **C,** The cranial border of the underlying superior articular facet of C6 is exposed, and the medial 50% of the superior articular facet is removed by making an L-shaped trough (arrow) just cranial to the C6 pedicle. **D,** Sickle-shaped decompression caused by failure to expose the cranial border of the C6 superior articular facet, resulting in burring away of the exposed facet only. **E,** The superior facet has been removed. Most of the medial 50% of the superior facet has been burred away, leaving a thin rim of bone. **F,** A micro nerve hook is used to palpate the lateral wall of the pedicle and to ensure that there is no remaining facet overhanging the cranial wall of the pedicle.

cal hemostatic agents (eg, powdered thrombin, gelfoam) may be used to gently tamponade these sites of bleeding (**video, 9:35**).

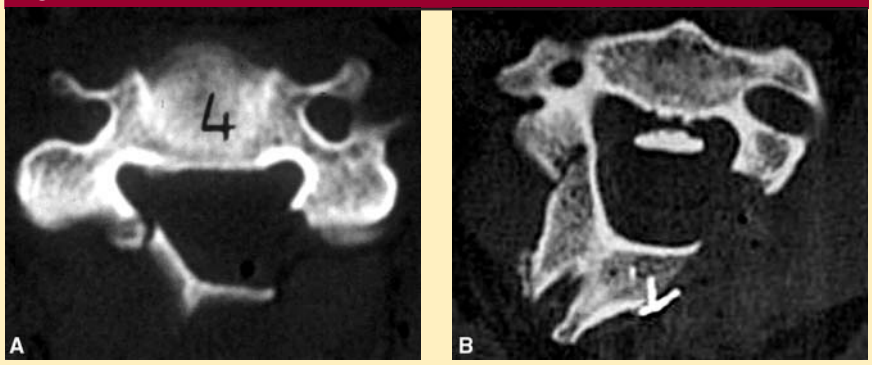
The osteotomy on the hinge is created by partially burring through the lamina, using a high-speed burr. Under microscopic visualization, one can differentiate between cortical and cancellous bone. Approximately one half of the underlying cancellous bone is removed. Because the cranial and caudal portions of the laminae are all cortical bone, they must be burred down to the dura to allow for easy opening of the lamina. For the surgeon who is less experienced with this technique, it is wise to frequently check the "springiness" of the spinous process during the burring of the hinged side (**video, 14:15**). This will help prevent making too deep a trough, which would result in the entire lamina breaking off. When it appears that an adequately deep trough has been made but the lamina still does not open, the surgeon should check to make sure that the ligamentum has been adequately resected on the opposite side, as well as at the cranial and caudal ends of the laminaplasty. The trough may have been made too laterally into the lateral mass. Palpating the pedicle or the lateral border of the lamina with a small probe or curet can help to reorient the surgeon. When the trough is too lateral, one can make a new trough or extend it more medially.

Next, the spinous process is pulled toward the hinged side while pulling up with a small curet on the open door side (**video, 16:00**). The surgeon should place a finger on the spinous process and place the curet underneath the open side to act as backup protection in case one or the other should slip and the lamina should snap closed on the unprotected spinal cord. Many methods

have been described for keeping the laminaplasty open, including laminaplasty plates, craniofacial reconstruction plates, suture anchors, and bone grafts (Figure 7). We typically use a laminaplasty plate with 5-mm screws placed into the lateral masses on one side and screws of similar length to fix the plate onto the laminar side (**video, 19:30**). The laminaplasty plate is easy to use and is effective in keeping the lamina open.

More recently, we have implemented a modification of the standard C3 through C7 laminaplasty technique. In this modification, we perform laminectomy of C3 and laminaplasty from C4 to C6. Additionally, we undercut the caudal lamina of C2 as well as the cranial aspect of the C7 lamina, when clinically indicated, to avoid extending the incision and potential propagation of instability, while still allowing decompression of those two additional levels (Figure 8). This effectively reduces the amount of bony work, muscle dissection, and disruption of the semispinalis cervicis off the C2 posterior elements while still allowing an effective decompression at the cephalad and caudal aspects of the laminaplasty. Decompression from C3 through C7 usually may be achieved with a laminaplasty of C4, C5, and C6 and with undercutting the caudal two thirds of C3 and the cranial one half of C7.

Figure 6



The lamina is cut completely on one side and approximately 50% on the hinge side. **A,** Computed tomography (CT) scan of C4. This hinge was made too medially, limiting the amount of opening. The medial wall of the pedicle is located at the juncture between the lateral mass and the lamina, just lateral to the interlaminar "V." This is easy to identify when the foraminotomy is performed first. This hinge has completely fractured off. **B,** CT scan demonstrating a hinge made more laterally, in the ideal position.

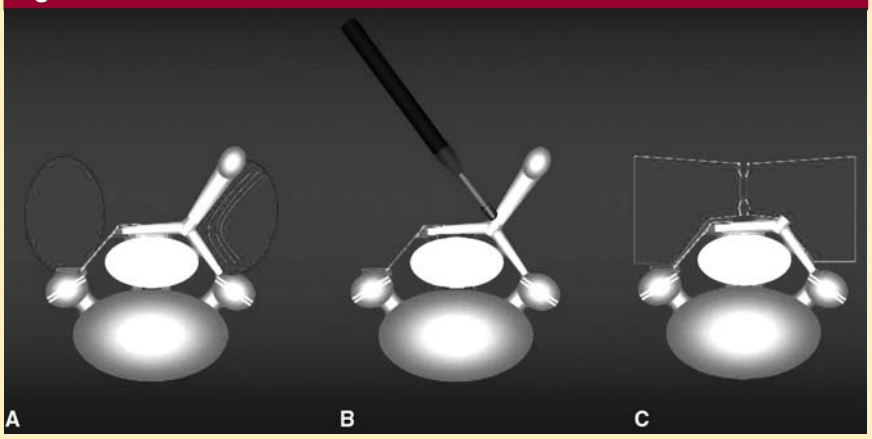
Figure 7

A, Plate fixation. To avoid neural injury when placing screws, use a two-handed technique, with one hand stabilizing the shaft and the other turning the screw. **B,** Intraoperative image of laminaplasty using the plating technique without strut grafting. Intraoperative images with **(C)** and without **(D)** bone spacers. **E,** When the hinge side breaks, one can use either a small plate designed to fix this or a small finger plate. (Photos courtesy of John Heller, MD, Atlanta, GA.)

Figure 8

Postoperative lateral radiograph of C4-6 laminaplasty with undercutting of C3 lamina (arrow), allowing additional decompression without the need for a complete laminectomy.

Figure 9



Resection of the spinous processes. **A,** When the laminaplasty is closed with the spinous processes intact, the muscles on the hinge side are asymmetrically compressed, making wound closure difficult. **B,** Resection of the spinous process with a burr gently removes bony impingement without fracturing the hinge side. **C,** With the spinous process removed, it is easier to reapproximate the muscles.

Once the laminaplasties have been secured from C3 to C7, a high-speed burr is used to resect the spinous processes at the base of the lamina. This prevents the spinous process from asymmetrically impinging on the muscles on the hinged side (Figure 9). The neck is maximally extended to ensure that the laminae do not impinge on each other. A burr is used to remove any bony impingement to full extension.

The final step before closure consists of rubbing all raw bony surfaces with a hemostatic agent or bone wax for hemostasis.

Closure

The posterior wound is closed in multiple layers to closely reapproximate the normal anatomy. When meticulous exposure in the midline is performed, then the preserved interspinous ligament, with its muscular attachment, is used as the first layer of closure. This tissue provides a strong subfascial layer for closure. The surgeon should take care to minimize the amount of muscle that is incorporated into the suture. With a well-exposed spine, the surgeon can find a thin fascial layer enveloping the muscle that can be used to close this layer. For a typical C2 through C7 exposure, 40 to 50 interrupted sutures are needed to close the deep and middle layers. The closure progresses from deep to superficial, with the placement of deep, middle, and superficial drains.

Postoperative Care

In patients younger than age 65 years who have normal renal function and no history of congestive heart failure, ketorolac is administered during hospitalization. The patient typically remains in the hospital for 24 to 48 hours, depending on drain output. No restrictions are placed on range of motion, and therapy with immediate cervical spine motion can begin once the patient is released from the hospital. A soft collar is given for comfort, but the patient is encouraged to discontinue using it as soon as possible. The patient is discharged on oral pain medication and is instructed to return to the clinic for routine follow-up at 6 weeks postoperatively. Rapid return to normal activities is encouraged, as is aerobic exercise.

Summary

Laminaplasty has many benefits. There is no need for postoperative immobilization; there is no concern about graft extrusion, pseudarthrosis, collapse, or graft-related complications; and it avoids the complications associated with an anterior approach. Laminaplasty may be done as an extensile approach to decompress the spinal cord in the patient with myelopathy. This technique is generally well tolerated and has satisfactory outcomes. Good results are attainable with meticulous care during each stage of the operation and postoperative management.

References

Evidence-based Medicine: No level I/II randomized prospective studies are cited. Level III and IV case-control series include references 1, 2, 4-12, 14-18, and 20-22.

Citation numbers printed in **bold type** indicate references published within the past 5 years.

Pearls

- The patient should be placed in bivector traction, using flexion for foraminotomy and extension for laminaplasty.
- A reverse Trendelenburg table is set up to reduce blood loss. A warming blanket is placed under the patient, on the ventral surface.
- Exposure is done via meticulous midline dissection through an avascular raphe.
- Bilateral foraminotomies are performed at C4-5 to minimize the risk of C5 nerve palsy.
- Adequate decompression requires resection of the superior articular facet (the roof of the foramen) to the lateral margin of the pedicles.
- With laminaplasty, the hinge should be based on the less symptomatic side; the opening side allows for more room to decompress the spinal cord.
- Placing a finger on the spinous process and the curet underneath the open side provides backup protection in case one or the other should slip and the lamina should snap closed on the unprotected spinal cord.
- A laminaplasty plate is affixed using 5-mm screws placed into the lateral masses on one side and screws of similar length to fix the plate onto the laminar side.
- Instead of doing a formal laminaplasty, the lamina of the cranial and caudal segments is undercut, thereby allowing two additional levels of decompression. This results in a shorter operation, less disruption of muscles, and less postoperative pain.
- The posterior wound is closed in multiple layers, with multiple drains, to more closely reapproximate the normal anatomy. Multiple small bites are taken with sutures to avoid muscle necrosis.
- Postoperatively, range of motion is not restricted, and the patient is not required to wear a brace. Some patients wear a soft collar for pain control and to prevent muscle guarding.

Pitfalls

- Avoid chin-lift, jaw-thrust maneuvers.
- Maintain in-line traction during intubation.
- Consider neuromonitoring during intubation and positioning.
- The head of the patient should not be positioned too close to the top of the table because the microscope can impinge on the top of the table.
- It is essential to have good coordination and communication with the anesthesia providers when changing the position of the patient's head.
- The neck should be extended to ensure that there is no bony impingement. Before closure, any such impingement should be burred off.
- The surgeon must take care not to detach the semispinalis cervicis from the spinous process of C2.
- The surgeon should not remain superficial to the facet capsules during dissection. The capsules provide some protection against postoperative kyphosis and must be preserved.
- With foraminotomy, approximately one half (medial-lateral) of the overlying inferior articular facet must be removed to expose the underlying superior articular facet.
- Any overhang of the superior facet over the caudal pedicle may result in persistent compression.
- With laminaplasty, the surgeon must ensure that the ligamentum flavum is resected. Failure to do so can prevent the opening of the lamina.
- The "springiness" of the spinous process should be checked frequently during the burring of the hinged side to avoid a broken hinge. A broken hinge, which may result from too much or too little bony removal, can be stabilized with a plate (Figure 7, E).
- The trough should not be made too laterally into the lateral mass or too medially into the lamina. Instead, it should be just medial to the medial pedicle wall.
- It is important to ensure that proper fixation is achieved; the use of autograft spacers may loosen and cause re-stenosis.

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