Surgical management of cervical myelopathy: indications and techniques for laminectomy and fusion

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Abstract

BACKGROUND: Cervical spondylotic myelopathy (CSM) is a commonly encountered surgical disease that may be approached through a variety of operative techniques. Operative goals in the treatment of CSM include effective neural element decompression and maintaining spinal stability to avoid delayed deformity progression and neurologic compromise. Determining the most appropriate operative approach requires careful consideration of the patient’s clinical presentation and radiographic imaging.

PURPOSE: To review the indications and techniques for multilevel laminectomy and fusion in the treatment of CSM.

CONCLUSIONS: When indications permit, a multilevel laminectomy is an effective and safe method of neural element decompression. Recognizing the potential for spinal instability is essential to prevent neurologic compromise and intractable axial neck pain caused by deformity progression. A variety of techniques have been described to supplement the posterior tension band after laminectomy; however, lateral mass fixation has evolved into the preferred stabilization technique. Although clinical success is well documented, a successful outcome is dependent on a comprehensive, individualized evaluation of each patient presenting with CSM. © 2006 Elsevier Inc. All rights reserved.

Keywords: Cervical; Fusion; Indications; Laminectomy; Myelopathy; Techniques

Introduction

Cervical spondylotic myelopathy (CSM) is a common diagnoses requiring surgical intervention among patients presenting with disorders of the spine [1–8]. A variety of well-known pathological processes, both congenital and acquired, can lead to canal compromise and myelopathy; however, the presentation and history are difficult to predict [1,3,4,8]. Thus, the prognosis and management of this patient population may be challenging. Although well-designed clinical outcome trials are lacking, the existing literature suggests that operative intervention reliably arrests the progression of myelopathy and may lead to functional improvement in the majority of patients [1,2,4–6,8–20]. The success of any operative procedure is dependent on a comprehensive evaluation of the individual patient’s clinical and radiographic characteristics.

Both static and dynamic forces contribute to direct compression, distortion, and ischemia of the spinal cord, resulting in injury that often extends beyond the limits of the compressive pathology [21]. Degenerative changes compromising the spinal canal are exaggerated by stretching the spinal cord across ventral pathology during flexion and in-folding of the ligamentum flavum with extension [22]. Repeated microtrauma contributes to a chronic progressive course, while acute deterioration due to irreversible cord injury may result from hyperextension. Patients suffering from CSM typically manifest signs and symptoms including upper extremity weakness and paresthesias, loss of hand dexterity, gait instability, or bowel and bladder dysfunction. Foraminal impingement will produce radicular complaints with pain and sensorimotor loss in a specific nerve root distribution.

The goals of operative intervention in the treatment of cervical spondylotic myelopathy include the following:
(a) decompression of the spinal cord and nerve roots; (b) deformity prevention by maintaining or supplementing spinal stability; and (c) alleviating pain. Achieving these goals will translate into improved clinical outcomes with stabilization or reversal of neurologic deficits, decreased pain, and maximal functional restoration.

A number of surgical strategies exist, including anterior, posterior, or circumferential approaches. Under most circumstances one approach will produce optimal results. The surgical management of patients presenting with CSM requires a comprehensive and individualized approach. Designing the most effective surgical plan is dependent on numerous factors, including the pathoanatomy of the patient, the patient’s neurologic presentation, medical comorbidity, assessment of procedure-specific risks, and the surgeon’s experience and comfort level with specific procedures.

The multilevel cervical laminectomy has been proven to be a safe and effective means to decompress the spinal canal and nerve roots [6]. Although this procedure carries the risk of a late kyphotic deformity, improved neurologic outcome is possible under the appropriate conditions. Absence of a fixed kyphotic deformity is mandatory when considering a multilevel laminectomy. Disregarding this basic premise will lead to suboptimal surgical results or worsening neurologic deficits.

The presence or possibility of spinal instability must be anticipated in order to avoid a postoperative deformity that could lead to delayed neurologic deterioration. Selecting the optimal posterior stabilization technique requires a thorough understanding of cervical biomechanics and the available techniques of spinal reconstruction. Points of fixation to stabilize the cervical spine after resection of the lamina are limited to the lateral masses and pedicles. The choice of fixation construct is dependent on the nature and extent of instability and the surgeon’s experience and comfort level [23]. Under the appropriate conditions, however, a multilevel laminectomy with or without an arthrodesis is a valuable and effective management strategy in the treatment of CSM.

Once the decision to proceed with surgery is finalized, a comprehensive radiographic evaluation of the pathologic spine is absolutely necessary to determine the most appropriate operative approach. Several important questions that should be considered when choosing the most appropriate operative approach include:

(a) What is the alignment of the cervical spine? Is the spine lordotic, straight, or kyphotic? Posterior procedures are primarily indicated for lordotic, and possibly straight, spinal configurations.

(b) How rigid is the deformity? A single-stage posterior approach with stabilization remains an option even in the presence of a kyphosis if postural reduction restores sagittal balance. Fixed kyphotic deformities are an absolute contraindication to the posterior approach.

(c) What is the nature of the pathologic process? How many spinal levels are involved? Does the patient demonstrate congenital stenosis? Anterior interbody strut grafting beyond two levels is associated with an increased failure rate. In such cases supplemental posterior stabilization is required or a single-stage posterior approach may be more appropriate.

(d) Does a static or mobile subluxation exist? Severe subluxation or any increase visualized on dynamic imaging would eliminate the possibility of a stand-alone laminectomy and require inclusion of a stabilization and fusion.

(e) What is the patient’s baseline medical status? Older patients typically are more prone to complications related to swallowing dysfunction with anterior approaches [7]. Severe osteoporosis will increase the chance of interbody graft subsidence. Under both circumstances a posterior approach may be more appropriate.

(f) Does the patient complain of significant axial neck pain? The presence of axial neck pain, if attributed to motion across a spondylotic segment, may support the addition of an arthrodesis.

**Preoperative surgical planning**

Deciding on the most appropriate surgical strategy is dependent on several factors, including neurologic presentation, pathologic anatomy, and medical comorbidity. The decision to pursue surgery and its timing is influenced by a patient’s neurological presentation. A rapid neurologic decline will require more urgent intervention whereas a stable deficit may be approached on an elective basis. Prophylactic surgery for patients with stable deficits is controversial and requires careful consideration by both the patient and surgeon. The decision is dependent on a careful assessment of the individual’s clinical and radiographic findings as well as the risk, whether operative or conservative, that the patient is willing to accept.

**Advantages of the posterior cervical approach**

A major advantage of the posterior approach in the management of CSM is the familiarity with the surgical procedure. A multilevel laminectomy is a commonly performed procedure, considered technically easier, with shorter operative times and fewer perioperative complications when compared with an equivalent anterior procedure [6]. Anterior exposure may prove exceedingly difficult for obese patients or patients with short thick necks. There is less risk of unintentional durotomy and cerebrospinal fluid leak with a posterior approach, particularly in patients with ossification of the posterior longitudinal ligament where the ventral dura is attenuated or absent. The risk of swallowing dysfunction or recurrent laryngeal nerve palsy is eliminated.
with the posterior approach. Finally, posterior fusion techniques eliminate the complications associated with intervertebral strut grafting, such as subsidence or dislodgment, particularly in the osteoporotic patient.

Disadvantages of the posterior cervical approach

The indirect mechanism of neural element decompression is one limitation of a multilevel laminectomy in the treatment of CSM. In the presence of ventral pathology, operative success is dependent on the dorsal translation of the neural elements. The posterior approach is therefore ideally suited for patients demonstrating a minimal degree of lordosis. The presence of a straight or kyphotic alignment, especially if associated with significant ventral pathology, will limit dorsal migration and cause the spinal cord and nerve roots to drape across ventral pathology, leading to further neurologic compromise [24].

The posterior approach also tends to be associated with increased postoperative pain and morbidity owing to the denervation and devascularization of the paraspinal muscles. Unsightly cosmetic defects resulting from atrophy of the paraspinal muscles may be cause for concern in certain patients. Release of the posterior tension band increases the risk of postoperative kyphotic deformity. The potential for this complication is influenced by numerous factors, including the underlying pathologic process, the number of spinal levels involved, the extent of the decompression, and the patient’s age and underlying medical condition (eg, presence of osteoporosis) [6]. Although the theoretical risk of spinal cord injury may be lower with posterior approaches, there are more specific neurologic deficits that are associated with a posterior decompression, in particular dysfunction of the C5 nerve root producing dissociated motor loss [25].

Flexible deformities or subluxation may be exacerbated with a stand-alone multilevel laminectomy, and therefore the inclusion of a posterior stabilization construct must be considered. The potential for open deformity reduction is limited with the more common posterior cervical fixation techniques because of the limited purchase of lateral mass screws. Although the use of cervical pedicle screws may provide a biomechanical advantage, the insertion of these devices is technically demanding with the potential for catastrophic neurovascular complications.

Indications for multilevel cervical laminectomy

For patients presenting with CSM, poor prognostic indicators and, therefore, absolute indications for surgery are: (1) progression of neurologic signs and symptoms; (2) presence of myelopathy for 6 months or longer; or (3) severe spinal cord compression, defined by a compression ratio approaching 0.4 or transverse spinal cord area of 40 square millimeters or less [1,2,4,6,9,12,18,26,27]. Under these circumstances, conservatively treated patients nearly always experience neurological deterioration [19], with surgical intervention being the most reliable method to prevent disease progression.

Factors that influence the surgical decision-making process include the extent of disease, location of compressive pathology, spinal alignment, and the presence of congenital canal stenosis (Table 1). For cases with anterior compression limited to one or two levels, fixed kyphotic deformity, and no significant developmental narrowing of the canal, an anterior or circumferential decompression and stabilization is favored [12,14,15,18,26,28]. In contrast, patients with compression extending more than two levels, developmental narrowing of the canal, lordotic alignment, and primary posterior compressive pathology are candidates for the multilevel laminectomy (Fig. 1) [9,16,20,24,29–32].

Among these factors, appropriate assessment of the cervical alignment is the most important factor when determining if a multilevel laminectomy is appropriate. Benzel defines an “effective” cervical lordosis as the configuration where no dorsal component of C3 to C7 crosses a line from the posterior caudal corner of C2 to an identical point on C7. Associated with this line is a zone of uncertainty, where a surgeon’s bias and experience determine if the global configuration is consistent with a lordosis or kyphosis. Others consider a configuration that falls into this “gray” zone as a “straightened” spine [33]. The decision to perform a multilevel laminectomy in the presence of a straight spine requires consideration of additional factors, such as the degree of canal encroachment. Dorsal migration of the spinal cord away from ventral pathology may be insufficient with a straight cervical spine. Limits of ventral encroachment have been suggested; however, no definitive value exists. Hamaishi and Tanaka considered a minimum lordosis of 10 degrees required for adequate dorsal migration of the spinal cord [34]. Yamazaki and coworkers observed continued ventral compression after posterior decompression when the lordosis was less than 10 degrees and the extent of ventral canal encroachment exceeded 7 mm in patients presenting with ossification of the posterior longitudinal ligament [35]. Under these questionable circumstances, the decision often rests on the surgeon’s clinical experience and procedural bias as there are no defined standards of treatment.

The decision has been made to perform a multilevel

Table 1
Indications for anterior and posterior approaches for cervical spondylotic myelopathy

<table>
<thead>
<tr>
<th>Anterior approach</th>
<th>Posterior approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primarily anterior compression</td>
<td>Primarily posterior compression</td>
</tr>
<tr>
<td>1-2 level of disease</td>
<td>≥3 levels of disease</td>
</tr>
<tr>
<td>Kyphotic deformity</td>
<td>Normal or lordotic deformity</td>
</tr>
<tr>
<td>Absence of congenital canal stenosis</td>
<td>Presence of congenital canal stenosis</td>
</tr>
<tr>
<td>Associated radiculopathy</td>
<td>No radiculopathy</td>
</tr>
<tr>
<td>Absence of OPLL</td>
<td>Presence of OPLL</td>
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laminectomy, the surgeon must then decide whether the addition of a posterior cervical fusion is indicated.

**Indications for posterior cervical fusion**

The primary surgical goals when performing a posterior cervical stabilization and fusion include restoring stability, maintaining alignment, providing stability until fusion has matured, and alleviation of pain. These constructs provide stability by reinforcing the posterior tension band that is compromised by the pathologic process or surgical decompression. Determining the presence and extent of instability rests on careful assessment of both static and dynamic imaging. There have been numerous models and definitions created in an attempt to identify and quantify spinal instability [36,37]. Although these models provide a foundation for operative decision making, each has limitations and cannot be universally applied to all clinical situations. From a practical standpoint, the presence of instability must be determined on an individual basis. Findings on radiographs that are suggestive of instability include: subluxation of more than 3.5 mm on static lateral radiographs; more than 11 degrees of angulation between adjacent segments; and more than 4 mm of subluxation on dynamic views [17]. Under these circumstances a posterior decompression without stabilization is likely to lead to a progressive deformity that will require intervention at a future date.

Although not an absolute indication for supplemental posterior stabilization, the presence of a straight cervical spine should alert the surgeon to an increased potential for a postlaminectomy kyphosis. The extent of decompression may prove more significant under these circumstances, and has been correlated to postoperative spinal instability, deformity progression, accelerated spondylotic changes, and constriction of the dura mater by formation of extradural scar tissue [6,8,11,16,20,24,27,32,38]. In vitro studies have demonstrated significant mobility and potential for postoperative instability with the resection of 50% of the facet complex [39,40]. Age has also been correlated to the development of a postlaminectomy kyphosis, requiring the surgeon to consider a stabilization when performing a multilevel decompression in a younger patient [41–43].

**Contraindications to the posterior approach**

Specific to the posterior approach, the presence of a fixed kyphotic deformity is an absolute contraindication when considering a multilevel laminectomy, even with the inclusion of a posterior cervical arthrodesis. These patients often require a circumferential approach to adequately decompress the neural elements, stabilize the spine, and optimize sagittal balance. A similar approach may be considered for patients with severe osteoporosis, who require 360 degree stabilization to prevent construct failure. Chronic injury to the spinal cord, as demonstrated on preoperative magnetic resonance imaging, is also considered a contraindication. Imaging characteristics consistent with intramedullary cystic necrosis, syrinx formation, or myelomalacia indicate permanent cord injury that is unlikely to improve with operative intervention [44].

Relative contraindications, not specific to the posterior approach, include a history of significant medical comorbidity, such as older age (>70 years), diabetes, coronary disease, obstructive pulmonary disease, peripheral vascular disease, stroke, and social history of tobacco use or alcoholism [45–47]. Under these circumstances the risks of operative intervention often do outweigh the benefits, particularly if there is no chance of neurologic recovery.

**Surgical technique**

**Patient positioning/operative setup**

An awake, fiberoptic intubation is preferred for symptomatic patients with severe cord compression. During the induction of general anesthesia the natural protective mechanisms resisting neck motion are inhibited, allowing unrestricted cervical manipulation that could result in spinal...
cord injury. Accurate blood pressure monitoring is required to avoid hypotension that could result in spinal cord ischemia or infarction. Before patient positioning, baseline electrophysiological monitoring, including somatosensory evoked potentials, motor evoked potentials, and free running electromyography, is obtained, particularly for patients with severe cord compression. Although the value of electrophysiological monitoring is debatable, it can provide useful information during reversible maneuvers, such as patient positioning [48–50]. Monitoring, however, should not be regarded as an insurance policy for poor surgical technique.

The patient is positioned prone with the arms tucked at the sides and appropriate padding to prevent pressure neuropathies. A Mayfield head holder or tongs with traction are used to secure the head (Fig. 2). A neutral position is favored because prolonged periods in either a flexed or extended posture may not be tolerated, especially in the presence of severe spinal cord compression. A second traction line is set up to extend the neck and maximize lordosis once neurologic decompression is achieved. After final positioning, repeat electrophysiological monitoring is performed. If a change is identified, factors that may affect potentials such as anesthetics or alterations in blood pressure should be verified and corrected. Neck position should be rechecked and returned to a more neutral position. Intraoperative fluoroscopic imaging is useful to verify cervical alignment after final positioning and confirm spinal level during the operative procedure. Also alignment may be rechecked during the procedure to optimize sagittal balance before any stabilization is performed.

**Multilevel laminectomy**

Once the patient is positioned and skin localization confirmed, the spine is exposed through a midline incision. Maintaining a midline approach in the avascular fascial plane will help decrease blood loss and minimize postoperative pain. The paraspinal muscles are elevated in a subperiosteal fashion using monopolar cautery. Dissection of the facet joints is completed if an arthrodesis is intended. Care is taken not to disrupt the facet capsule of uninvolved adjacent segments or if only a laminectomy is intended (Fig. 3). Localization can be performed with anatomic landmarks, such as the prominent C2 spinous process; however, confirmation with intraoperative imaging is recommended.

Resection of the lamina en bloc is the favored approach. If required, keyhole foraminotomies are performed before...
resection of the lamina so that the lamina can act as a protective barrier during drilling of the foramen. The en bloc resection tends to be less time-consuming and avoids the insertion of any instrument into the central canal before the decompression. Using a high-speed drill equipped with a matchstick or small round burr, troughs are drilled bilaterally at the lamina–facet junction. The drill is held perpendicular to the dorsal surface of the lamina to provide the shortest route to the canal and avoid drilling of the lateral mass (Fig. 4). Drilling initially passes through the dorsal cortex followed by the soft cancellous core, and finally the dense ventral cortex of the lamina. Bleeding from the medial wall of the trough is easily controlled with wax. Although a diamond bit may be used, this tends to slow the process and generate more heat. Regardless of the drill bit used, continuous irrigation is recommended to avoid thermal injury. The rostral aspect of the lamina tends to dive deep and requires more extensive drilling to completely disarticulate the lamina. Entry into the epidural space is confirmed with gentle palpation with either the drill bit or nerve hook. The ventral cortex may also be resected by inserting a small foot-plated rongeur into the trough.

Once the bony troughs are completed, the spinous processes at the rostral and caudal extremes of the decompression are elevated with clamps and the ligamentous attachments of the ligamentum flavum within the troughs are stripped with rongeurs. Epidural bleeding encountered during this maneuver is easily controlled with bipolar cautery and gelfoam. Symmetric elevation of the lamina is required to avoid levering the bone into the spinal canal (Fig. 5). Once all ligamentous attachments are resected, the entire complex is removed. The underlying dura is inspected and epidural bleeding controlled. If no fusion is intended, a hemovac drain is placed to prevent postoperative hematoma and a multilayer closure is performed. The hemovac drain is typically removed within 24 hours of the operation. Patients may be placed in a soft cervical collar for comfort measure for several weeks.

**Posterior cervical stabilization and fusion**

The earliest attempts at stabilizing the subaxial cervical spine involved the placement of autologous bone along the posterior elements; however, this approach lacked immediate stability and required prolonged periods of immobilization. Wiring techniques were first described in 1891 by Hadra [51], and since that time a variety of posterior wiring techniques have been developed that have demonstrated acceptable fusion potential with relatively low complication rates [52–56]. Postlaminectomy wiring techniques required the wire to be passed between adjacent facets or tied to either bone grafts or metallic rods (Fig. 6) [57,58]. Although
facet wiring techniques have largely been replaced by more rigid, newer generation constructs, wiring continues to be a viable option.

Over the last several decades the emergence of lateral mass fixation has become the stabilization technique of choice [59–63]. Lateral mass fixation has proven to be a safe and biomechanically superior technique when compared with wiring procedures. Gill et al. demonstrated the increased rigidity and fusion potential with lateral mass fixation compared with posterior wiring techniques [64]. The intrinsic strength of the lateral mass screw provides immediate stabilization, allowing early mobilization and possibly eliminating the need for external bracing. The placement of cervical pedicle screws has also been described, demonstrating superior fixation when compared with lateral mass and anterior plating techniques [65]. Despite the biomechanical rationale for inserting cervical pedicle screws, this technique is not routinely practiced because of the technical demands and the potential neurovascular complications [66].

Lateral mass fixation

Fixation to the lateral masses has evolved from early generation screw-plate constructs to more versatile multi-axial screw-rod constructs. Plating systems were generally unyielding because of the predetermined position of the screw hole within the plate. These constructs could not adapt well to variations in the patient’s anatomy, instead the patient’s anatomy was forced to conform to the construct. Because of the rigidity of the plate in the coronal plane, all screws had to be positioned in line. In addition, points of fixation were sacrificed if the plate hole did not match the entry site within the lateral mass (Fig. 7). Due to the dynamic interface between the screw and plate, the potential to maintain reduction was limited and required bicortical screw purchase to obtain maximal stability [67]. Surface area for fusion formation was compromised because the plate was positioned flush against the dorsal wall of the lateral mass. Finally, revision surgery required removal of all the screws in order to disengage the plate. These deficiencies have largely been overcome with the evolution of multi-axial screw rod constructs [62].

Various lateral mass screw insertion techniques have been described in the literature (Fig. 8). The Roy-Camille technique uses the midpoint of the lateral mass as the insertion site and directs the screw without any rostral or caudal angulation and 10 degrees laterally [68]. Jeanneret and Magerl describe a starting point 1 to 2 mm medial and superior to the midpoint of the lateral mass with the trajectory aimed 30 degrees superior and 15 to 25 degrees lateral [69]. Anderson et al. recommended a starting point 1 mm medial to the lateral mass center and angled 15 degrees cranial and 30 degrees lateral [70]. Finally, Anderson et al. modified the Magerl technique with a starting point 1 mm medial to the lateral mass center and aimed 20 to 30 degrees cranially and 10 to 20 degrees laterally [71].
Several studies have investigated the biomechanical characteristics and anatomic relationships of the various lateral mass screw techniques [72–75]. Montesano and co-workers demonstrated a 40% greater pullout strength when screws were placed using the Magerl compared with the Roy-Camille technique [74]. From a clinical perspective, however, there has been no difference in the complication rate between the different techniques [73]. Bicortical purchase of the lateral mass is associated with greater complications without a clear biomechanical advantage [75,76]. Ultimately measurement of exact angles for screw placement is impractical, and a trajectory with a bias in the medial to lateral direction with a rostral angulation starting close to the lateral mass midpoint will create an appropriate screw trajectory (Fig. 9). The surgeon needs to develop a clear understanding of the anatomy, perform an appropriate exposure, and study preoperative imaging in order to obtain the optimal screw insertion.

Exposure for lateral mass fixation requires soft-tissue dissection to be extended until the far lateral margin of the facet is identified. To avoid compromise of uninvolved segments, care must be taken to maintain the facet capsule at the rostral and caudal extremes of the intended fusion. Lateral mass landmarks must be clearly identified for appropriate placement of screws. The medial border is defined by the valley at the lamina–lateral mass junction. The rostral and caudal boundaries are defined by the adjacent facet joints; and the lateral boundary by the exposed lateral edge. Although the relationship of the vertebral artery and nerve root to the subaxial lateral masses is generally consistent, appropriate screw placement requires a detailed understanding of these anatomical relationships. The vertebral artery lies anterior to the lamina–lateral mass junction whereas the nerve root passes anterolaterally, deep to the caudal superior facet.

Once the soft-tissue exposure is completed, entry sites for the lateral screws are marked by scoring the dorsal cortical wall with a high-speed drill. This site is typically in close proximity to the midpoint of the lateral mass. The drill bit is placed into the entry site, perpendicular to the dorsal cortex. Once the bit engages the bone, the trajectory is altered aiming from the infero-medial quadrant toward the supero-lateral quadrant, away from the nerve root and vertebral artery. Resection of the spinous process, as described above, allows for access to the spinal canal.

Fig. 5. The posterior elements, including the lamina and spinous processes, are resected en bloc making sure the rostral and caudal ends are simultaneously elevated to avoid leveraging one end into the spinal canal. Curettes or rongeurs are inserted into the troughs to release any ligamentous tissue tethering the lamina.

Fig. 6. Wiring techniques used to stabilize the cervical spine after a multilevel laminectomy include passage of the wire between adjacent facets, securing individual wires to a structural graft, or to a rigid rod, such as the Hartshill rectangle.
processes may be necessary to obtain the optimal trajectory (Fig. 10). Laminectomies are not performed until after the holes are drilled to protect the dura and neural elements. Once completed, the screw holes may be tapped and filled with bone wax to prevent excessive bleeding. The lamina are then resected with the en bloc technique (Fig. 11). If a fusion is performed, all bone resected is saved as autograft. Lateral mass screws are inserted into the predrilled holes aiming in a supero-lateral direction (Fig. 12). Malleable rods are cut and contoured, and locking mechanisms are engaged. Rods should be contoured so that significant force is not required to seat the rod within the screw. The posterolateral spine, including the facet joints, is decorticated and the grafting material is impacted across the spine and into the facet joints (Fig. 13). Closure is performed in the same manner as for an isolated laminectomy.

**Cervical pedicle screws**

Specific indications for cervical pedicle screws have not been defined. With the exception of C7, the placement of subaxial cervical pedicle screws is not routinely performed due to the potential for catastrophic neurovascular injury, morphologic characteristics and variation of the cervical pedicles [77], the technical difficulty involved with

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**Fig. 7.** This anterior-posterior radiograph demonstrates how plate constructs have a limited ability to conform to the surgical anatomy. The right sided screw hole second from the top is positioned over the facet joint, eliminating the possibility for screw placement.

**Fig. 8.** The entry site for the screw with the Roy-Camille method is the midpoint of the lateral mass, perpendicular to the dorsal cortex in the sagittal plane. The screw is directed laterally by 10°. Using the Magerl technique the screw entry site is located slightly medial and cranial to the midpoint of the lateral mass. The screw trajectory is parallel to the facet joint in the sagittal plane and directed 25° laterally in the transverse plane. The entry site for the Anderson technique is located approximately 1 mm medial to the lateral mass midpoint with a rostral angulation of 30°–40° and a lateral angle of 10°. Finally, the An technique uses an entry site similar to the Anderson technique but only 15° of rostral angulation and a lateral angulation of 30°. These trajectories are intended for placement of screws into the lateral masses of C3 to C6. (Reprinted with permission from Barrey et al. [72] and Xu et al. [75])
insertion, and the lack of clinical data supporting the superiority of cervical pedicle screws over lateral mass screws. Despite the technical difficulties, placement of cervical pedicle screws may serve as a pragmatic solution under unusual circumstances where lateral mass fixation cannot be achieved. In animal and cadaveric biomechanical studies, the placement of cervical pedicle screws has demonstrated superior stability, fixation, and reduction potential when compared with lateral mass fixation [65,78].

In vitro studies have demonstrated an unacceptable potential for injury when depending only on anatomic topography for the placement of cervical pedicle screws [79,80].
The inability for accurate insertion based on visualized anatomic landmarks is primarily due to the inherent morphologic variability of the cervical pedicle trajectories and the minimal margin of error allowed for appropriate screw placement (Fig. 14). Increased accuracy has been observed with direct exposure of the pedicle through a laminoforaminotomy and the addition of computer-assisted navigational techniques [79–81]. Even with a laminoforaminotomy, however, in vitro studies have demonstrated a 39.6% incidence of critical violation, with possible nerve root or vertebral artery injury [66].

Abumi et al. have published extensively on the placement of cervical pedicle screws [66,82–86]. They chose an entry site just lateral to the midpoint of the lateral mass in close proximity to the posterior edge of the superior articular surface. The cortical bone is drilled away to expose the dorsal cancellous bone of the pedicle. Trajectory through the pedicle is created with a hand-held probe with a lateral to medial inclination ranging from 25 to 45 degrees. Cannulation of the pedicle is performed with real-time fluoroscopic imaging to supplement tactile feedback. Using this technique, Abumi and colleagues reported rates of pedicle violation ranging from 5.3% to 6.9%; however, no injury to the vertebral artery was observed. Using the same technique, Ludwig et al. [97] reported a 12% rate of critical injury to the vertebral artery, nerve root, or spinal cord in a cadaveric model.

Based on the available literature, it seems that successful placement of cervical pedicle screws not only requires a comprehensive understanding of the three-dimensional pedicle anatomy and the surrounding neurovascular tissues, but also requires supplementation with direct visualization of the pedicle or utilization of advanced navigational techniques. Despite these maneuvers, considerable risks remain and more conventional methods of posterior cervical stabilization should strongly be considered before the placement of these implants.

Complications

Iatrogenic deformity, as a result of a previous laminectomy, is considered one of the more common causes of a progressive cervical kyphosis. Because of the increased flexibility of the cervical spine, stability is more dependent on the integrity of the posterior muscles and ligaments. The posterior exposure causes denervation and atrophy of the posterior cervical musculature and compromises the ligamentous capsule of the facet joints [42,87,88]. The incidence of kyphosis after dorsal cervical procedures has been reported to be as high as 21% [88]. As many as 53% of patients under 18 years of age who undergo a multilevel laminectomy will develop a progressive kyphosis [41]. Younger patients are at an increased risk as a result of incomplete ossification of the vertebral bodies and reduced resistance to the incremental compressive forces that develop with compromise of the posterior tension band [42,43]. Additional risk factors include compromised preoperative sagittal balance, extent of posterior element disruption, and the number and location of lamina resected [42,89–91]. Cadaveric studies have demonstrated a significant increase in cervical mobility after resection of more than 50% of the facet complex [39,40].

Neurologic complications can be divided into cord and root injuries. The incidence of spinal cord injury ranges from 0% to 3%, whereas injury to an individual nerve root has been reported as high as 15% [47,92]. Technical error, introduction of instruments under the central lamina, as well as ischemic injury due to hypoperfusion or aggressive distraction can lead to irreversible spinal cord injury. Nerve root injury may result from direct manipulation but has also been attributed to the dorsal translation of the spinal cord after midline decompression [47]. The resulting loss of motor function in the absence of sensory loss has been termed dissociated motor loss. Radicular complaints are more commonly described in the C5 and C6 nerve root distributions. Symptom onset typically occurs within hours to days after surgery, with specific pain and weakness. Spontaneous recovery is the general rule; however, deficits may persist for months. Isolated reports have been published that demonstrate neurologic recovery
with aggressive posterior decompression after onset of symptoms [25].

Complications associated with lateral mass fixation result from impingement of the traversing nerve root or penetration of the vertebral artery. Potential for nerve root injury is increased when attempting bicortical purchase. Cadaveric studies have investigated the potential for inappropriate placement with the various fixation techniques [75,76]. Seybold and colleagues using a modified Magerl technique, demonstrated a 17.4% incidence of nerve root impingement and 5.8% incidence of potential vertebral artery injury when placing bicortical screws [76]. No such injuries were recorded with unicortical screws, and no significant difference in pullout strength was observed between unicortical and bicortical screws. Xu and coworkers observed a 95%, 90%, and 60% incidence of nerve root violation with the Magerl, Anderson, and An techniques respectively [75]. In this study a fixed screw length of 20 mm was used to ensure bicortical purchase. The Magerl technique commonly violated the dorsal ramus, whereas the An technique violated the ventral ramus.

The risk of injury is not only related to the technique but also to the morphology of the lateral masses. Barrey et al. observed an increased incidence of poor screw position at C3–C4 with the Magerl technique and at C5–C6 with the Roy-Camille technique [72]. This variation was attributed to the change in the height/thickness ratio as one descends down the spine, with more caudal lateral masses becoming longer and thinner. These authors concluded that variations in the technique of lateral mass screw placement should be considered to achieve optimal purchase and reduce incidence of nerve injury. Despite the potential for neurovascular injury, most studies have demonstrated that fixation to the lateral masses is a safe and effective means of posterior cervical stabilization [93].

Insertion of cervical pedicle screws is associated with risks to the vertebral artery, nerve root, and spinal cord. Because of the technical difficulty, small size, and morphological variation in the cervical pedicle, the risk is considered greater than observed with lateral mass fixation. The greatest potential for injury is to the vertebral artery injury owing to the steep lateral to medial inclination required for appropriate screw placement. Abumi and Kaneda observed a 6.7% incidence of pedicle penetration; however, only 4% of these screws produced a clinically significant radiculopathy [66]. In vitro studies have demonstrated rates of critical pedicle violation as high as 65.5% depending on the insertion technique [79,81]. A greater degree of accuracy was achieved when direct visualization of anatomic landmarks was supplemented with computer-assisted stereotactic navigation techniques. Pedicle screw placement is generally reserved for levels with larger diameter pedicles, such as C7, when crossing the cervicothoracic junction, or when fixation to the lateral masses is not possible.
Outcomes

Under the appropriate conditions, a multilevel laminectomy with or without arthrodesis is an effective management strategy when treating cervical myelopathy. Most clinical series are retrospective in nature and describe an individual surgeon’s experience. Laminectomy as a stand-alone procedure has demonstrated comparable
immediate postoperative results to anterior procedures and laminoplasty [18]. Other series report a significant incidence of delayed deterioration, with rates as high as 40% [10,18,94].

Herkowitz, in 1988, compared results of patients undergoing anterior decompensation and strut grafting, laminoplasty, and laminectomy without fusion [15]. Only 66% of patients after laminectomy reported good to excellent outcomes, whereas the anterior group and laminoplasty group reported good to excellent outcomes in 92% and 86% respectively. Twenty-five percent of the patients in the laminectomy group developed a postlaminectomy kyphosis within 2 years of the operation.

Outcomes after multilevel laminectomy and arthrodesis for cervical degenerative disease have been favorable [71,95,96]. Long-term improved neurologic status and maintenance of cervical alignment have been demonstrated [3]. Retrospective studies have compared the complexity, safety, and clinical results of laminectomy versus corpectomy in patients with multilevel cervical spondylosis [6,9,11,15,18,26,28]. Whereas anterior decompensation and fusion procedures at one or two motion segments have predictable results, procedures involving three or more levels are associated with increased morbidity. Outcome parameters have included operative time, blood loss, length of stay, and rate of complications. These investigations have concluded that posterior decompensation by laminectomy for multilevel stenosis (>2 levels) requires shorter operative time and results in fewer complications than anterior cervical decompensation with similar clinical results. Factors that have been shown to correlate with poor outcome after laminectomy for CSM include advanced age (>70 years at the time of the first surgery), severe original myelopathy, and recent trauma [7,20,32,38]. In short, laminectomy, with or without fusion, may be successfully employed to address multilevel cervical pathology in carefully selected patients.

Cervical laminectomy with posterior fusion is valuable in cases of CSM when preoperative dynamic imaging demonstrates instability. Several retrospective studies have focused on this topic. One review by Huang et al. involving 32 patients with multilevel CSM treated by laminectomy and lateral mass plate fusion confirmed the clinical utility of this procedure [38]. The etiology of disease in these patients was either cervical spondylosis or ossification of the posterior longitudinal ligament, the mean postoperative follow-up was over 15 months, and in all cases myelopathy was graded using the Nurick system. The authors noted the mean Nurick score improved from 2.6 (range 1–4) to 1.8 (range 0–3) postoperatively (p < 0.001). More specifically, 22 patients (71%) had an improvement in Nurick grade of at least one point and nine showed no improvement. Of note, no patients had neurologic deterioration. Severe myelopathy, advanced age, and myelomalacia on preoperative magnetic resonance imaging had no prognostic value for improvement of myelopathy. Overall, this study demonstrated that laminectomy and fusion may result in excellent outcomes for carefully selected patients with multilevel cervical myelopathy.

Conclusions

Under the appropriate conditions, a multilevel cervical laminectomy with or without a supplemental fusion is an effective management strategy for the treatment of CSM. Careful preoperative assessment of the pathologic anatomy, clinical presentation, and medical comorbidity is essential to achieve operative success. Patients requiring surgery with evidence of a reducible deformity or static lordosis are ideal candidates for a posterior decompression. The potential or presence of instability must be recognized and prevented with a supplemental stabilization technique. Lateral mass fixation is the stabilization procedure of choice, demonstrating superior biomechanical properties, technical simplicity, and low complication rate. These operative techniques are essential to the surgeon’s armamentarium when treating patients with CSM.

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