Cervical spondylotic myelopathy: surgical decision making

Sait Naderi, M.D., Edward C. Benzel, M.D., and Nevan G. Baldwin, M.D.

Department of Neurosurgery, Marmara University, School of Medicine, Istanbul, Turkey; and Division of Neurosurgery, University of New Mexico, School of Medicine, Albuquerque, New Mexico

Cervical spondylotic myelopathy can produce a variety of clinical signs and symptoms secondary to neural compromise and biomechanical involvement of the spine. The surgical treatment of cervical spondylotic myelopathy remains a controversial issue after many years of study, evolution, and refinement. Several ventral, dorsal, or combined approaches have been defined. The complications associated with ventral approaches and the concerns about kyphosis following dorsal approaches led to the development of a variety of laminoplasty procedures. This paper reviews the biomechanical basis of cervical spondylotic myelopathy and its effect on choosing the appropriate surgical approach.

Key Words * cervical spondylotic myelopathy * effective kyphosis * effective lordosis * straightened spine * ventral approach * dorsal approach

Cervical spondylotic myelopathy (CSM) occurs secondary to cervical spondylosis and is characterized by degeneration of the cervical intervertebral discs, with subsequent changes in the bones and soft tissues. Cervical spondylotic myelopathy often has an accelerated pattern of progression,[44] and results in three clinical manifestations: 1) myelopathy; 2) radiculopathy; and 3) myeloradiculopathy. The rationale for this categorization scheme is based on the differing clinical manifestations (that is, myelopathy vs. radiculopathy) and surgical approaches (that is, decompression of the spinal cord vs. decompression of the nerve root) associated with each. Many surgical approaches have been proposed for patients with CSM; however, there are no standard methods for determining which is preferable. These approaches include: 1) laminectomy, with or without fusion; 2) laminoplasty; 3) medial (central) corpectomy with grafting, with or without fusion; and 4) ventral discectomy.

These multiple surgical options raise many questions regarding the decision-making process. The following pages address these questions by outlining the surgical component of the decision-making process.

RATIONALIZING A SURGICAL APPROACH TO CSM

Both ventral and dorsal surgical approaches play a role in the management of CSM. The advantages and disadvantages of each must be considered in nearly all cases. It is imperative that one determines which patients are most likely to benefit from any given surgical approach while minimizing the risk/benefit ratio.

Dorsal surgical approaches to spinal canal decompression appear to be safe and

effective.[2,8,10-14,20,21,40,41,60,62-64] Laminectomy, and to a certain extent laminoplasty, are relatively simple operations. The complications associated with dorsal approaches are predictable and preventable,[8,10] and laboratory-based arguments against the effectiveness and safety of laminectomy, such as diminished post-laminectomy spinal cord blood flow, are weak and easily defended.[1,4] Although ventral operations for CSM have recently been reported to be superior to dorsal approaches,[15,23,24,35,38,41,49,50,65,73] it has also been reported that these ventral approaches to CSM are less satisfactory or are associated with an increased incidence of complications.[36,48,70,79] Traditionally, the extent of the compressive pathology in patients undergoing surgery via a ventral approach has been limited to three levels. The rates of both graft-related complications and instrumentation-related complications increase as the length of the fusion increases.[22,81] Furthermore, significant neurological and nonneurological complications associated with ventral approaches, in addition to long-term complications related to fusion, such as increased spinal laxity, hypermobility, and degeneration of the adjacent vertebral segments, affect outcome. Therefore, they must be taken into account when using any ventral decompressive approach.[23,34,35,49,50,65]

Consideration of spinal geometry is also integral to the decision-making process in selecting the type of surgical procedure to be performed; geometry may dictate the use of a ventral approach. Appropriate operation selection maximizes optimum neurological outcome, while minimizing complications.

FACTORS AFFECTING THE CHOICE OF THE OPTIMUM SURGICAL APPROACH

Treatment selection is critical for the surgical management of CSM. First, it involves the selection of surgical candidates. Second, it involves the selection of the most appropriate operation. Surgical failures may occur secondary to either. Selecting a good surgical candidate is relatively straightforward, whereas selecting the type of operation to be performed is much more complicated, and as such, is very controversial. The factors affecting the selection of the surgical approach include the patient's age, the geometry of the spinal canal, and the presence or absence of the spinal stability.

Patient Age

One consideration in selecting the type of operation is patient age. The age of the patient at the time of presentation with cervical spinal cord compression may affect the decision-making process because of 1) the effect of age on the spine, its ligaments, and on intrinsic spinal stability; 2) the effect of age on the spinal cord and its vasculature; and 3) the effect of age on bone density.

Older patients usually have greater intrinsic spinal stability, which they acquired through the aging/spondylotic process. The aged spine is characterized by a decreased range of motion; however, in some cases, dynamic spinal stenosis (retrospondylolisthesis of the vertebral body following neck extension) occurs. The latter is obviously in contrast to the aforementioned patient population, in which relative immobility, rather than hypermobility, is present.[25] In general, the degenerative process is associated with widening of the anteroposterior (AP) diameter of the vertebral bodies, which results in narrowing of the AP diameter of the spinal canal.

Any operation, such as a laminectomy, that destabilizes the spine however slightly, is less invasive provided greater intrinsic stability already exists. As mentioned, spinal stability is acquired as one ages. Conversely, the younger the patient with CSM (myelopathic patient), the greater the chance that congenital cervical stenosis is playing a role in the pathological process.[17,27] Normal and pathological sagittal spinal canal diameters have been defined and documented.[3,28-30,57,58] These data help the

clinician determine to what extent congenital stenosis is involved. Because congenital cervical stenosis is not usually associated with dorsally directed ventrally located osteophytes, a laminectomy is most often expected to offer symptomatic relief and is, therefore, the operation of choice in most cases.[17,19] Furthermore, in the young patient population, there is a greater potential for long-term complications due to cervical fusion.

The dorsal ligamentous complex is composed of the nuchal ligament, the interspinous ligaments, and the facet capsules (capsular ligaments). They are important tensile load (that is, flexion) resistors in the cervical spine. Nolan and Sherk[56] reported that the dorsal ligamentous complex acts as a static stabilizer of the cervical spine, whereas the extensor musculature (that is, the erector spinae muscle) acts as a dynamic stabilizer, particularly of the lower cervical spine. Age-related ligamentous insufficiency should prompt consideration of surgical fusion. In cases with paraspinous ligamentous and musculature weakness, the likelihood of postoperative kyphosis is greater. Therefore, a ventral approach may be more appropriate.[26] Alternatively, a dorsal approach for decompression (laminectomy) and stabilization (lateral mass fusion) may be appropriate in selected cases. The latter alternative may be an appropriate choice in situations in which significant kyphosis is not present, and simultaneously, in which progressive deformity such as kyphosis is likely; for example, in a straightened spine with moderately advanced degenerative changes.

Vascular changes associated with spondylosis may be more severe in the older patient group and may result in ischemia of the nerve roots or spinal cord. This phenomenon can affect the tolerance of the spinal cord to compression. On the other hand, the spinal cord may be atrophic in older patients,[9,25] thus minimizing the compressive effect of spinal stenosis.

Bone density can affect surgical strategies. A 50% decrease in the mass of osseous tissue results in a reduction of strength to 25% of the original strength.[76] Age-related osteoporosis (Type 2 osteoporosis) can complicate a patient's postoperative course. In cases of corpectomy and grafting, and in the presence of soft bone, an aggressive bracing management strategy may be necessary.

Geometry of Spinal Canal

Spinal canal size and shape in the coronal plane and the presence of compressive degenerative changes ventrally or dorsally can affect both neurological and biomechanical aspects of CSM. Edwards and LaRocca[16] reported that a narrow spinal canal in association with a dorsal osteophyte in the spinal canal is a mechanical factor of major clinical significance in CSM. They reported that a 10-mm or less segmental sagittal diameter of the spinal canal is associated with cervical spondylosis and that this is likely to be associated with myelopathy (10-13 mm may be considered as a premyelopathy group, a 13-17 mm diameter exhibiting a tendency for symptomatic spondylosis, and a spinal canal diameter > 17 mm less prone to develop CSM). In addition to dorsal osteophytes, there are several structures that may compromise the spinal canal. These include a herniated intervertebral disc, degenerated hypertrophic facet and uncovertebral joints, and a hypertrophic or calcified ligamentum flavum that may invaginate the spinal canal.[36,54] Of note is that the disc and the ligamentum flavum in the human spine are at approximately the same vertical coordinate level. If both are protruding into the spinal canal at the same level, as with extension of the neck, there is a likelihood of significant spinal cord compression. In this situation, there is a dynamic compression, known as the pincer phenomenon, in which there is a guillotine effect on the spinal cord (Fig. 1).

Fig. 1. Drawing illustrating the pincer phenomenon, with the spinal cord in flexion (left) and extension (right) positions.

It has been reported that, in cases of CSM, the vertebral body is larger than in the normal population.[33] The presence of a static or dynamic compressive lesion, either ventral or dorsal (or at the both the ventral and dorsal aspects), as well as the presence of an effectively large vertebral body, can affect the decision-making process regarding the surgical approach and operative strategy.

One of the most important aspects of spinal geometry affecting the choice between the ventral and dorsal approaches is the geometry of the spinal canal in the sagittal plane: in other words, the intrinsic curvature of the cervical spine.[2,5-7] This is predominantly affected by the degenerative process. The cervical spine degenerative spondylotic process may involve the intervertebral disc, facet joints, and uncovertebral joints. Degeneration of the intervertebral disc results in a loss of disc height, predominantly in the ventral aspect of the disc, which is normally thicker than the dorsal aspect. This ventral thickness contributes to the "natural" cervical lordosis. As the ventral aspect of the disc interspace decreases, the lordotic posture of the cervical spine is diminished and is eventually lost. This pattern of the loss of lordosis can be affected by: 1) the presence of preexisting degenerative disease; 2) the number of motion segments involved; 3) the age of the patient; and 4) the presence of accompanying minor trauma. A "straightening" of the spine increases the forces placed on the ventral aspect of the vertebral bodies by increasing the length of the lever arm, thus exposing the ventral aspect of the vertebral bodies to increased stresses and a tendency toward compression (by the application of forces associated with axial loading via progressively longer bending moments). As the loss of lordosis progresses and the kyphosis-producing forces on the spine increase, the vertebral bodies begin to lose height ventrally (more than dorsally) (Fig. 2). This process results in the collapse of the disc interspace and vertebral body and development of a forward bending of the dural sac and spinal cord. The bending of the dural sac and the spinal cord not only compress the neural structures but also can cause compression of the vessels located ventral to the spinal cord. Kyphosis increases tension on the cervical spinal cord, which in turn places the ventral spinal cord blood vessels under tension and thus may constrict their lumina.

Fig. 2. Drawing illustrating a nonpathological situation in which the dorsal vertebral body height is less than the ventral height. This contributes to the normal "lordotic" curvature of the cervical spine (left). Ventral disc interspace height loss results in the loss of this lordotic posture (center). This causes the creation and elongation of the moment arm applied to the spine (d), leading to ventral vertebral body compression. A further exaggeration of a pathological kyphotic posture may then ensue by the creation of an even longer moment arm (right).

The importance of kyphosis or lordosis of the cervical spine dictates a thorough assessment of the sagittal plane geometry of the spinal canal. The cervical spine's curvature can be determined to be either an "effective lordosis," "effective kyphosis," or a borderline form termed "loss of lordosis" or "straightened spine." [6] Such an evaluation requires the definition of the configuration of the dorsal aspects of the C3-7 vertebral bodies with a line drawn (in the midsagittal plane on the lateral plain radiograph) from the dorsocaudal aspect of the vertebral body of C-2 to the dorsocaudal aspect of the vertebral body of C-7 (Fig. 3).

Fig. 3. Drawing showing evaluation of the intrinsic curvature of the cervical spine based on a line drawn from the dorsocaudal aspect of the vertebral body of C-2 to the dorsocaudal aspect of the vertebral body of C-7 (dotted line) and the gray zone. Left: A case of effective cervical lordosis showing no portion of the vertebral bodies dorsal to gray zone. Center: A midsagittal section of a cervical spine in the case of effective cervical kyphosis showing some portions of the vertebral bodies dorsal to the gray zone. Right: A midsagittal section of a straightened cervical spine showing the most dorsal aspect of a cervical vertebral body to be within the gray zone, but not dorsal or ventral to it.

Effective lordosis can be defined as a configuration of the cervical spine in which no aspect of the C3-7 vertebral bodies crosses this line, whereas with effective kyphosis, some portion of the dorsal aspect of the C3-7 complex must cross this line. Therefore, decisions about the type of surgery to be performed may be made, in part, on the basis of cervical curvature (Fig. 3 left and center).

In patients with an effective kyphosis, there is a high probability of failure associated with a dorsal approach.[3] These cases perhaps should be treated via a ventral approach. The most important hazard of laminectomy in cases with an effective kyphosis is the risk of the "sagittal bowing" of the spinal cord, in which the spinal cord can be tethered over ventral osteophytes in the sagittal plane.

Effective lordosis is often associated with dorsal compression of the cervical spinal cord; a dorsal approach may be appropriate in this situation.

Surgical decision making, however, may be more complex in cases with a straightened spine. For these cases, it may be necessary to use not only this imaginary line, but also a zone that consists of this imaginary line with approximately a 4-mm-wide (2 mm on each side of the midpoint) gray zone (Fig. 3). Cases in which the dorsal aspect of the vertebral body lies within this zone may be defined as a straightened spine (Fig. 3 right). Patients with a straightened spine may be managed via ventral or dorsal

surgery. The size of the gray zone may be large or small, depending on the surgeon's bias.

Intrinsic Stability of the Spine

The presence or absence of intrinsic spinal stability[74,75] plays a role in surgical decision making. The presence of an intrinsically unstable spine often dictates a ventral approach for both decompression and fusion or a dorsal approach for decompression combined with dorsal fusion.

Although dorsal decompressive operations diminish intrinsic spinal stability,[77,78] the extent of their effect on stability is often exaggerated. A standard and appropriate laminectomy should not significantly diminish intrinsic spinal stability. The relationship between laminectomy width and stability has been clearly demonstrated.[61,80,82] Postoperative instability is rare in series in which laminectomy is extended only to the lateral-most aspect of the dural sac.[8,10,18,19,23,37] Therefore, wide laminectomies that are extended past the medial one-quarter to one-third aspect of the facet and foraminotomies that disrupt facet integrity should be avoided or be accompanied by a stabilization and fusion procedure, if appropriate.

MECHANISMS OF SPINAL CORD DISTORTION

Fundamentally, three mechanisms of spinal cord distortion play a role in the CSM process: 1) spinal cord compression; 2) tethering of the spinal cord over extrinsic masses in the sagittal plane; and 3) tethering of the spinal cord over extrinsic masses in the coronal plane. Each must be considered and accounted for prior to surgical intervention.

Spinal Cord Compression

The main cause of neurological deficit in CSM is spinal cord compression. Spinal cord compression results from annular constriction of the spinal cord secondary to ventral osteophyte, dorsolateral facet, and dorsal hypertrophied ligamentum flavum compression.[67] Of note is that the effectiveness of decompression for spinal cord compression has been experimentally documented.[13]

Sagittal Bowstring Effect

Tethering of the spinal cord over extrinsic structures is an underestimated cause of neurological dysfunction in CSM, which can be related to either ventral or dorsal structures in sagittal plane; however, extrinsic masses located ventral to the spinal cord are most commonly implicated. The neurological deficit in a patient with an effective kyphosis is, in part, related to tethering in the sagittal plane (sagittal bowstring effect). This explains the likelihood of neurological worsening in some cases following dorsal decompression procedures (Fig. 4). Morgan, et al.,[52] documented this phenomenon clinically in patients with posttraumatic ventral mass lesions. This phenomenon has also been documented experimentally.[4] The neurological dysfunction in these cases may be related, in part, to vascular compromise of the spinal cord.[14]

Fig. 4. Illustrations showing the sagittal bowstring effect. The mechanism by which a patient with a kyphotic spine (upper) may be worsened neurologically by a dorsal decompressive procedure (lower) is depicted. This occurs via a dorsal distortion of the spinal cord. This is exaggerated by a flexion deformation.

Coronal Bowstring Effect

It has been suggested that the spinal cord can also be tethered in the coronal plane.[8,39] This coronal plane tethering (coronal bowstring effect) is secondary to the ventral tethering of the spinal cord by the nerve roots or dentate ligaments (Fig. 5 upper left). A laminectomy is often ineffective in relieving spinal cord distortion when this occurs (Fig. 5 upper right). A ventral decompressive procedure or a laminectomy plus dentate ligament section (DLS) (Fig. 5 lower) may alternatively relieve the spinal cord distortion in this type of situation.[8]

Fig. 5. Illustration showing the coronal bowstring effect. Upper left: An axial section through a stenotic region of the cervical spine demonstrates a patent dorsal subarachnoid space and ventral tethering of the spinal cord by the dentate ligaments. Upper right: Following a laminectomy, the tethering persists. Note the persistence of the obliteration of the ventral subarachnoid space. Lower: Tethering of the coronal plane deformity is relieved following a DLS or a ventral decompression operation.

CHOOSING AN APPROPRIATE SURGICAL APPROACH

Choosing an appropriate surgical approach necessitates a thorough neurological assessment of the patient, determination of the predominant cause of neural compression (spinal canal compromise), and determination of the spinal canal geometry in both the coronal and sagittal planes.

Ventral Approaches

A patient with an effective kyphosis of the cervical spine usually requires a ventral surgical approach, provided surgery is indicated. The ventral approach, combined with grafting (with or without instrumentation) provides: 1) decompression of the spinal cord, nerve roots, and vessels ventral to the spinal cord; and 2) the ability to limit or reduce the kyphosis. The ventral approach is indicated in some cases of ventral plus dorsal compressive degenerative processes of the cervical spine, with an effective lordosis or straightened spine. In these cases, a dorsal surgical approach may be considered as a second stage.

The variety of ventral approaches to cervical decompression include corpectomy and discectomy (multiple level) combined with osteophylectomy. The use of single-level ventral decompression in the treatment of CSM is widespread. However, as the length of decompression and fusion increases, the incidence of both early and late postoperative complications increases.

Regardless of the decompression procedure used, grafting is necessary. The use of grafting introduces the risks of graft-related problems, such as donor-site morbidity, graft migration (intrusion or extrusion),

nonunion, or delayed union.[22,81] The use of instrumentation following corpectomy in the degenerated cervical spine continues to be controversial. Most studies demonstrate a decreased rate of union and an increased rate of graft-related complications following multiple-level corpectomies without instrumentation. Furthermore, in cases with long decompression and fusion, the use of external splinting is necessary.

Dorsal Approaches

A dorsal approach may be selected in cases of an effective lordosis. Laminectomy for the treatment of CSM has been accepted as a standard procedure for years.[63,64,66,68,69] It is most commonly indicated in patients who have a compressive myelopathy with an associated effective cervical lordosis.[8,10] Cases with a straightened spine may be treated by either a ventral or dorsal decompressive operation. A dorsal decompression may be combined with a dorsal fusion in such cases.

In rare cases, a DLS may be added to a laminectomy procedure. The addition of DLS to laminectomy is considered safe,[8,39,60] although its efficacy has been reported to be questionable.[10,51,60] Laminectomy plus DLS is most clearly indicated in those patients who are adversely effected by the coronal bowstring effect (Fig. 5) and in whom an effective kyphosis does not exist. Laminectomy plus DLS provides similar neurological outcomes to ventral decompressive operations, particularly in patients with more severe myelopathies.[8] On the other hand, laminectomy plus DLS has no significant acute risks for ventral bone graft and upper airway complications.[24,65] Furthermore, long-term risks of accelerated degenerative changes above and below the fusion are not factors.[34] The similarity of neurological results (compared with ventral decompressive operations) may be related to the effective ventral decompression associated with DLS (that is, relief of the coronal bowstring effect). Thus, in selected patients with a patent cerebrospinal fluid space dorsal to the spinal cord and no cerebrospinal fluid space ventral to the spinal cord, DLS appears to provide additional ventral spinal cord decompression over that attained with cervical laminectomy alone. These cases, it is emphasized, are rarely encountered.

Fig. 6. Illustration of an algorithm for the decision-making process for the surgical treatment for CSM.

In selected cases, laminectomy may be combined with a dorsal fusion. A dorsal fusion should be performed: 1) to prevent kyphosis; 2) to obtain a wide laminectomy; 3) in the presence of a straightened spine (Fig. 6); and 4) to prevent progression of the degenerative process (which is motion dependent). Fusing the spondylotic spine does not significantly effect movement and range of motion in most cases, because normal movement is already substantially reduced via the spondylotic process.

Cervical laminoplasty has become the choice of treatment for CSM in many countries. This procedure has been recommended for CSM and ossification of the posterior longitudinal ligament (OPLL). The theory behind performing laminoplasty in CSM is to prevent kyphosis and instability, postlaminectomy membrane formation, arachnoiditis, and restenosis.[42,44-47] The main goal of laminoplasty is to enlarge the spinal canal and, in turn, to increase the cross-sectional area of the spinal cord without stability reduction. In 1972, Hattori introduced Z-plasty, which has not been widely accepted because of the technical difficulties of the operation.[61] Open door laminoplasty was first described in 1978.[29-31] Laminoplasty via splitting the spinous processes (French door) was described in 1982.[43]

Today, three fundamental laminoplasty procedures are commonly used: Z-plasty; hemilateral open door laminoplasty; and bilateral open door laminoplasty (middorsal laminoplasty or French door laminoplasty). To date, several additional modifications have been reported. In one study comparing three modification of laminoplasty, no outcome difference between modifications was demonstrated.[53]

In the presence of an effective lordosis, cervical laminoplasty may be indicated in multiple level OPLL, congenital spinal canal stenosis, multilevel cervical stenosis, dorsal ligamentous hypertrophy, and as part of a staged ventral-dorsal spinal canal expansion procedure.[57] Most of the studies on CSM and OPLL have reported postoperative enlargement of the spinal canal and an improved neurological outcome. However, several recent studies suggest that there may be no significant postoperative difference between laminectomy and laminoplasty regarding decompression, neurological recovery, kyphosis, and instability.[32,55] Laminoplasty was found to provide increased stability, with less translation, tilting, and range of motion compared with laminectomy.[80] Comparing the results of 28 cases (10 laminectomy and 18 laminoplasty with 5-year follow up), Hukuda, et al.,[32] did not find superiority of laminoplasty over laminectomy in CSM for functional recovery and enlargement of the epidural space. There was no difference in the occurrence of kyphosis or instability. They reported a reduction in neck extension in those patients who underwent laminoplasty. Naito, et al.,[53] compared the results of hemilateral, bilateral open door laminoplasty, and Z-plasty and found no difference among these three modifications. Yoshida, et al.,[79] reported 50% limitation in flexion and extension of the neck following laminoplasty. On the other hand, Tsuzuki, et al.,[72] reported radiculopathies following laminoplasty procedures. They hypothesized that this was caused by an extradural nerve root tethering. Although all laminoplasty techniques have been used for the prevention of kyphosis and instability, several authors reported a rate of kyphosis development of up to 28%.[32,71]

CONCLUSIONS

The surgical approach to the treatment of CSM has proven to be controversial over the past four decades and remains so. This controversy can be mitigated to some degree by accurately assessing the cervical spine geometry and determining the predominant orientation of the neural compression process. Two main aspects of the disease should be taken into account, presence or absence of an effective kyphosis

and the presence or absence of ventral compression. The presence of either of these aspects suggests the use of a ventral surgical approach. The presence of an effective lordosis may dictate the use of a dorsal approach. The selection of the surgical approach in the presence of straightened cervical spine relies on the surgeon's experience, bias, and common sense. However, in the case of a straightened cervical spine, if the dorsal approach is chosen, decompression should be accompanied by a dorsal fusion (Fig 6).

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Address reprint requests to: Edward C. Benzol, M.D., Division of Neurosurgery, University of New Mexico School of Medicine, Albuquerque, New Mexico 87131-5341.