Cervical Laminoplasty

Sanjitpal S. Gill, M.D., and John G. Heller, M.D.

Summary: Definitive treatment of cervical spinal stenosis for patients with substantial or progressive impairment of neurologic function without any sustained remission is operative. The source of spinal compression, the number of vertebral levels involved in the spondylosis, sagittal alignment, and surgeon preference are criteria that must be factored into whether an anterior or posterior cervical approach is used. Historically, laminectomy has been favored for posterior decompression, but the resultant instability, kyphosis, and late neurologic deterioration have decreased the enthusiasm for laminectomy alone. Even with the addition of a posterior fusion procedure, laminectomy and fusion have met with limited success because of the rate of complications, including kyphotic alignment, subjacent level degeneration, and progression of myelopathy. The advantages of laminoplasty include the preservation of motion, the reduction of adjacent segment degeneration, and the absence of fusion-related complications such as nonunion, autograft site discomfort, and instrumentation failure. However, laminoplasty is not without its difficulties because the creation of the “troughs” and “hinges” can be technically demanding. Key Words: Posterior decompression—Cervical laminoplasty—Multilevel cervical myelopathy.

The surgical management of multilevel cervical myelopathy affords a wide degree of choices among procedures. In designing the appropriate strategy for any given patient, a number of variables must be taken into consideration: What is compressing the cord? From what direction? Is there concomitant nerve root compression? Is the overall cervical alignment lordotic, straight, or kyphotic? Is there any associated segmental instability? In deciding between anterior fusion-based procedures and laminoplasty, one might also wish to consider host factors that could influence graft mechanics and healing.

Until the 1960s, laminectomy was the principal means of decompressing cervical stenosis involving multiple levels. However, kyphosis, instability, and late neurologic deterioration limited the overall success of laminectomy. Concomitant posterolateral fusion has also been espoused, but laminoplasty has demonstrated equivalent neurologic results but markedly fewer complications compared with laminectomy and fusion. Anterior procedures such as multilevel diskectomies with fusion (ACDF) and corpectomies with fusion have also been used in treating multilevel cervical myelopathy since the 1960s. The logic of these operations is compelling, because the surgeon is able to remove directly anterior sources of spinal cord compression. The subsequent anterior fusion, however, mandates a corresponding decrease in motion and its consequences. With increasing vertebral levels of cervical spondylotic myelopathy, anterior decompression and fusion have been reported to cause substantial morbidity in 25 to 50% of patients, principally as a result of graft complications. For equivalent neurologic outcomes, early active range of motion and reduced complication rates have been shown to favor laminoplasty when compared with the anterior corpectomy and fusion. Motivated by unsatisfactory outcomes with laminectomy, laminoplasty evolved in Japan to achieve predictable spinal cord decompression yet avoids most of the pitfalls of laminectomy. Over time two schools of laminoplasty have established themselves: the “open-door” laminoplasty, as described initially by Hirabayashi in 1978 and its derivatives, and a spinous process-splitting (“French door”) laminoplasty, most recently modified in...
1998 by Tomita et al.\textsuperscript{14} with their description of using a thread wire saw (T-saw) to cut the laminae in the midline. Proponents of either school of laminoplasty debate over technical ease, bleeding, symmetry of canal expansion, ability to perform concomitant foraminotomies or fusions, residual motion, and so forth. As yet, no consensus has emerged favoring one school over the other, with the institution where one trained remaining as the primary factor in a surgeon’s preference. As North American surgeons embrace the merits of laminoplasty, they should be exposed to both surgical methods and then draw their own conclusions.

**INDICATIONS AND CONTRAINDICATIONS**

Morbidity considerations favor posterior decompression via laminoplasty over anterior decompression and fusion when the cervical spondylosis involves three or more motion segments.\textsuperscript{7} Furthermore, with laminoplasty procedures, the cord may be predictably decompressed while preserving motion, yet the adverse consequences of laminectomy (segmental instability, kyphosis, and perineural adhesions) may be avoided.\textsuperscript{2} In addition to cervical spondylotic myelopathy, indications for laminoplasty include ossification of the posterior longitudinal ligament, congenital and developmental stenosis of the spinal canal, and spinal cord tumors. Laminoplasty is contraindicated in kyphotic alignment of the cervical spine, previous posterior cervical surgery, and ossification of the ligamentum flavum. It is relatively contraindicated in the presence of segmental cervical instability, although it may be combined with posterior fusion. We also consider a primary complaint of axial pain a relative contraindication, because anterior fusion-based procedures are generally more effective in treating axial pain. The decompression is achieved via posterior displacement of the spinal cord within the enlarged spinal canal, given the absence of kyphosis.

**PREOPERATIVE PLANNING**

The patient’s neutral plain radiographs and magnetic resonance images are correlated with the patient’s symptoms and signs (Fig. 1). With absent notable cervical kyphosis, multilevel cervical myelopathy may be treated effectively via laminoplasty. In most cases, cervical laminoplasty is done from C2–C3 through C7–T1, adhering to the dictum for posterior decompression of including at least one full lamina above and below the extent of cord compression. If necessary, the decompression may be extended cranially via a “dome laminectomy” of C2 and caudally by including T1 in the laminoplasty.

![Preoperative magnetic resonance image of a patient with multilevel cervical spondylolysis.](image)

Determination of the patient’s clinical and radiographic range of motion is valuable. Lateral flexion–extension radiographs may be used to exclude segmental instability patterns, which might indicate the need to fuse one or more motion segments at the time of laminoplasty. The clinical range of motion may also help determine the safe functional range of motion to be respected when intubating the patient, as well as intraoperative positioning of the head and neck.

Noncontrast computed tomographic (CT) scans or CT myelograms may be useful. The point of transition from lamina to lateral mass is not always as easily recognized...
as one would like. Because of their unique ability to
render bone detail, CT scans are quite useful in deter-
mining the landmarks to guide trough placement. The
size and location of the vertebral arteries may be inferred
from the foramina transversaria, thus reducing the risk of
arterial injury when preparing troughs. Stenosis of the
neuroforamen is also readily appreciated on CT scans,
which may suggest the need for a supplemental forami-
notomy at the time of laminoplasty, if warranted by the
patient’s symptoms and signs.

SURGERY

Position and exposure
The patient is intubated with due precaution taken for
the presence of pathologic spinal cord compression. The
patient is positioned prone with the head secured in a
three-point head holder (Mayfield’s tongs; Fig. 2). A
position of slight flexion is preferable initially because
posterior skin folds are reduced, which facilitates both
exposure and closure. Overlapping of the laminae is also
reduced, making the preparation of troughs easier. The
cross-sectional area of the spinal canal is slightly en-
larged, thus decreasing the epidural pressure to some
degree. To the extent possible, the reverse Trendelenburg
position helps to reduce both paravertebral and epidural
venous pressure and bleeding.

The surgical field may include the posterior iliac crest,
if it is likely that a fusion will be required. For most
circumstances either local spinous process bone grafts,
plate–screw fixation, or some combination of the two
will obviate the need for an iliac crest graft.

A midline posterior exposure is performed, with care
taken to avoid detachment of the semispinalis muscles
from the spinous process of C2. The inferiormost margin

of the C2 lamina will be exposed to gain access to the
C2–C3 interlaminar space. However, most of the exten-
sor muscle attachments can be preserved. This maintains
effective cervical extensor power and aids in stabilizing
cervical alignment. Subperiosteal exposure of the poste-
rior elements is performed out to the middle of the lateral
masses so that bone troughs can be made in the medial
one third of the lateral mass. Unlike the exposure for a
posterior cervical fusion, the dissection need not extend
to the edges of the lateral masses. Thus, more of the
muscular origins and insertions are respected. Care must
also be taken to avoid excess injury to the facet capsules
(Fig. 3).

Open-door laminoplasty

Preparing the troughs
The spinous processes are amputated at their bases,
with the better formed ones saved for potential use as
local bone grafts to prop open the laminoplasty (Fig. 4).
The locations of the bone gutters are identified along the
medial margin of the facets by correlating the local bone
anatomy with the CT scans (Fig. 5). The “open” side
trough is fashioned first. Whether it is made on the right
or the left is subject to a number of considerations. Some
maintain that the canal should be opened on the more
symptomatic side. Others suggest that it should be
opened on the side of greatest spinal cord compression,
independent of the symptoms. In the event that forami-
notomies will be required, these are done most easily on
the open side. But when all other factors are equal, the
handedness of the surgeon will dictate the side to be
opened first. Right-handed surgeons generally prefer to
stand on the patient’s left (when the patient is prone) and work cranially to caudally with the burr. Conversely, left-handed surgeons prefer to begin on the patient’s right side.

In normal circumstances three layers of bone must be removed: two cortical layers and an intervening cancellous layer. The initial cortical and cancellous bone may be removed with a more aggressive burr tip, if one prefers. The inner cortical layer must be removed with greater caution. At the caudal end of each lamina, the ligamentum flavum presents a protective barrier for the dura and epidural veins. This is not the case at the cranial end, where it projects deeper into the spinal canal. Greater finesse is required to avoid potentially frustrating epidural bleeding. For this reason, some surgeons prefer to switch to a 3.0-mm diamond burr to thin the inner cortex more slowly.

Once the bone has been thinned enough or removed, each level must be inspected carefully to ensure that the laminae have been separated from their respective lateral masses. Close inspection will reveal that the cranial end of the lamina takes on a bluish hue as the bone becomes thin enough. At the caudal end one can usually distinguish the yellow of the ligamentum flavum from the whiter cortical bone. Palpation with a Penfield elevator or nerve hook can confirm the absence of bone. Residual bone bridges may be removed with a 1.0-mm Kerrison punch. Unless the separation is complete, it will not be possible to assess the proper “stiffness” of the contralateral “hinge” as it is being fashioned. For the time being, the ligamentum flavum and veins should be left undisturbed. They are divided as the laminoplasty is opened.

We recommend using a low-aggression 4.0-mm oval cutting burr or a coarse diamond burr for most of the trough preparation. Changing to a 3.0-mm round diamond burr may be desirable for the last stages of thinning the inner cortex, especially early in one’s experience. In either case, it is not necessary to make the trough any deeper than the diameter of the 4.0-mm burr. After descending to that depth, any additional working pressure should be applied medially, not ventrally. This helps ensure that the separation occurs at the junction of the lateral mass and the lamina. The more ventral one proceeds, the more likely one is to encounter bleeding from the longitudinal veins within the epidural space, which is more difficult to control than bleeding from the dorsal branches of these veins.

The “hinge”-side trough is placed similarly with respect to the lamina–lateral mass junction. The primary difference is that the bone is carefully thinned to the point of forming a stiff hinge that yields to moderate pressure. Thus, after removing the outer cortex and the cancellous layer, the surgeon proceeds cautiously, pausing to assess the stiffness of each laminar hinge. One’s attention must be redirected to the cranial edge of the laminae, as the tendency is to thin the caudal side too much, forgetting that the cranial side projects deeper toward the epidural space. If the laminar hinge does not yield to pressure, check to be sure that the open-side bone bridge was removed completely. Above all else, be patient. The objective is a stiff “greenstick” bone hinge, not a floppy hinge of ligamentum flavum that risks displacement and neurologic injury (Fig. 6).

**Opening the laminoplasty**

The ligamentum flavum is resected bilaterally at C2–C3 and C7–T1 (Fig. 7). Then, proceeding from
caudal to cranial, the capsular soft tissues and the epidural veins are divided. The edge of the lamina on the open side is elevated carefully, from caudal to cranial, with an angled curette, nerve hook, or similar instrument, and a bipolar forceps is used to coagulate and divide the tissue and veins. Although not readily appreciable when compressed, the veins are present in a segmental pattern. A great deal of frustration can be avoided by ligating them prophylactically before they bleed. The veins are controlled most readily when coagulated as far dorsally as possible, thus staying away from the longitudinal veins more ventrally. Once the soft tissues have been divided at all levels, a gradual, repeated deformation of the hinge in a greenstick fashion is ideal. To avoid undue tension on the dura and nerve roots, a 90° dural elevator is used to lyse any epidural adhesions that may be present. Adequate enlargement of the spinal canal and dura is readily appreciated with restoration of normal dural pulsations. Any epidural bleeding will also diminish substantially as a result of the reduced tourniquet effect of the stenotic canal. If foraminotomies are needed, they may be performed at this time.

Posterior arch reconstruction: keeping the door open

The laminoplasty door must be held open until the hinge has healed successfully to provide permanent protection. Generally speaking, the door may either be tethered open or propped open. The classic procedure by Hirabayashi and Satomi9 used sutures passed through the facet capsules and paravertebral muscles and then the interspinous ligaments to provide a tethering force. For those who still favor using a tether, arthroscopic suture anchors placed within the center of the lateral mass provide a faster and more secure form of fixation.

An open-door laminoplasty may also be propped open by any number of means. Although requiring a bit more surgical finesse, notched local spinous process autografts may serve such a purpose (Fig. 8). Usually C6 and C7 are suitably sized for the task. However, if additional bone is required, one can harvest the T1 spinous process or use allograft, such as rib. It would be unusual to subject the patient to the morbidity of harvesting autograft from another site solely for this purpose. When used, such prop grafts are typically placed at C4 and C6.

Rigid internal fixation of the open door is our method of choice. As originally described by O’Brien et al.,11 miniplates could be adapted to this purpose from maxillofacial or hand surgery implants. The technique fixes the laminae securely, and may be combined with prop grafts if desired. Specially contoured titanium plates may be used to simplify further the fixation technique (Fig. 9). The security of this intrasegmental fixation has allowed for a more aggressive postoperative protocol of early active range of motion, which has been suggested as a way of preserving motion and reducing axial pain.

Pitfalls

Creation of the troughs and hinges is technically artful. The hinge side of the laminoplasty is susceptible to displacement if excessive bone is removed. Placing a trough too deep or too lateral can create neurovascular problems or segmental instability respectively. Also, release of the posterior spinal musculature from the spinous process of C2 can lead to neck extensor weakness.
“French door” laminoplasty

The midline cut

The so-called “French door” style of laminoplasty relies on dividing the laminae in the midline, then opening them on bilateral bone hinges. Proponents of this method favor the symmetry of canal expansion as well as the paucity of dorsal midline epidural veins with which to be contended. The patient positioning and surgical dissection are as described earlier. The midline bone cut is made first. Although described originally using a burr, Tomita et al.14 have described a method using a T-saw, which is only 0.54 mm in diameter (Fig. 10). The proposed advantages include cutting away from the spinal cord rather than toward it, as well as notably less bone loss. However, attention to detail is required to avoid inadvertent harm to the spinal cord.

After excision of the ligamentum flavum at C2–C3 and C7–T1, the T-saw is passed along the midline epidural space from caudal to cranial (Fig. 11). This technique is analogous to passage of a conventional epidural catheter or electrode. The smooth, tapered tip of the outer sleeve facilitates passage without damaging the

FIG. 8. (A, B) Intraoperative view (A) and postoperative computed tomographic scan (B) of self-locking, notched spinous process grafts used to maintain the open-door laminoplasty.

FIG. 9. (A) Frontal and lateral views of an open-door laminoplasty titanium plate. (B, C) Intraoperative view (B) and postoperative computed tomographic scan (C) of titanium plates to keep the lamina propped open.
meninges. The advancing tip of the sleeve is grasped as it appears in the flavectomy at the other end of the decompression zone (Fig. 12). The T-saw is advanced through the sleeve, so that it can be held securely while the sleeve is withdrawn in a retrograde fashion over the saw.

At this point, the unsheathed saw spans the midline of the spinal canal along the area to be decompressed (Fig. 13). Each end is grasped with the accompanying special clamp. After a position of cervical lordosis has been ensured, the T-saw is pulled tight before initiating a reciprocating motion. The T-saw should fit snugly at the midline of the inner wall of the laminar arch. A continuous reciprocating motion will cut the laminae spinous processes from ventral to dorsal, away from the dura and spinal cord. The supra- and interspinous ligaments are subsequently dissected at the midline by the T-saw. The saw should be irrigated continuously with sterile saline solution to avoid excessive heat or friction.

**Spinal canal enlargement**

Bilateral hinge troughs then are made just as described for the hinge side of the open-door procedure (see Figs. 5 and 6). They are positioned in the medial one third of the lateral mass. The outer cortex and cancellous bone are removed. The second cortex is carefully thinned to the point that the “hinge” can be bent by a gentle, repetitive application of force. Ideally, the hinge opens

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**FIG. 10.** The thread wire saw (T-saw) within its sheath.

**FIG. 11.** Passage of the T-saw (0.54 mm in diameter) contained within its sheath (1.2 mm in diameter) under the C7 lamina for sublaminar passage toward C2–C3.

**FIG. 12.** Sublaminar passage of the T-saw with exposure of the tip of the T-saw at the cranial end of the area to be decompressed.

**FIG. 13.** After cervical lordosis has been confirmed, the T-saw is unsheathed and pulled taut under the lamina. The laminae and the spinous processes are cut with a reciprocating motion while the T-saw is irrigated continuously with saline solution.
by plastic deformation of bone, or a greenstick fracture. The split laminae are opened in sequence, like French doors, along the decompression zone, aided by the use of a modified laminar spreader (Fig. 14). Proper dural pulsation usually is observed once the hemilaminae are separated. Careful dissection of any dural adhesions is imperative and facilitates the decompression. The thoracic spinous processes may be split in a similar fashion if additional caudal levels are needed. If C2 must be included, it usually can be undercut by a diamond burr (dome laminectomy) without compromising its structural integrity or detaching the extensors.

Keeping the “French door” open
At this stage, separation of the hemilaminae must be maintained by one of a number of techniques. Generically speaking, French doors are propped open, rather than tethered. If the spinous processes are well developed at C6 and C7, as many as four hemispinous process grafts can be obtained by amputating the split spinous processes (Fig. 15). Corticocancellous iliac crest autograft is another option. Allograft rib or fibula may be fashioned to the appropriate size and shape. Ceramic and hydroxyapatite spacers are also available in Japan and elsewhere to be used as structural props. In either case, small drill or burr holes must be made in each hemilamina, through which sutures or wires are passed to secure the grafts or spacers. Rigid fixation with titanium clips will simplify and speed this process by eliminating the tedious work associated with traditional methods (Fig. 16).

Pitfalls
When the cervical canal is too narrow and the catheter cannot be passed the entire length, or if the alignment is not lordotic, simultaneous cutting of all the spinous processes is contraindicated. With kyphosis, the taut T-saw would be drawn like the string of a bow, possibly injuring the spinal cord by further compression. In such instances, one or two additional laminotomies should be made, so that only two or three levels are cut at one time or the technique changed altogether, perhaps to an open-door procedure. Epidural scarring from previous posterior cervical surgery and ossification of the posterior longitudinal ligament are specific contraindications to French door laminoplasty because of the danger and decreased success rate of passage of the polyethylene sleeve. As with any laminoplasty, hinge displacement may be a problem, especially after excessive bone resection.
POSTOPERATIVE MANAGEMENT AND REHABILITATION

Independent of the laminoplasty method used, we approach postoperative care similarly. The patient is placed in a soft collar postoperatively. The head of the bed is kept elevated to 30 or 45° to reduce epidural pressure and bleeding. Out-of-bed activity is initiated on postoperative day 1 for most patients, if their myelopathy is not too severe. The wound drain is removed 24 to 48 hours after the operation, depending on the amount of drain output. Patients are encouraged to move their neck within the limits of comfort. As incision pain permits, they are encouraged to use the soft collar as an active resistive therapy device. The soft collar is weaned over 2 to 4 weeks. Active resisted neck and shoulder range of motion and rehabilitation are initiated at 6 weeks under the supervision of a physical therapist.

RESULTS

Our results have compared favorably with those reported in the literature regarding cervical laminoplasty for multilevel cervical myelopathy. Eighty-six percent of patients had a good or excellent result with laminoplasty (Fig. 17) compared with 92% with anterior cervical disectomy and fusion. However, laminoplasty patients were permitted early active range of motion, unlike those patients undergoing multilevel fusions. Independent clinical evaluation of the French door laminoplasty showed an arrest of myelopathic progression in all patients and improvement in subjective symptoms among most: gait, 67%; strength, 78%; dexterity, 67%; numbness, 83%; and pain, 83%. Overall pain assessed with the Robinson scale showed marked decreases at the latest follow-up when compared with preoperative levels. No patients used narcotic analgesics at the time of the most recent follow-up compared with 44% of patients before surgery. Activity-associated axial pain or neck fatigue, however, was the chief complaint at follow-up (38%). The frequency and character of postoperative axial symptoms are consistent with previously reported results by Hosono et al. However, axial neck pain has also been demonstrated with anterior corpectomy with similar frequency to laminoplasty. We tend to think of axial pain not so much as something that distinguishes one surgical approach from the next, but as the burden the patient must bear for having multilevel cervical spinal cord compression that required surgical decompression. Whether operated anteriorly or posteriorly, their complaints are similar in character and severity, although the cause of the complaints may differ.

Reduced range of motion is inherent to laminoplasty. Although unintended, a 47% decrease in sagittal motion with open-door laminoplasty techniques has occurred after a 1-year follow up and 56% at final follow-up (7.8 years). The findings have been similar for French door laminoplasty, but the loss of motion was less, resulting in a 38% decrease in sagittal motion at approximately 2 years’ of follow-up. In either case, laminoplasty spares motion, which would be necessarily eliminated in an anterior fusion-based procedure, which theoretically decreases the risk of adjacent segment degeneration, let alone the graft and implant complications that occur with multilevel fusion procedures.

COMPLICATIONS

The overall complication rate is 7% for expansive laminoplasty whereas the complication rate for anterior corpectomy is 29%. Technical problems may arise
from the hinges during their preparation or later before they heal. During trough preparation, nerve root or vertebral artery lesions can be created with excessively deep or misguided troughs (Fig. 18). On the hinge side, excessive bone removal or bone removal that is too medial can result in a floppy hinge, which may displace into the canal, causing either radiculopathy or myelopathy (Fig. 19). Potential segmental instability is created by too lateral a trough resulting from an inadvertent partial facetectomy. Hinge closure and graft dislodgment were initially the primary concern with laminoplasty, leading to recurrent spinal cord compression (Fig. 20). However, contemporary techniques, especially rigid laminar fixa-

**FIG. 17.** (A, B) The successful expansion of the cervical canal as viewed by a postoperative sagittal computed tomographic scan (A) and magnetic resonance image (B).

**FIG. 18.** Placement of the trough too deep and too lateral as noted by the arrowhead. Although there was no adverse consequence in this case, the potential for nerve root or arterial injury must be noted.

**FIG. 19.** A floppy hinge resulting from excessive bone removal during an open-door laminoplasty technique.
tion, appear to reduce this risk and afford early, more aggressive rehabilitation.

Segmental motor paresis or paralysis, more commonly referred to as a motor root lesion, can be observed postoperatively in 5 to 7% of laminoplasties. To this end, the possible risk must be discussed during preoperative counseling. However, it should be noted that the complication is by no means unique either to laminoplasty or posterior surgery. Although any cervical root distribution might be affected, the weakness most commonly is manifest in deltoid and biceps function (C5). The deficit may evolve postoperatively, mandating a careful neurologic examination daily. In our experience it has evolved commonly on postoperative day 2 or 3. This condition is treated supportively with a sling and shoulder physiotherapy with substantial recovery expected within 3 to 6 months.

Excessive bleeding can occur as a result of the lateral branching epidural veins on the trough side of the laminoplasty. Canal stenosis also creates relative epidural hypertension. Helpful technical pearls include patient positioning, availability of a microangled bipolar cautery, powdered gel foam and thrombin, and careful trough placement. The bleeding is best and most easily managed once the canal is opened. One then has access to the veins, and the pressure is reduced. Overzealous attempts to control the bleeding without adequate exposure of the spinal cord and nerve roots may result in a neurologic injury.

Kyphosis and listhesis greater than 3 mm is rarely seen. Dural tears with the open-door technique are quoted in the literature to occur 1.9% of the time. Primary repair with or without a fascial or muscle patch is essential. The repair can be decompressed further with a lumbar drain for 2 to 3 days.

**SUMMARY**

In the absence of certain contraindications, years of clinical experience and accumulated data support laminoplasty as a compelling choice of treatment for multilevel cervical spinal cord compression. Laminoplasty achieves clinically effective spinal cord decompression while preserving motion and allowing early active range of motion of the cervical spine. Complications related to bone, grafts, and instrumentation are avoided, and the functional outcomes are similar to those with anterior corpectomy and fusion or laminectomy and fusion.

The choice of laminoplasty method—open door versus French door—appears to be of little consequence. Each has its good and bad points when compared with the other. With attention to detail, either procedure is safe and effective. Recent advances in surgical techniques have further simplified securing the door in its open position by eliminating some of the tedious steps associated with the classic techniques.

**REFERENCES**


