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DECISION MAKING PROCESS: PROBLEM-BASED DECISION MAKING.
Daniel Shedid, M.D.; Edward C. Benzel, M.D.
Cervical spondylosis and its most common clinical manifestation, myelopathy, are common pathological entities. They are the result of the degenerative process and, hence, are a natural part of aging. Unfortunately, cervical spondylotic myelopathy is often underdiagnosed. Our aging population is often expected to not only be old but to act old as well. Therefore, progressive myelopathy is often attributed to senescence (i.e., “getting old”).

The spondylotic process advances at an accelerated pace in later life and after cervical spine surgery. The pathoanatomic factors involved include disc bulging and herniation, facet joint hypertrophy, soft tissue (particularly ligamentum flavum) thickening, and joint laxity. The process is not only progressive but also kyphogenic.

The surgical management of cervical spondylotic myelopathy usually involves decompression. Surgical decompression is often appropriately accompanied by stabilization and fusion. Decompression relieves compression and distortion while fusion “stops” trauma. Such surgery however, further destabilizes the spine, resulting in fusion in a straightened or kyphotic posture and/or resulting in a variety of complications that can also hasten the advancement of the degenerative cascade.

The myelopathy associated with cervical spondylosis is a result of repetitive trauma and spinal cord distortion and tethering (1). The process is illustrated by a patient who had undergone multiple previous operations and who experienced progressive myelopathy and significant mechanical neck pain. She exhibited all of the aforementioned aspects of cervical spondylotic myelopathy. Multiple previous operations resulted in a stenotic and kyphotically deformed spinal canal and intramedullary spinal cord signal changes. The latter was a manifestation of repetitive trauma and spinal cord distortion (Fig. 1).

Interestingly, after decompression, deformity correction, and fusion, this patient’s myelopathy and neck pain improved and her signal change disappeared (Fig. 2). This patient illustrates the repetitive nature of trauma in the spondylotic myelopathy process. Static imaging shows that (Fig. 1) there is cerebrospinal fluid signal present ventral and dorsal to the spinal cord. Yet, the myelopathy progressed until surgical intervention aborted and reversed the process. Spinal cord tethering most likely played a role in both the signal change and the myelopathy. Both were most likely the result of a repetitive stretching or tethering of the spinal cord over the apex of the kyphotic deformity at the C4–C5 disc interspace level.

On the surface, it would seem intuitive that motion preservation would be an appropriate clinical strategy for cervical spondylosis. After all, motion is usually a good thing. Cervical arthroplasty could be used as a strategy to treat the myelopathy while, at the same time, maintaining motion. Although cervical disc replacement is not the focus of this supplement, it may be considered as a potential adjunct to the treatment of myelopathy in selected cases. The indications for cervical disc arthroplasty, however, are unclear. Both the short- and long-term results are not known at this time. I remain skeptical that existing disc arthroplasty strategies will be associated with a decrease in degenerative changes at adjacent levels and that they will provide sufficient clinical benefit to warrant their widespread use. Nevertheless, time will tell.
Please read and enjoy this supplement. The subject matter is timely, and the articles are both relevant and thought provoking. They serve, in part, as reminders to maintain a high level of vigilance regarding surgical strategy determination for cervical spondylosis and cervical spondylotic myelopathy. We are also reminded to consider and repetitively reconsider the obligatory association between symptoms, spine structural factors, and the pathophysiology of myelopathy. Hopefully, the contents of this supplement will assist with both.

Edward C. Benzel
Cleveland, Ohio


In the first chapter of the Overview section, the authors discuss the anatomy, pathophysiology, and biomechanics of cervical spondylosis. Knowledge of this material is mandatory to understand the pathophysiology of cervical spondylosis and the potential consequences of myelopathy, radiculopathy, and deformity.

In the following article, the authors competently discuss the signs and symptoms of myeloradiculopathy and provide several cervical grading scales for both preoperative and postoperative use. These multiple schemes are helpful for determining outcomes of treatment for cervical myeloradiculopathy.

The next article addresses the controversial topics of mechanical neck pain and cervicogenic headache and is followed by an article that describes the pathophysiology and clinical evaluation associated with cervical radiculopathy. The authors also discuss the differential diagnoses that can mimic cervical radiculopathy. They emphasize that a thorough neurological examination combined with confirmed radiographic and diagnostic studies will distinguish cervical radiculopathy from other diagnoses. Both these findings and differential diagnoses are summarized in the tables.

Next, the authors emphasize that neurosurgeons should be diligent in ruling out other disease processes that can mimic cervical myelopathy. They also emphasize that surgery might be beneficial once a patient shows signs of cervical myelopathy without obvious improvement. This is a well-written, succinct presentation.

The first article in the Medical and Surgical Considerations section states that the use of anti-inflammatory medicine, muscle relaxants, analgesics, antidepressants, anticonvulsants, steroids, and physical therapy to treat cervical spondylosis, with or without radiculopathy and myelopathy, is not based on scientific evidence. Nonetheless, the authors reach some conclusions based on the limited literature available.

Surgery for only neck pain is controversial; this is emphasized in the following article. The authors state that discography can help identify patients who would benefit from surgical intervention for axial neck pain. I have not routinely used this modality.

Posterior cervical spine surgery for radiculopathy was once routine, but it is now seldom used. The authors emphasize that this operation is best suited for patients with normal lordosis, minimal or no neck pain, and lateral compression from a herniated disc or foraminal stenosis. The more common approach is described in the next article in which the authors describe the anterior approach to the cervical spine. They provide the rationale for the circumstances that warrant consideration of an anterior approach. The following article focuses on dorsal surgery for myelopathy and myeloradiculopathy and the appropriate indications.

Occasionally, both anterior and posterior approaches must be used, as addressed in the next section. Use of this combined approach is relatively rare, but as the authors outline in Table 1 of their article, the combination should be considered.

Cervical deformity usually consists of a kyphosis, which should be addressed primarily through an anterior approach but occasionally through a posterior approach. The authors emphasize size that preoperative reduction should be attempted. If it is unsuccessful, intraoperative reduction followed by fixation via a combined anterior and posterior approach should be performed.

In the first article within the Technical Considerations section, the authors present the pros and cons of using allograft or autograft. They conclude that autograft is used more routinely, especially as the use of anterior cervical plates has increased. This trend reflects my colleagues’ and my own personal practice pattern. Placing a plate avoids the need for postoperative orthosis after surgery for one- or two-level disc disease. This option should be offered to patients as an alternative to wearing an orthosis.

Next, the authors emphasize the pros and cons of the various C1–C2 stabilization procedures. They also emphasize that if only graft and wiring are used, patients need to be placed in a halo brace after surgery to optimize their chances of fusion. Alternatively, after internal fixation, usually with screws, a postoperative halo brace is unnecessary.

Concerning the use of ventral plates for cervical arthrodesis, the authors reviewed 143 articles from which they concluded that plating is indicated for traumatic disorders of the cervical spine and for two or more levels of discectomy or corpectomy. However, there is little support in the literature for the utility of ventral cervical plates after a single-level fusion. The authors note that plating after a one-level discectomy is controversial. Personally, as mentioned before, I offer patients the choice of wearing a cervical collar for several weeks after surgery or of undergoing a plating procedure. In the past 3 years since this policy was introduced, only one patient has elected to wear an orthosis.

Next, the indications for rigid internal fixation in the surgical management of cervical spondylosis are reviewed. The authors provide the rationale for using anterior and posterior cervical instrumentation and compare the disadvantages of constrained and semiconstrained systems with respect to anterior plating systems. The authors warn that only experienced spine surgeons should consider pedicle fixation of the midcervical spine. This observation is appropriate, and I thank the authors for reviewing instrumentation of the subaxial cervical spine.

The section closes with a discussion of ventral or dorsal decompression of the cervical spine. The authors provide their decision making rationale. They emphasize that the site of pathology, the presence of axial pain, and the alignment of the cervical spine all need to be considered to choose the appropriate approach.

The last section includes surgical techniques, addressing corpectomy first. The authors state that when three or more level corpectomies are performed, the procedure must be supplemented with posterior fixation or a halo brace. The authors also present several “pearls” for performing a cervical corpectomy in order to avoid injury to the vertebral artery.

Next, the indications for performing multiple discectomies are described. The authors emphasize that this is the best technique to restore cervical lordosis compared with a posterior or anterior approach with corpectomy. Although used less frequently, cervical laminectomy without fusion still should be con-
sidered in patients with normal lordosis with circumferential or primarily dorsally located compression. This concept is described in the following section.

An alternative to laminectomy is cervical laminoplasty as described in the next section. The authors described the technique and apparently had excellent outcomes. I am somewhat puzzled by this particular technique of laminoplasty because it does not seem to restore the dorsal tension bands.

Alternatives to decompressing the dorsal elements are described in the next section. Tubular retractor systems can be placed through an endoscopic working channel to perform a microendoscopic foraminotomy and decompressive laminectomy of the cervical spine. The former is used for radiculopathy and the latter is used for myeloradiculopathy. In the authors’ hands, they obtained excellent results. Longer follow-ups will determine whether this technique is superior to traditional procedures.

In the Conclusion, the authors discuss the decision making process for the treatment of cervical spondylotic myelopathy. The authors emphasize that problem-based decision making is founded on evidence and logic, which should not be confused with evidence-based decision making. They cite Sackett’s: “Good doctors use both individual clinical expertise and the best available external evidence, and neither alone is enough” (1). They also discuss the assessment of types of errors in clinical decision making, specifically in the treatment of cervical spondylosis. Although many of us do so intuitively, it is important to have their analysis presented in a rational fashion.

This supplement describes cervical spondylosis and the non-surgical and surgical techniques for treating various cervical spondylotic abnormalities. It will be a welcome addition for clinicians who treat this abnormality.

Volker K.H. Sonntag
Phoenix, Arizona


This comprehensive, topic-organized supplement on cervical spondylosis is a remarkable effort. Nearly all relevant aspects of this complex, dynamic, and heterogeneous subject have been comprehensively addressed by recognized leaders in spinal surgery from both orthopedic and neurosurgical specialties. Dr. Benzel, in his characteristic holistic approach, has organized this supplement into several logical and compartmental aspects of cervical spondylosis to include anatomy, biomechanics, pathophysiology, clinical evaluation, technical considerations, and treatment. In doing so, he also underscores in Chapter 23 the importance of such a deconstruction approach in the evaluation and management of individual patients with cervical spondylosis.

Not surprisingly, there are some degree of repetition and redundancy in this multi-authored work, particularly because each author took a comprehensive approach to their assigned topic in order to provide the appropriate context. For example, in the chapters on surgical technique, the authors do not simply describe how they perform a particular procedure, but they also address when they perform it, in whom do they perform it, and why they perform it.

Unfortunately, because of practical constraints, some potentially relevant topics, such as adjacent segment disease, artificial disc replacement, a critical assessment of the value of intraoperative monitoring, and diagnostic imaging were either not covered or were addressed in only a limited fashion in some of the chapters. In addition, the lack of evidence in certain areas such as bone morphogenetic protein, sagittal balance maintenance, and kyphosis correction do not allow strong evidence-based treatment recommendations.

Having the opportunity to thoroughly assess each chapter of this supplement, I was struck not only by how far we have advanced in our knowledge, understanding, and management of the patient with spondylotic disease but also how much we still have to learn. In many ways, our rapidly evolving knowledge, techniques, and technologies have made management decisions more difficult as we try to identify the optimal management objective for each patient from a weighted analysis of an increasing number of often interrelated and incompletely understood considerations. Surgical decision making is not simply a linear equation of numerous objective components, such as decompression, stabilization, deformity correction, and fusion, but instead it is a complex ratio of factors that relate the short and long-term benefits of the proposed surgery to both the incidence and severity of the potential risks of the surgical procedure and its different components. The logical organization and comprehensive nature of each individual chapter as well as the overall supplement will be enormously helpful in these deliberations. All the authors and, in particular, Dr. Benzel should be acknowledged for this outstanding contribution to our field.

Paul C. McCormick
New York, New York

This supplement provides a comprehensive overview of cervical spondylosis. The first four articles address the pathophysiology of cervical spondylosis. Although each of these has its own specific focus, there is a fair amount of overlap. The last articles within this group concentrate on the clinical syndromes of radiculopathy and myelopathy as associated with spondylosis. The review of the pathophysiology, clinical course, and diagnosis of cervical spondylotic myelopathy by Baron and Young is a particularly good article on a critical topic. The medical management of cervical spondylosis is important but flawed in that rigorously generated data to support many of our treatments do not exist.

Surgery for axial neck pain is a controversial topic. Wieser and Wang provide a comprehensive and thoughtful overview. This treatment should be restricted for select patients who have failed all other treatment modalities. I concur with the authors that this can be an effective treatment for carefully chosen patients.

The remaining articles address the surgical treatment of radiculopathy, myelopathy, or combinations of both, deformity, ossification of the posterior longitudinal ligament, and miscellaneous topics, such as graft selection, rigid fixation, and decision making. Pathophysiology, clinical presentation, radiological...
evaluation, and surgical management of these entities are all covered. There is a fair amount of overlap among many of these articles, which may impede reading the work completely from start to finish. The redundancy, however, allows for each of the articles to be freestanding and serve as a good reference for its topic of focus.

Vincent C. Traynelis
Iowa City, Iowa

This special supplement to Neurosurgery, compiled by one of the modern leaders in spinal surgery, contains an exhaustive review of the “state of the art” for the treatment of cervical spondylosis. The topic itself is not to be underestimated, as cervical spinal degeneration is the cause of epidemiologically significant disability in humans and has proven to be one of our most successful areas of surgical intervention. Furthermore, recent advances in our understanding of the relevant disease processes and technologies to aid in their remediation require such an update for the neurosurgical community. Several chapters of this text deserve special mention.

In Chapter 1, the authors, who are well-recognized authorities in the field of biomechanics, provide a general overview on the relationship between physical forces and the natural progression of cervical spondylosis. Understanding the biomechanics of the cervical spine is critical for neurosurgeons treating anything besides the simplest cervical disorders, particularly in an era where spinal instrumentation is proliferating at a frenzied pace. The chapter illustrates that one cannot successfully treat cervical spondylosis without a thorough understanding of the long-term effects of spinal fusion.

Chapter 3 reviews the clinical presentation and differential diagnoses for cervical radiculopathy. The authors present the relevant clinical findings for cervical root entrapment at various levels with a catalogue of potential pathologies that may mimic cervical radiculopathy. This is an excellent review to aid clinicians in avoiding potential misdiagnoses as there are many non-structural diseases that can mimic cervical radiculopathy and myelopathy.

Chapter 6 reviews the non-operative management of cervical spondylosis. The literature review is an excellent summary of the available data on drug treatments for neck disorders. In addition, the authors synthesize the available information into a simple, but practical, algorithm for treating cervical spondylosis. The information presented is vital for neurosurgeons treating spinal disorders and emphasizes the frequent efficacy of non-operative treatment options.

Chapter 7 introduces a highly controversial topic: the surgical treatment of axial neck pain. While classical neurosurgical teaching emphasizes the treatment of patients with neurological impingements and impairments, it should be recognized that an increasing number of surgeons are applying fusion or arthroplasty techniques for the management of medically refractory neck pain due to a structural, non-neurological etiology. There is a particular need for prospective studies to guide future management, a point the authors clearly make.

Chapters 13 to 22 cover the spectrum of surgical techniques available to the neurosurgeon. Chapter 14 demonstrates an innovative method for C2 fixation (C2 crossing laminar screws) pioneered by the author, which I have personally found to be highly useful in situations where the C2 pars has been too small to accommodate screw fixation. In Chapter 16, the authors provide a review of the current perspective on rigid cervical fixation for degenerative disease. The discussion is fresh, balanced, and objective, presenting the data both in favor of and against cervical plating for short segment anterior decompressions. In addition, the authors address the potential advantages of the various dynamic plating systems that are becoming increasingly available. I agree with the authors and find that anterior plating should be routinely used in cases involving deformity reconstruction, decompressions spanning more than two disk levels, and in patients with a propensity for mechanical failure such as smokers. The controversy surrounding the role of plating for shorter segment surgeries relates to the high fusion rates for these surgeries in general, reducing the statistical power of any contemporary prospective cohort. While plating does seem to increase the fusion rates in these cases, definitive statistical proof from a Class I study is not forthcoming in the near future.

Chapter 23 serves as a fitting conclusion to this monumental work. After presenting a mass of evidence regarding the current state of knowledge on cervical spondylosis, the guest editor reiterates that the need for placing evidence into clinical contexts is vital to arriving at the correct diagnostic strategy.

In summary, the guest editors and contributing authors should be congratulated for highlighting modern cervical spinal techniques in a balanced, objective format that improves our clinical practice and outcomes. This supplement should be reviewed in detail by all neurosurgeons treating cervical spinal disorders.

Michael Y. Wang
Los Angeles, California

This special edition to Neurosurgery on the topic of cervical spondylosis represents a significant effort by multiple experienced clinicians whose professional interests lie primarily in the realm of spinal disorders. While not a medical evidence-based review, it is a remarkable summary of thoughts and opinions, strategies and techniques, experiences, successes, and failures, and science in the clinical management of patients with age-related cervical spinal disease. It is a condensed, contemporary, well-edited and referenced review of 23 topics related to the evaluation and treatment of patients with cervical spondylosis. Several chapters offer insightful and detailed surgical techniques by recognized, experienced surgeons. This is a remarkable compilation found nowhere else in the published literature. Chapter 23 is a logical discussion of decision making when treating patients with symptomatic cervical spondylosis that has been progressively troublesome and refractory to medical management. This supplement is a “must read” for practicing spinal surgeons and all orthopedic and neurosurgical residents in training.

As with any invited, editor-led, multi-authored, comprehensive medical publication, some topics appear more interesting and/or germane than others. Some are fundamental and basic, and others are more contemporary; one or two are perhaps more futuristic. Some chapters benefit from science and/or biome-
The first question when treating a patient who has symptomatic myelopathy from cervical stenosis involves addressing whether surgery is necessary or if a non-surgical therapy could be utilized. Nurick’s original study on nonoperative treatment reported that 22% of the nonoperatively treated patients improved spontaneously, 45% remained unchanged, and 33% continued to deteriorate (1). One interpretation of these results, therefore, is that nonoperative treatment is a reasonable option for symptomatic cervical myelopathy. However, in recognition of the many surgical series showing a high probability of improvement following decompression of stenosis, and the disabling nature of cervical myelopathy to the patient, one might question the wisdom of this decision. An appropriate analogy might be standing under a heavy safe that is suspended by a frayed rope. You don’t know whether the rope is going to break or not. If you stay there and the rope doesn’t break, you saved the effort of moving. If you stay there and the rope does break, the consequence is devastating. A reasonable alternative, then, might be to simply step to the side and avoid the risk altogether.

If one does elect to have surgery, what is the best surgical procedure to perform? Over the decades, the preferred techniques have included laminectomy, anterior cervical corpectomy, laminectomy with fusion, laminoplasty, multi-level anterior cervical disectomy and fusion, and they now include minimally invasive decompression of stenosis. Each of these is still utilized and is individualized based on the patient’s specific pathology and the surgeon’s experience. No single operation is clearly better than the other in all cases, and each must be used to achieve the best result for the specific patient being treated. Each of these procedures is discussed in detail in this edition, as is the decision making process supporting or arguing against its use. The correlated questions, such as whether instrumentation is necessary and what type of bone should be used for fusion, are also considered in detail in this edition. Finally, the pros and cons of evidence-based decision making in the context of cervical stenosis conclude this edition.

In summary, this special edition on cervical stenosis provides an up-to-date synopsis of the pathophysiology, pathoanatomy, diagnosis, treatment options, and prognosis of cervical stenosis. Any physician treating this problem would be wise to read it thoroughly.

Richard G. Fessler
Chicago, Illinois

Spondylosis has been defined as “vertebral osteophytosis secondary to degenerative disc disease” (42). It is considered the most common progressive disorder in the aging cervical spine (3, 12, 13, 20, 30). It is different from inflammatory processes that are associated with osteophyte formation and that are grouped together as arthritis. Arthritis classically involves the synovial membranes of diarthrodial joints that are lined with synovium, whereas the osteophytes of spondylosis are associated with degeneration of the intervertebral disc, which is an amphiarthrodial joint without a synovial membrane. The presence of spondylosis is defined, therefore, by the presence of noninflammatory disc degeneration (6). The process of disc degeneration is complex and involves many alterations of normal physiology, as well as the process of aging. It is often preceded by mild segmental instability (6). Spondylosis is a natural process of aging; it is seen in 10% of individuals by the age of 25 years and in 95% by the age of 65 years (22). In this article, we discuss the biomechanics, the pathophysiology, the clinical presentation, and the imaging evaluation of cervical spondylosis.

PRESENTATION

Most people with degenerative changes of the cervical spine remain asymptomatic. Symptomatic patients are usually older than 40 years of age and present with symptoms that are caused by the compression of neural structures (40). There are three main symptom complexes related to cervical spondylosis: neck pain, cervical radiculopathy, and cervical myelopathy (11).

Neck pain can be acute or chronic and is frequently encountered without a precipitating incident. It seems to occur more often from degenerative disc than from degenerative facet changes. The facets are innervated by branches of the posterior primary ramus (22). As an isolated complaint, it is associated with abnormalities in the structures innervated by the sinuvertebral nerve, which include the posterior longitudinal ligament, the epidural vasculature, the dura, and the spinal peristeum (11).

Cervical radiculopathy can be acute, subacute, or chronic. Patients younger than 55 years are more likely to present with radiculopathy caused by herniated nucleus pulposus. Patients older than 55 years are more likely to have canal or foraminal stenosis caused by osteophyte formation (40). The involvement of the nerve roots may be unilateral, bilateral, symmetric, or asymmetric. Radicular symptoms, in a dermatomal distribution, may be caused by intraforaminal herniation. If the herniation is caused by a soft herniated disc, motor findings of weakness and atrophy are more common. In the presence of a hard disc degeneration, sensory symptoms are more common and consist of paresthesias, hyperesthesias, or hyperalgeasias. Motor and reflex changes occur less frequently and are often associated with a chronic condition (11).

Cervical myelopathy develops in only a fraction of patients with spondylosis (3, 35). It may be rapidly progressive or become static, with relatively minor symptoms (12).
Patients are usually beyond the fifth decade, and long-tract signs are a hallmark. It is more common in men and in laborers (3, 35). The signs and symptoms include neck pain, sub-scapular pain, or shoulder pain, shock-like sensations in the limbs, with rapid flexion or extension of the neck (Lhermitte’s sign), ascending numbness in the lower extremities with neck extension, and gradual signs of spinal cord dysfunction with spasticity (2, 3, 12, 24, 35, 41). Some early subtle findings include hyperreflexia, and/or Babinski’s sign, and/or Hoffman’s reflex, and/or clonus in an asymptomatic patient (10, 30). However, Babinski’s sign, clonus, and a decrease in abdominal reflexes usually occur only late in the clinical course (11). The signs and symptoms are characteristic and include spastic weakness of the hands and forearms earlier than other muscle groups, hand numbness, loss of dexterity, and painful paresthesias (3, 11, 12, 13, 26). Other common features include lower extremity weakness, as well as spastic gait and dorsal column function loss (3, 14, 23). The characteristic stooped, wide-based, somewhat jerky gait of the aged is well known (11). Late findings include atrophy or fasciculation in the distal upper extremities and sphincter dysfunction (16, 26, 30). These later findings are associated with a poor prognosis for recovery (26). Some of the signs may be confused or masked by a superimposed upper extremity radiculopathy, worsened with head compression (Spurling’s maneuver) (12, 28, 30). However, this radiating pain may be referred or “pseudoradicular” (2). The combined syndrome of radiculopathy and myelopathy produces motor findings that are characterized by lower motor neuron involvement at the level of the lesion and upper motor neuron signs below the level of the lesion (11). Another confusing clinical picture is observed in patients with combined cervical and lumbar involvement, which may be found in approximately 13% of the patients (14). These patients may have combined upper and lower motor neuron findings in their lower extremities (11).

**IMAGING EVALUATION**

The diagnostic workup often includes static or dynamic plain cervical x-rays or tomograms, computed tomography (CT), magnetic resonance imaging (MRI), and myelography. Cervical x-rays may demonstrate loss of disc space height, spondylotic bars, foraminal osteophytes, kyphosis, subluxations, posterior compression from facet arthropathy, or late uncovertebral joints (1, 3, 12, 20, 22). Flexion-extension lateral films may be useful to assess significant instability. CT is useful for evaluating the transverse foramina, size and shape of the spinal canal, facet, and uncovertebral joints (1, 20). Axial images alone can be very misleading with regard to sagittal neural element and extrinsic mass relationships. This is particularly true if sagittal-plane spinal deformation is present and if thick axial CT cuts are used (6). MRI is useful for evaluating the spinal canal diameter, spinal cord, intervertebral discs, and vertebral ligaments (1, 2, 3, 12, 19, 20, 22, 31, 35). Signal changes on T2-weighted MRI scans at the level of spinal compression are often increased in patients with cervical spondylotic myelopathy. This represents edema, inflammation, ischemia, myelomalacia, or gliosis (31). However, bone quality assessment on MRI scans is not as good as with CT (22). Myelography has been widely replaced by MRI. However, some authors think that postmyelography CT is superior to MRI for distinguishing a bony spondylotic spur from a “suculent cartilaginous precursor to a hard spur, or a frank soft disc extrusion” (3, 21). It is of note that radiological findings have not been well correlated with clinical symptoms (2, 18), and that electromyography, nerve conduction studies, and somatosensory evoked potential findings have been shown to delineate myelopathy and radiculopathy in cervical spondylosis (3, 20).

**CLINICOPATHOLOGICAL DISTINCTIONS**

It is possible to encounter other spinal cord injury syndromes resulting from cervical spondylosis, including the central cord syndrome or, less commonly, Brown-Séquard syndrome. Damage to the spinal cord can result from superimposed acute or chronic trauma (3, 12, 19, 26, 30). There are clinical differences in patients with “medial” spinal cord lesions (thought to be ischemic from vascular compression in the spinal canal and/or intervertebral foramina caused by a degenerative disease) versus those with “lateral” or more radicular syndromes (1, 5, 19, 44). In ischemic spondylotic myelopathic patients, proximal lower extremity weakness and stiffness may be the earliest symptoms, followed by dorsal column sensory loss and spastic gait (20). In these patients, the course is often more acute (41). It is worth mentioning that patients with cervical spondylotic myelopathy are at higher risk to sustain a spinal cord injury syndrome from a relatively minor cervical trauma because of the narrow nature of their cervical spinal canals (2, 20, 41).

The differential diagnoses of cervical radiculopathy include intrasinal or extraspinal tumor, angina, reflex sympathetic dystrophy, infection, peripheral entrapment syndromes, thoracic outlet syndrome, brachial neuritis, and shoulder pathology. Some entities that may mimic spondylotic myelopathy include amyotrophic lateral sclerosis, myelitis, multiple sclerosis and demyelinating conditions, intracranial pathology, intraspinal tumors, syringomyelia, Chiari malformation, calcification of the ligamentum flavum, ossification of the posterior longitudinal ligament, and ankylosing spondylitis (3, 4, 5, 17, 3, 33, 40).

**PATHOPHYSIOLOGY**

**Primary Degenerative Phenomena**

**Etiology of Cervical Spondylosis**

Although the degeneration of cervical spinal elements is the primary pathological lesion in cervical spondylosis, the secondary spinal cord or spinal vascular compression are respon-
sible for the myelopathic symptoms. Both neural and vascular processes are involved in causing the neurological symptoms in cervical spondylotic myelopathy (2, 13, 30, 36, 38, 43). White and Panjabi (43) have divided the mechanical factors involved in the pathogenesis of cervical spondylotic myelopathy into static and dynamic groups. The static pathological mechanisms relate to the primary degenerative processes, which ultimately result in a reduced sagittal spinal canal diameter. They are congenital spinal canal stenosis, disc herniation, vertebral body osteophyte growth into the spinal canal, degenerative osteophytosis of the uncovertebral and facet joints, hypertrophy of the ligamentum flavum, and degenerative or calcific processes of the posterior longitudinal ligament and the ligamentum flavum. The dynamic pathological factors that foster myelopathy are abnormal forces on the spinal column and spinal cord during normal and abnormal movements and loads. These secondary features, which are advanced by the static, primary mechanisms leading to cervical spondylotic myelopathy, lead to the neurological symptoms and sequelae (13, 43).

Pathogenesis of Cervical Spondylodyis

The reduction in sagittal spinal canal diameter is the main pathophysiological process involved in the primary degenerative phenomena leading to cervical spondylosis. This process predisposes patients to the secondary compressive and vascular lesions. It begins with cervical disc desiccation (20). Disc desiccation is accompanied by biochemical changes, with a relative increase in the ratio of keratin sulfate to chondroitin sulfate (6, 15). Loss of water, protein, and mucopolysaccharides with age allow the nucleus pulposus to lose elasticity and to become smaller and more fibrous. The annulus fibrosus then takes on more of the responsibility for weight bearing and is likely to bulge into the spinal canal as the interspace loses height (3, 6, 15, 20, 30, 36, 41). This loss of disc space height initially occurs ventrally and may lead to loss of cervical lordosis. This process creates a positive feedback cycle because more forces are then placed on the ventral aspect of the vertebral bodies leading to a kyphotic deformity (Figs. 1 and 2) (6).

The layers of the annulus fibrosus are thinner dorsally, thus, nuclear material can dissect through the layers, leading to disc herniations into the spinal canal (20, 30, 41). These alterations of spinal biomechanical forces cause the peripheral fibers of the annulus fibrosus and Sharpey’s fibers to be dissected away from the vertebral body edges and the posterior longitudinal ligament to buckle and peel off of the vertebral bodies near the endplates (36, 41). Pain may result from disc herniation or annular bulging, degenerative changes, and ligamentous laxity, which can lead to abnormal cervical movement (41).

Subsequently, on the bare edges of the dorsal vertebral bodies, reactive bone formation is observed. This produces spondylotic spurs, which may span the width of the vertebral body (30, 36). This has been termed cervical hyperostotic myelopathy (27). With the height loss of the disc space, greater loads will be borne by the uncovertebral joints, which may lead to accelerated osteophyte formation, with angulation of the vertebral body ventrally (20). The osteophytes may project into the intervertebral foramina. Facet joints tend to hypertrophy as they assume more of the axial load (30). We note that motion, which is more common at C5–C6 and C6–C7, tends to accelerate the formation of osteophytes (2, 30). These degenerative bony changes lead to the reduction of the sagittal spinal

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**FIGURE 1.** A. In a neutral spinal orientation, the facet joints of the cervical spine are unloaded during moderate axial loading. B, in a lordotic orientation (relative extension), however, they are loaded and, thus, subject to injury during axial loading.

**FIGURE 2.** A. The nonpathological state, in which the dorsal vertebral body height is less than the ventral vertebral body height, results in normal cervical lordosis. B, loss of the ventral disc interspace height, which occurs with the natural degenerative process, results in loss of lordosis. This causes elongation of the moment arm applied to the spine (D), leading to ventral vertebral body compression. C, a further exaggeration of pathological kyphotic posture may then ensue. (From, Benzec EC: Biomechanics of Spine Stabilization. Rolling Meadows, American Association of Neurological Surgeons Publications, 2001 [6].)
Spinal Canal Size

Reasons for the reduction in the sagittal diameter of the cervical spinal canal in spondylotic patients are predominantly related to degenerative spurs, congenital small canal, and primary degeneration of the cervical spinal canal (3, 4, 23). The diameter seems to be, on average, 3 mm smaller in patients with cervical spondylosis and even smaller in patients with congenital cervical stenosis (3, 30). The dimension of the cervical canal corresponds to the distance from the spondylotic process (typically at the caudal portion of the vertebral body) to the dorsal aspect of the cervical spinal canal (base of the spinous process) of the next caudal vertebra (20). White and Panjabi (43) reported that patients with diameters less than 14.8 mm were at greater risk of developing cervical spondylotic myelopathy. To entertain the diagnosis of myelopathy from bony cervical spinal cord compression, Fergusson and Caplan (20) and Pattern (35) reported that the distance must be less than 13 mm, whereas Asgari (3) and Fager (18) wrote that the average spinal canal diameter in patients with myelopathy was 14 mm, with the normal diameter (between C3 and C7) being approximately 17 to 18 mm, with slight variation between sexes (7).

Other anatomic features of cervical spondylosis that may participate in the ventrodorsal narrowing of the spinal canal and potential annular constriction of the spinal cord (5) include the degenerative uncovertebral joints (3, 16, 43), degenerative and hypertrophied facet joints (3, 5, 16, 43), thickened laminae (16), annular or nuclear portions of bulging or herniated intervertebral discs (43), thickened posterior longitudinal ligament (3), and thickened or buckling ligamentum flavum (6, 19, 20, 25, 30, 36, 43). The superimposition of this degenerative narrowing of the canal diameter on preexisting congenital spinal stenosis magnifies the progression of the degenerative process and leads to earlier myelopathy (2, 4, 19, 20, 41, 43, 44).

Radicular symptoms may be caused by spondylotic processes, degenerative uncovertebral joints, nerve root sleeve fibrosis, herniated disc, and facet joint disease (5, 16, 30).

Myelopathy from the primary pathophysiological mechanism of cervical spondylosis may be referable to one or more cervical segments. The disease process is typically contiguous, but may proceed rostrally and/or caudally. Crandall and Batzdorf (12) observed that the involvement of two intervertebral levels was the most common and always included the C5–C6 interspace. The most affected levels by both disc herniation and chronic spondylosis are C6–C7, followed by C5–C6 (33). As stated earlier, osteophyte formation is accelerated by motion and is, therefore, more common at C5–C6 and C6–C7, where most of the cervical flexion and extension occur (30, 36).

Cervical Spinal Posture

The upper cervical spine is anatomically complex. It provides a highly mobile functional support to the cranium, while protecting the spinal cord from injury (6). The total range of motion of the upper cervical spine is summarized in Table 1.

The middle and lower cervical spine does not provide the same complexity of motion that is present in the upper region of the cervical spine. A unique characteristic of this region is its lordotic posture. This may aid in spinal cord injury prevention because axial loads are imparted symmetrically to the spine rather than where a significant flexion component is applied. The orientation of the facet joints in the coronal plane does not significantly limit spinal movement in any direction except extension, where the spine’s ability to resist axial loading is greatest. This may be related to the fact that the facet joints can participate in axial load support most effectively in extension.

Late Pathological Features

The spondylotic processes, originating from the vertebral bodies, tend to extend into the spinal canal and across the intervertebral space, and, therefore, the vertebral bodies may combine and fuse. This may lead to a paradoxical increase in the stability of the cervical spine by the process of autofusion (5, 20). The decrease in cervical mobility, caused by the autofusion, may be responsible for the symptomatic relief in patients with mild or moderate myelopathy (2). This process of fusion typically occurs in relative kyphosis and may account for the occurrence of additional stresses on adjacent cervical segments rostral and caudal to the fusion segment, leading to longitudinal progression of the spondylotic abnormalities.

Secondary Compressive Processes

Spinal Cord Compression

Sagittal plane compression of the cervical spinal cord from the primary degenerative pathological lesion of cervical spondylosis is the most frequently cited cause of myelopathy in this condition (5, 12, 18, 36, 43, 44). The compression may occur ventrally via spondylotic bars and/or dorsally from a bulging ligamentum flavum (36, 38, 43). The compression may not be continuous and may be exacerbated by abnormal cervical postures, as mentioned above (36).

Because the dynamics of cervical motion reduce the sagittal diameter of the spinal canal, they also affect the compression of the cervical spinal cord in cervical spondylotic myelopathy (2). Flexion may induce compression against ventral spondyl-

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<tr>
<th>Joint</th>
<th>Motion</th>
<th>Range of motion (degrees)</th>
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<tbody>
<tr>
<td>Occiput–C1</td>
<td>Combined flexion/extension</td>
<td>25</td>
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<td>Lateral bending (unilateral)</td>
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<td>Axial rotation (unilateral)</td>
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<tr>
<td>C1–C2</td>
<td>Combined flexion/extension</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Lateral bending (unilateral)</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Axial rotation (unilateral)</td>
<td>40</td>
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otic bars (9, 25, 41). This problem is worse with cervical kyphosis (41). Furthermore, during flexion there is a deformation of the lateral and ventral columns of the spinal cord and a reduction in the sagittal dimensions of the cord. This has been thought to be related to axial tension (20). Extension may result in compression of the spinal cord dorsally by the buckling ligamentum flavum, resulting in the Lhermitte’s sign and myelopathic symptoms (3, 20, 23, 25, 34–36, 41). Brieg et al. (9) and Taylor (39) separately showed that spondylotic processes caused marked indentation of the cervical spinal cord during hyperextension. Panjabi and White (34) noted that lesser changes take place during lateral bending and axial rotation. Muhle et al. (32), using flexion and extension MRI studies, observed that increased spinal stenosis was observed in twice as many patients during extension than during flexion (Fig. 3). Whereas an increase in cervical stenosis was mentioned at flexion only from the anterior direction, narrowing of the canal was observed at extension from the anterior and/or the posterior directions. Ventral osteophytes prevent the normal up-and-down movement of the cervical spinal cord during flexion and extension. When this occurs, the cervical spinal cord becomes deformed ventrally (18, 20). Cervical spondylosis may also foster abnormal spinal movements, such as telescoping (or shingling) and subluxation, and a further reduction in the sagittal dimension of the cervical spinal canal as a result of the degenerative process on the facet joints (12, 16, 20).

A pincer phenomenon on the cervical spinal cord, in which unstable cervical segments may exhibit subluxation during flexion or extension or both and pinch the spinal cord, has been described (Fig. 4) (23, 24, 41, 43). This dynamic secondary pathological factor is exacerbated by large osteophytes and ligamentous laxity with instability.

Regions of the spinal cord containing upper extremity motor tracts receive up to five times more compressive stress with extension than those tracts subserving lower extremity function (37). Brieg et al. (9) demonstrated that the dorsal half of the cervical spinal cord shortens more than the ventral half in extension and that the spondylotic bars produce deep grooves in the ventral surface of the cord during this maneuver.

The spinal cord may be tethered in the sagittal and coronal planes. In the sagittal plane, this involves either ventral or dorsal structures. The cervical spinal cord elongates and displaces significantly during flexion (6) and in the presence of an “effective kyphosis” (4–6, 18, 20). This may result in significant distortion. The neurological deficit in a patient with a focal kyphosis is related, in part, to spinal cord tethering over the kyphosis in the sagittal plane (sagittal bowstring effect) (Fig. 5). This may affect the neurological outcome in the presence of a kyphotic deformity. An “effective” cervical kyphosis is a configuration of the cervical spine in which no part of the dorsal aspect of any of the vertebral bodies C3 through C7 crosses this line. The definition of this imaginary line is associated with a zone of uncertainty (gray zone), within which the surgeon’s bias and clinical judgment together determine whether lordosis or kyphosis is the predominant spinal configuration in the midsagittal section (Fig. 6) (6). The spinal cord can also be

![FIGURE 3. Sagittal MRI scans of the cervical spine (A) showing ventral spinal cord compression from disc herniation at C3–C4 and vertebral body osteophytes. Note the compression of the spinal cord in extension (B) that is diminished flexion (C). (from, Benzel EC: Biomechanics of Spine Stabilization. Rolling Meadows, American Association of Neurological Surgeons Publications, 2001 [6]).](image)

![FIGURE 4. The lateral view of the cervical spine with spondylosis showing the pincer mechanism in flexion and extension. (from, Benzel EC: Biomechanics of Spine Stabilization. Rolling Meadows, American Association of Neurological Surgeons Publications, 2001 [6]).](image)

![FIGURE 5. A, a kyphosis associated with cervical spondylosis causes neural injury, in part, by tethering the spinal cord over a ventral mass via the “sagittal bowstring” effect. B, dorsal decompression (i.e., via laminectomy) may worsen deformation. (from, Benzel EC: Biomechanics of Spine Stabilization. Rolling Meadows, American Association of Neurological Surgeons Publications, 2001 [6]).](image)
tethered in the coronal plane (coronal bowstring effect) by nerve roots or the dentate ligaments (Fig. 7). In this case, a laminectomy may be ineffective in relieving spinal cord distortion. Thus, a ventral decompression procedure is required to adequately relieve the spinal cord distortion (6).

Pathological and Histological Changes

Gross pathological findings include flattening and indentation of the spinal cord. Histopathologically, changes are most often observed in the dorsal and lateral columns. Demyelination is most prominent in the lateral columns at the levels of osteophytic bars. In the corticospinal tract, changes occur caudal to compressive lesions. Necrosis and cavitation in the central spinal gray matter constitute severe and chronic changes (7, 8, 20, 25, 30). The zone of cervical spinal cord damage has been termed “butterfly” partial necrosis. This affects the lateral columns, lateral portions of central gray matter, and ventral portions of the dorsal columns (Fig. 8) (24, 30).

Among the surgical findings, we note dorsal displacement of the spinal cord by osteophytic bars, an undulating contour observed on the dorsal surface of the cord over single or multiple levels, and sagittal thinning and pallor of the spinal cord (12).

Effect of Trauma

The chronic, repetitive, concussive spinal cord injuries from spinal elements may lead to the development of a central cord syndrome in the elderly. This can also happen in the event of acute spinal cord injury. Each episode of spinal cord infringement may be minor, but the chronic collection of them may be significant (20, 43). Other spinal cord injuries may occur in patients with cervical spondylosis acutely, such as spinal cord concussions, contusions, and Brown-Séquard syndrome (20, 30).

Vascular Compression

Among the pathological evidence supporting vascular mechanisms in cervical spondylotic myelopathy, we note that necrosis and cavitation may be found in the more ischemicsensitive spinal gray matter, that the spinal cord has a more tenuous radicular vascular supply between C5 and C7, and that
an acute presentation of cervical spondylotic myelopathy without related trauma may be caused by the spontaneous thrombosis of a compressed artery and subsequent spinal cord ischemia (7, 11, 31, 41).

Local arterial supply to the spinal cord, such as the anterior spinal artery and the posterior spinal artery, radicular vessels feeding the anterior and posterior spinal arterial plexus, pial plexuses, and penetrating vessels of the spinal cord, may all be compressed by the degenerative changes in cervical spondylosis (3, 5, 6, 18, 19, 20, 23, 29, 30, 36, 38, 41, 43).

Impairment of venous flow may also play a role in the development of myelopathy. Drainage of the central areas of the spinal cord occurs via central sulcal tributaries into the anterior median spinal vein. This vein can be compressed by vertebral body osteophyte (30). Delayed syringomyelic cavitation from cervical spondylosis, which occurs 5 to 10 years after the initial spinal cord trauma, may be caused by a venous infarction pattern. Butterfly necrosis of the spinal cord is thought to be secondary to occlusive arterial or venous phenomena or both (24, 30).

CONCLUSION

The management of cervical spondylosis is complex. A thorough knowledge of anatomy, biomechanics, and the variety of available surgical approaches is imperative.

REFERENCES

Myeloradiculopathy is a clinical syndrome produced from degenerative changes of the vertebral column resulting in compression of the neural elements, spinal cord (myelopathy), and nerve roots (radiculopathy). The pathophysiology of the radiculopathy and the myelopathy may result from a multimodality process. Factors that may contribute include direct compression of the nerve roots and spinal cord, vascular insufficiency, venous engorgement, and inflammation, along with some degree of a genetic contribution in the ability of neural elements to sustain and respond to injuries.

Cervical spondylosis is a common degenerative condition in industrial populations, in which approximately 50 to 80% of patients have at least one episode of neck pain, with or without associated radicular component, annually (20). The natural history of spondylotic cervical myelopathy needs to be further delineated, although its course most likely results in a progressive neurological decline (8, 40). However, occasional reports have suggested arresting of the process (4) or subsidence of symptoms (27).

Through the normal aging process, arthropathies or arthritic disorder patients may present with compressive symptoms with involvement of nerve roots or the spinal cord (Figs. 1 and 2). Radicular compression may present as a weakness in the respective myotome, sensory losses, or radiating pain in dermatomal distribution. The goals of treatment are to eliminate symptoms, by methods including pain reduction and strength restoration; this can typically be achieved through conservative treatment algorithms (34). However, occasionally, in recalcitrant cases of radicular symptoms or symptomatic spinal cord compression, surgery may be warranted (17).

Arthropathy, a diffuse disorder, may involve multiple cervical joints and concurrently compress the spinal cord. Hence, in this setting, multiple nerve root involvement is not uncommon. This combination of signs and symptoms are referred to as cervical spondylotic myeloradiculopathy.

The earliest references to cervical disorders as a cause of neurological deterioration are credited to Strumpell (1888), Marie (1898), and von Beckteren (1899), and the disorder was referred to as cervical spondylitis secondary to an assumed infectious or inflammatory condition (4). Horsley first surgically addressed the condition of cervical spondylotic myelopathy in 1892, performing a C6 laminectomy and spinal cord decompression in a patient with a progressive quadriparesis. The patient had a significant improvement and recovery; within 8 months, the patient was able to walk and, at 1 year, was fully recovered (5). In 1952, Brain et al. (4), in his landmark article, redefined the etiology and pathophysiology of this degener-


EXAMINATION

In the evaluation of a patient with cervical spondylotic myelopathy with or without a concurrent radiculopathy, particular attention must be placed on the assessment of motor function, the different modalities of sensation, and the signs of spinal cord compression (long-tract signs).

Individual muscle groups supplied by specific nerves should be isolated and tested for weakness. The grading of key muscle groups is performed bilaterally, using a six-point scale (1, 25). Additionally, attention to the muscle tone, flaccid or spastic, is helpful.

Sensory modalities consist of light touch, pin prick, and vibratory or proprioception, which are all transmitted through the spinal cord via different neuronal tracts. The sensory modalities should be recorded and scored on a three-point scale (0 = none; 1 = impaired partial or altered appreciation, including hyperesthesia; and 2 = normal) (1).

Deep tendon reflexes are generally a simple monosynaptic reflex consisting of an afferent input with a synapse in the spinal cord and an efferent output. Upper motor neurons inhibit the efferent signal. Thus, if the reflex is increased, a decrease in upper motor influence is inferred. Reflexes are graded between 0 and 4+ where, a Grade 3+ or 4+ (Table 1) reflex suggests an upper motor nerve dysfunction. Hyperactivity of the muscle stretch reflexes is characterized by a decrease in the reflex threshold, an increase in the speed of response, exaggeration in the vigor and range of movement, prolongation of muscle contraction, repeated contractions and relaxations, extension of the reflexogenous zone (zone of provocation), and propagation of the reflex response (Table 2) (16).

<table>
<thead>
<tr>
<th>TABLE 1. Deep tendon reflex gradesa</th>
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</tr>
<tr>
<td>0</td>
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**TABLE 2. Reflex grading**

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<tr>
<td>0</td>
<td>Complete absence</td>
</tr>
<tr>
<td>+</td>
<td>Diminished</td>
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<tr>
<td>++</td>
<td>Normal reflex</td>
</tr>
<tr>
<td>+++</td>
<td>Hyperactive reflex</td>
</tr>
<tr>
<td>++++</td>
<td>Markedly hyperactive, often with clonus</td>
</tr>
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Definitions of Spinal Disorders (30)

Spondylosis: any or various degenerative diseases of the spine

Myelopathy: any disease or disorder of the spinal cord or bone marrow

Radicul: of, relating to, or involving a nerve root

Radiculopathy: any pathological condition at the nerve roots.

FIGURE 1. A, sagittal T2-weighted magnetic resonance imaging (MRI) scan of the cervical spine in an asymptomatic patient with degenerative changes or cervical spondylosis. Note the normal caliber of the spinal cord with some effacement of the anterior thecal sac caused by disc and osteophyte complexes (arrow), but no spinal cord compression. B, axial T2-weighted MRI scan of the cervical spine on the same patient with tomogram marker seen in (A) at the C5–C6 interspace. Note the encroachment on the nerve roots as they exit the canal through the foramen (arrow) caused by uncal vertebral joint hypertrophy.

FIGURE 2. Cervical flexion (A) and extension (B) plain x-rays of a 55-year-old man who presented with an acute C5 radiculopathy. Plain x-rays illustrate severe degenerative changes with loss of disc height and osteophyte formation, particularly at C5–C6 (arrow). Note the increased rotation at C4–C5 and subluxation.
Clonus: Rhythmic involuntary muscle movement with stimulation
Tone of the muscle: The degree of tension of the muscle at rest
Spasticity: Increased muscle tone or a resistance to motion
Flaccidity: Yielding to pressure for want of firmness, lack of tone

SIGNS AND SYMPTOMS: RADICULOPATHY

Primary compression of the nerve root without impingement of the spinal cord can result in a radicular pain pattern, loss of strength and/or sensation, or diminished-to-absent reflexes. This is contrary to lesions of the spinal cord, which typically produce hyperreflexia and/or nondermatomal or nonmyotomal sensory or motor disturbances.

The abduction relief sign and Spurling’s sign are two confirmatory examination maneuvers that implicate compression of a nerve root at the level of the foramen. Abduction relief sign: the patient abducts the shoulder by placing the hand of affected side onto the top of his or her head. A positive sign is relief of the radicular symptoms (10). This may worsen a patient’s symptoms if thoracic outlet syndrome was the etiology of the pain. Spurling’s sign: the examiner places axial pressure on the cranium, with the patient holding their neck in extension, with a concurrent lateral bend of their neck towards the affected side. A positive test provokes the radicular pain.

Identifying the process as radicular in nature is extremely important in localizing the concordant pathology on x-ray films. However, the distribution of the nerves may vary considerably because of the variability of the brachial plexus anatomy and extradural anastomosis of nerves (36). Cervical disc protrusion or foraminal stenosis that results in compression of the nerve roots C1–C4 does not manifest as weakness or atrophy unless there is concurrent compression of the spinal cord.

C3 Nerve Root

The C3 nerve root exits the spinal canal through the C2–C3 neural foramina. It is unusual to have a patient present with signs or symptoms of a C3 radiculopathy. This is thought to be caused by the paucity of movement at the C2–C3 segment (31). Concurrently, the C2–C3 has the largest foramen and is traversed by the smallest cervical nerve root (29). Clinical symptoms include radicular pain, often referred to by the patient as a headache, caused by the sensory distribution of the nerve over the upper neck and occiput or sensory loss. There is no distinct motor distribution for this nerve.

C4 Nerve Root

The C4 nerve root exits the spinal canal through the C3–C4 neural foramina. The increased mobility and smaller foramina-to-nerve ratio predisposes this nerve to an increased risk for compression. However, it is also uncommon for patients to present with a pure C4 radiculopathy (17). Pain may radiate to the posterior neck and trapezius region and to the anterior chest (21), but does not typically radiate into the upper extremity. Jenis and An (21) presented a series of 12 patients with neck pain from C4 radiculopathy and all had normal neurological examinations.

C5 Nerve Root

A C5 radiculopathy typically radiates from the neck over the posterior shoulder girdle and into the proximal lateral arm. A C5 lesion can demonstrate weakness in the deltoid muscles and, to a lesser extent, in the biceps muscles and the supraspinatus and infraspinatus muscles. Clinically, patients with C5 motor weakness are typically unable to abduct or raise their arm over their head, and this manifests during dressing or hair brushing. Signs of nerve dysfunction may be visualized as a diminished pectoralis, biceps, or brachioradialis reflex. Numbness can be isolated to the lateral aspect of the arm in the deltoid region (26). A C5 nerve root lesion can be difficult to distinguish from a primary shoulder disorder, although a careful physical exam of the nerves and dermatomes along with manipulation and rotation of the shoulder joint may help differentiate the two.

C6 Nerve Root

C6 compression is the most common radiculopathy, largely because the greatest amount of degenerative change (spondylosis) is usually seen at the C5–C6 level (8, 31). C6 nerve root weakness will typically present through the biceps muscle along with the extensor carpi radialis (longus and brevis). The extensor carpi radialis muscle is unique because it is innervated solely by the C6 nerve and functionally performs extension at the wrist. The C6 nerve may manifest as weak biceps and/or brachioradialis reflexes. The C6 nerve also supplies the sensation to the thumb and the lateral portion of the index fingers. Numbness can be isolated over this region, but it is not unusual for numbness to be absent (26). Radicular symptoms typically consist of pain referred from the neck, down the shoulder and medial border of the scapula and into the lateral arm and radial forearm down to the thumb and index fingers (36).

C7 Nerve Root

The C7 nerve root supplies motor innervation to the triceps muscle and performs extension of the arm at the elbow joint. Signs of a compressive lesion may also manifest as a diminished or absent triceps reflex as well as weakness in this muscle. Sympathetic dysfunction from impairment of the autonomic system may present as Horner’s syndrome, although this is a variable finding (17, 26). Numbness may be isolated to the middle and index finger (26). Pain is usually in the interscapular area and radiates through the mid-arm and midforearm, down to the middle three fingers.

C8 Nerve Root

The C8 nerve root controls the hand intrinsic and finger flexor muscles and can present as Benediction sign (the inabil-
ity to extend the fourth and fifth digits. Sympathetic dysfunction from impairment of the autonomic system may present as Horner’s syndrome, although this is also variable (17, 26). Pain radiates through the medial aspect of the arm, the medial aspect of the forearm, and the medial two fingers. Motor loss or weakness can be isolated to all of the wrist extensor muscles (except the extensor carpi radialis) as well as the flexors (except carpi radialis) and the hand intrinsic muscles.

**T1 Nerve Root**

T1 radiculopathies are extremely rare, and Murphey et al. (26) reported their occurrence to be less than 1% in their series of 648 patients. These lesions tend to be acute disc herniations and not related to spondylotic degenerative changes. Harrop et al. (17), in their series of cervicothoracic radiculopathies, reported on three patients; two of the patients had cervicothoracic radiculopathies resulting from disc herniations and the third had a cervicothoracic radiculopathy from a foraminal stenosis. These patients can be differentiated from C8 radiculopathy patients by the significant hand intrinsic weakness, typically with minimal pain. Patients also can have atrophy of the first dorsal interosseous muscles and a Froment’s sign. Sym pathetic dysfunction from impairment of the autonomic system may present as Horner’s syndrome, although this is variable (17, 26). Numbness occasionally is present and usually is located over the ulnar side of the forearm (26).

**SIGNS AND SYMPTOMS: MYELOPATHY**

The clinical definition of a myelopathy is the presence of long-tract signs, which are the results of inhibition of the spinal afferent or efferent (pyramidal) nerve tracts. Some myelopathic signs include hyperreflexia of the deep tendon reflexes of the upper and lower extremities, increased muscle tone or clonus, and the presence of pathological reflexes, including Babinski’s sign (plantar reflex) and/or Hoffman’s sign. The plantar reflex (Babinski’s sign) is elicited using a blunt object to stimulate the lateral aspect of the plantar surface of the foot, from the heel to the ball of the foot, and curving medially across the ball. The normal response is a plantar flexion of the toes. Babinski’s sign consists of slow tonic dorsiflexion of the big toe accompanied by fanning of the other toes (3, 11). There are numerous variations of Babinski’s sign, such as Oppenheim’s, Gordon’s, Schaefer’s, Bing’s, Chaddock’s, Gonda’s, and Allen’s signs. Oppenheim’s sign is elicited by applying heavy pressure with the thumb and index over the tibial bone and stroking down the medial aspect of the calf. Gordon’s sign is obtained by squeezing or applying deep pressure under the tibial head and flexing the knee. Schaefer’s sign is produced by deep pressure on the posterior aspect of the calf. Chaddock’s sign is elicited by stimulating the lateral aspect of the foot with a blunt point. Gonda and Allen have independently described a sign that is elicited by forceful downward stretching or snapping of the distal phalanx of either the second or the fourth toe (11). Bing’s sign describes a stimulus that is nociceptive to the great toe with a pin prick. All of these variations of Babinski’s sign are considered a positive response with dorsiflexion of the great toe.

The upper extremities may be affected with compression of the cervical spinal cord. Hoffman’s sign is referred to as the “upper extremity Babinski’s sign.” Hoffman’s sign is elicited by stimulating the extensor tendon to the third digit by forcible flexion of the distal phalanx, followed by a sudden release, resulting in a flexion and adduction of the thumb and concurrent flexion of the index finger (12, 42). Sometimes there is flexion of the other fingers as well. The sign is incomplete if only the thumb or only the index finger responds (11). Hoffman’s sign has a significant false positive rate, particularly in younger women, and care must be taken with interpreting this sign (12, 42).

Additional signs of cervical myelopathy are the inverted radial reflex and the finger escape sign. The inverted radial reflex is tested by stimulating the distal brachioradialis tendon through gentle percussion, producing hyperactive finger flexion (14). The finger escape sign is provoked by placing the patient’s arms forward with the elbow pronated. A positive sign is noted if the patient is unable to maintain their hands in an extended position and the third through fifth digits abducted. Inability to grip and release rapidly with these fingers is an additional sign of a myelopathic hand (28). Occasionally, patients describe an electrical shock-like sensation shooting down the spine, with flexion of the neck, known as Lhermitte’s sign. Originally described with multiple sclerosis and thought to be the result of posterior column dysfunction, this phenomenon may be seen in patients with severe cervical cord compression from stenosis or a disc herniation.

Myelopathy may also manifest as a loss of proprioception, and, more commonly, gait or fine motor dysfunction, such as difficulty in buttoning one’s shirt or changes in the handwriting. Spillane et al. (40) noted that the early phase of cervical spondyloitic myelopathy is also characterized by clumsiness and unsteadiness with gait. Severe muscle atrophy caudal to the level of stenosis is uncommon with a spondylotic myelopathy, unless it is detected in much latter stages. Therefore, if atrophy is present, physicians must evaluate for fasciculations, particularly proximal to the level of stenosis (i.e., tongue), and exclude amyotrophic lateral sclerosis.

A patient with cervical spondyloitic myelopathy can present acutely after a trauma. The central cord syndrome, described originally by Schneider et al. (38) in 1954, is characterized by greater motor impairment in the upper extremities than the lower extremities, bladder dysfunction, frequent urinary retention, and various degrees of sensory loss below the level of the lesion. Burning hands, with paresthesias and dysesthesias in the hands, was later described as a mild variant of central cord injury. Central cord syndrome occurs in patients with cervical spondylosis if they suffer neck trauma, especially in hyperextension (24). Various functional classifications (Appendix 1) are used to evaluate patients with cervical spondylosis. They are all based on pure clinical testing to evaluate the patient’s progress during the
course of the disease and to document response to different treatment schemes.

SIGNS AND SYMPTOMS: MYELOPATHY WITH RADICULOPATHY

Cervical radiculopathy occurs in a subset of the myelopathic patients. In this process, the spinal cord is stenotic along with concurrent focal compression on one or more particular nerve root(s). These radicular symptoms, mainly including pain, typically motivate patients to seek medical attention. The physician must carefully evaluate the patient with a myeloradiculopathy with a thorough history and physical exam. Important elements in the history are to elucidate the timing and progression of symptoms, function and integrity of muscle groups, loss of dexterity, gait function, bowel and bladder function, and fine motor control.

The majority of the patients who present with myelopathic features have concurrent axial neck pain. However, approximately 20% may not have neck discomfort at all (15). Crandall and Batzdorf reported that neck and shoulder pain was present in less than half of the 62 patients in their series, and approximately one-quarter of patients had a cervical radiculopathy that could be reproduced with a Spurling test (8). Interestingly, the most frequent clinical finding or myelopathic sign that patients presented with was spasticity (61 out of 62), followed by weakness (40 out of 62) (8). This spasticity was often noted in the hands, manifesting as a slowness and stiffness during opening and closing the fist, particularly in the flexor forearm muscles (8). Crandall and Batzdorf (8) illustrated that this is a diffuse disorder with a two-level disease affecting C4–C5 and C5–C6 more than C5–C6 and C6–C7, and more than C3–C4 and C4–C5; and three-level involvement affecting C4–C7 more than C5–C6 (Figs. 2 and 3).

CONCLUSION

The diagnosis of cervical spondylotic myelopathy, with or without a concurrent radiculopathy, is determined through a thorough clinical evaluation and physical examination. Radicular symptoms can be diagnosed and isolated to a specific spinal level by a careful evaluation of motor and sensory distributions. Concurrent spinal cord compression must be evaluated for the presence of long-tract dysfunction. The clinical evaluation must be correlated with radiographic analysis to direct the appropriate surgical intervention.

REFERENCES

43. The American College of Rheumatology (Steinbrocker’s) grading system (1949) (41) is a general disability grading system, not specifically designed for spondylotic myelopathy
I: Complete ability to carry out all the usual duties without disability
II: Adequate for normal activities despite discomfort or limited motion for one of the joints
III: Limited or none of the duties of usual occupation or self-care

APPENDIX

1. The American College of Rheumatology (Steinbrocker’s grading system (1949) (41) is a general disability grading system, not specifically designed for spondylotic myelopathy

2. Nurick grading (1972) (27) includes six grades of disability
Grade 0: Signs or symptoms of root involvement but without evidence of spinal cord disease
Grade 1: Signs of spinal cord disease but no difficulty in walking
Grade 2: Slight difficulty in walking that did not prevent full-time employment
Grade 3: Difficulty in walking that prevented full-time employment or the ability to do all housework, but which was not so severe as to require some one else’s help to walk
Grade 4: Able to walk only with someone else’s help or with the aid of a frame
Grade 5: Chair-bound or bedridden

3. Ranawat classification (1972) (33) was originally designed for patients with cervical myelopathy caused by rheumatoid arthritis
Class I: No neural deficit
Class II: Subjective weakness with hyperreflexia and dysesthesia
Class III: Objective findings of weakness and long-tract signs
III A: Could walk
III B: Quadriparetic, nonambulatory

4. The modified Japanese Orthopedic Association (2) incorporated a grading scale assessing upper extremity, lower extremity, and bladder function as well as sensation

Modified Japanese Orthopedic Association Cervical Spine Myelopathy Functional Assessment Scale

Motor dysfunction score of the upper extremities
0: Inability to move hands
1: Inability to eat with a spoon, but able to move hands
2: Inability to button shirt, but able to eat with spoon
3: Able to button shirt with great difficulty
4: Able to button shirt with slight difficulty
5: No dysfunction

Motor dysfunction score of the upper extremities
0: Complete loss of motor and sensory function
1: Sensory preservation without ability to move legs
2: Able to move legs, but unable to walk
3: Able to walk on flat floor with aid (cane/crutch)
4: Able to walk up and/or down stairs with hand rail
5: Moderate to significant lack of stability, but able to walk up and/or down stair without handrail
6: Mild lack of stability but walks with smooth reciprocation unaided
7: No dysfunction

Sensory dysfunction score of the upper extremities
0: Complete loss of hand sensation
1: Severe sensory loss or pain
2: Mild sensory loss
3: No sensory loss

Sphinctor dysfunction score
0: Inability to micturate voluntary
1: Marked difficulty with micturition
3: Normal micturition

5. Casey et al. (1996) (7) developed a functional scoring system for rheumatoid arthritis patients with cervical myelopathy. A questionnaire filled out by the patients included six questions related to usual daily activities, and was graded from 0 to 3 with a score of zero when performed with no difficulty and 3 when unable to perform. The system had a total possible score of 30 points.

6. Singh and Crockard (39) developed a 30-m walking test as a quantifiable measure of severity of cervical spondylotic myelopathy.

MECHANICAL NECK PAIN AND CERVICOGENIC HEADACHE

Mechanical or axial neck pain refers to neck pain that does not radiate into the upper extremities but is confined to the cervical, occipital, or posterior scapular areas. Oftentimes, this mechanical pain is associated with severe headaches that may radiate into the occipital, temporal, or periorbital regions. Mechanical neck pain may take many forms; it may be unilateral or bilateral, cause headaches, and lead to stiffness in one or all directions of cervical motion. Although the majority of cases involve injury to the muscle or paraspinal soft tissues and resolve within 6 weeks of onset with conservative treatment alone, large population studies have demonstrated that chronic neck pain persists in 10 to 34% of adults in the general population (19, 28, 59). Of these patients, approximately 50% will also complain of headaches radiating into the occipital region. These refractory cases provide a great dilemma for the spine surgeon.

In addition, the differential diagnosis remains very wide and the clinician must remember not to focus exclusively on one possible etiology when taking care of these patients. In addition to examining for organic causes for pain, the clinician must take great care to consider the psychosocial condition of the patient and the possibility for a nonorganic component. This article will focus on the appropriate work-up in the patient with mechanical neck pain and headache, the differential diagnosis, and patterns of pain generation in the most common syndromes.

HISTORY AND PHYSICAL EXAMINATION

Although the history and physical examination for the cervical spine patient has been described in a previous section, specific consideration must be taken to several points in the initial evaluation. Certain findings should raise “red flags” to the evaluating clinician and lower the threshold for referral to the spine surgeon. These include the presence of night pain, weight loss, and unrelenting pain, which are suggestive of a neoplastic or infectious process (1, 47, 68). Other “red flags” include significant head and neck trauma and the presence of a neurological deficit (6).

Many patients with axial neck pain will present with associated symptoms of radiculopathy and/or myelopathy because the same degenerative changes that may cause axial neck pain may also cause nerve root or cord impingement (5, 8, 70, 71). Thus, a complete neurological examination is important in any patient complaining of axial neck pain. Motor and sensory examination, as well as testing of normal and abnormal upper motor neuron
reflexes, are mandatory in all cases (28). In some instances, the axial neck pain may be so severe as to mask pain, weakness, or numbness in the extremities; thus, simply asking the patient if he or she has had any neurological deficits is not sufficient.

The full range of motion should be tested with special emphasis on flexion-extension, left and right rotation, and left and right side bending. It is best to estimate motion based on degrees from midline. Active and passive motion should be examined separately and any motion that reproduces pain should be noted. Axial compression should be performed to determine if pain is reproduced. In addition, provocative maneuvers that apply compression on the nerve roots, such as Spurling’s and L’Hermite’s signs, should be evaluated (28).

Many cases of C4 radiculopathy may be masked as axial neck pain because the dermatomes are located in the posterior scapular and proximal neck regions (45). Sensation should be tested in these distributions and the patient should be questioned as to whether or not paresthesias are present in these areas.

Unfortunately, there is always the possibility of secondary pain confounding the examination, and all patients should be tested for nonorganic pain. Severe sensitivity even to light touch in a random distribution, is a sensitive indicator for nonorganic pain. An examination that changes when the examiner retests specific elements should also be suspect. When strength is tested, cogwheeling or jerking motions actually require more strength than holding a stable position because they require deceleration against resistance. Finally, the patient’s demeanor and overall facial expression should correlate with the amount of pain that the patient states he or she is experiencing (77).

**RADIOGRAPHIC EVALUATION**

In the patient complaining mainly of pain with no neurological deficit, it is reasonable to wait 6 weeks before x-rays or other imaging studies are obtained and to start with conservative treatment. If symptoms do not resolve after a 6 to 8 week period, it is helpful to obtain radiological studies (30).

The clinician must use some judgment in delaying radiological studies. Although 6 to 8 weeks is a generally accepted time frame, a patient with severe, unrelenting pain which is getting progressively worse may be at risk for a tumor or infection. In such a case, the radiological workup should be initiated sooner. Likewise, a history of fevers, chills, sweats, or of recent significant weight loss should alert the physician that the problem may be more serious and warrant more immediate radiological assessment. Finally, the patient with recent trauma and pain is clearly at risk for a fracture or dislocation, and radiological studies should be obtained immediately (1, 6, 68).

Imaging studies should start with conventional radiography. Anteroposterior and neutral lateral views, as well as flexion-extension views, should be obtained to see if there is any evidence of instability or listhesis. The overall lordotic contour should be evaluated. Loss of cervical lordosis may be a primary structural problem owing to severe disc degeneration and loss of disc height, or it may be secondary to cervical muscle spasm from pain. Although the discs cannot be imaged on plain x-rays, degenerative levels can often be determined by the associated changes in the adjacent bony structures. These changes include loss of disc height, bone spurs, endplate irregularity, and endplate sclerosis (47, 60).

Flexion and extension lateral x-rays are invaluable in determining stability, particularly in cases of trauma, tumor, or pseudoarthrosis. If the patient has a degenerative spondylolisthesis, it is also useful to know how much motion is occurring with flexion and extension (4, 6, 60).

Magnetic resonance imaging (MRI) is very useful in determining the overall health of the cervical discs when the plain x-rays are negative. The sagittal T2 images are usually helpful in determining if any of the discs are dehydrated and diseased, as they will appear black. In addition, severely degenerative levels may demonstrate a “vacuum disc sign,” indicating gas attracted from surrounding tissues that accumulates within clefts of the degenerated disc or in unstable facet joints. Annular tears may primarily cause pain or may be a precursor to degenerative cervical disease and can be identified on MRI scans. Finally, facet or uncovertebral joint arthropathy may be identified with hypertrophy and osteophytic spur formation (47, 60).

Computed tomographic (CT) scans may give more information on the amount of bony destruction that has occurred in case of tumor, infection, or trauma, but, in general, are not very useful in the evaluation of patients with axial neck pain. CT scans with 45-degree oblique reconstructions can be helpful in cases of axial neck pain with a component of radicular pain, as this is superior in evaluating the foramen for bony spurs (23, 60). Regular sagittal reconstructions oriented at 90 degrees rather than 45 degrees add little information as to the patency of the foramen and space available for the exiting nerve roots.

Imaging studies should not be delayed in patients presenting with a neurological deficit, particularly if the deficit is severe and unacceptable to the patient, if myelopathy is present, and/or if the patient has any changes in bowel or bladder function. In such patients, conventional x-rays and MRI scans should be obtained in a timely fashion.

**DIFFERENTIAL DIAGNOSIS OF MECHANICAL NECK PAIN AND CERVICOGENIC HEADACHE**

**Cervical Strain and/or “Whiplash”**

The most common cause of axial neck pain is cervical strain, which is thought to result from an injury to the soft tissue structures of the neck, including muscle, tendon, and ligament. When this type of injury occurs after an acceleration-deceleration-type trauma, it is often referred to as “whiplash.” It is unclear whether or not the changes in the paraspinal muscles and ligaments that occur in patients with cervical strain are a cause or result of the chronic pain syndrome. Some authors have hypothesized that muscle or ligament injury leads to ves-
sel tears and small hematomas within the muscle tissue (31, 52, 61, 79, 84–85). These hematomas may irritate the muscle and cause resulting spasm. The hematomas may also initiate a fibrosis response, which may alter the muscle structure and lead to continuing spasm and pain. Injury to the longus coli muscle from the level of C1 to C6 has been implicated as a potential cause, as changes in this muscle have been noted on MRI scans in patients with chronic mechanical pain.

Others feel that injury to the posterior facets may be a primary cause of whiplash and cervical strain. Based on cadaver studies, Bogduk and Yoganandan (16) postulated that rapid deceleration-type injuries cause the articular surfaces of the facet joints to chisel into one another instead of gliding freely. Others feel that injury-induced stretch or tears of the facet capsules, rather than damage to the actual articular surfaces, are the source of pain (14, 50, 86–87). In defense of the theory that the facets are primarily mechanical neck pain generators, numerous studies have demonstrated that stimulation of the cervical facet joints reproduces mechanical-type neck pain in predictable patterns that have been subsequently mapped (Fig. 1) (17–18, 29).

Others think that the pain in patients with cervical strain is generated from the cervical disc itself. Microscopic tears in the annulus occurring after an injury may cause a relative destabilization of the intervertebral level. This may, in turn, increase the motion of the posterior facets to generate pain (46, 62, 69). However, the theory that the disc itself, independent of the facets, may constitute the pain generator has also been proposed. Each cervical disc is innervated by a plexus formed by the sinuvertebral nerve dorsally and by a plexus formed by the cervical sympathetic trunk ventrally (Fig. 2) (15). It has been suggested that these nerves may generate pain if the annulus is torn or lax (2, 15–16, 21), but objective abnormalities within the disc have been absent in the MRI scans of the majority of patients with cervical strain (27, 80). However, this hypothesis is strengthened by the fact that analgesic injections into the cervical discs have been found to temporarily eliminate mechanical neck pain in some series (72).

Despite the extensive literature available regarding cervical strain, the etiology of cervical strain remains mostly speculative and is the subject of much continued research and controversy. Because cervical strain is very common, pathognomonic findings on examination or radiographic studies are generally not present. The fact that cervical strain is very common has made it difficult to isolate a single pain generator. In addition, none of the theories listed above explains why the majority of patients with cervical strain or whiplash improve within a short period of time, whereas others do not. Thus, cervical strain is most likely multifactorial and may include biochemical, biomechanical, and even psychosocial and behavioral influences (12, 55, 83).

Typically, physical examination will reveal diffuse tenderness along the paraspinal musculature of the cervical spine with diminished range of motion in all directions. The neurological examination should be normal, and the patient should not display any gait changes or coordination problems. Certain areas, sometimes referred to as “trigger points,” may be hypersensitive to palpation and may be associated with localized areas of muscle spasm (78).

Fortunately, the majority of cervical strain injuries will improve over a 6-week period of time with conservative measures alone. The Quebec Task Force noted that whiplash-associated disorder is nearly always self limited and rarely results in permanent disability (66). However, a 20 to 40% rate of persistent neck pain after whiplash-type cervical trauma has been noted in some series with long-term follow-up periods (33, 41, 58). These cases of persistent and progressive neck pain, which is organic in nature, most likely signify patients with resulting cervical degenerative disease after the traumatic incident.

Cervical Degenerative Disc Disease

A patient with neck pain that has persisted longer than 12 weeks will, in most cases, have cervical degenerative disc disease. As mentioned above, this is thought to result from a cascade of changes starting with dehydration and incompetence of the disc ventrally, which result in loss of disc height and increased forces on the adjacent endplates. The resulting abnormal stresses result in endplate sclerosis, osteophyte formation, and hypertrophy of the uncovertebral and facet joints (26, 53). The decreased disc height may also result in loss of cervical lordosis (37, 38, 64, 75).

The actual pain generator in cervical degenerative disease is currently unknown. Most authors think that the incompetent disc itself is the major pain generator (30, 36, 53, 75). As mentioned above, each cervical disc is dorsally innervated by a sinuvertebral nerve plexus and ventrally innervated by the cervical sympathetic trunk, and disc degeneration may stimulate these nerves and generate mechanical pain.
Other authors think that facet joint degeneration may also contribute significantly to the development of mechanical neck pain (9, 14, 30). As mentioned above, the facets and cervical discs are closely related and, together, form each motion segment. Thus, a consequence of disc degeneration may be instability at the affected level; this, in turn, may lead to increased motion and incompetence of the facets. However, cervical facet blocks and radiofrequency neurotomy have had mixed results in the patient with axial neck pain and cervical disc disease. Thus, it is not clear that the facets are the major pain generators in this degenerative process (10, 11, 44, 56, 57, 73).

Another hypothesis that has been suggested is that the overall loss of cervical lordosis from the disc degeneration may cause muscle spasm and subsequent axial neck pain (9, 14, 30). As mentioned above, the facets and cervical discs are closely related and, together, form each motion segment. Thus, a consequence of disc degeneration may be instability at the affected level; this, in turn, may lead to increased motion and incompetence of the facets. However, cervical facet blocks and radiofrequency neurotomy have had mixed results in the patient with axial neck pain and cervical disc disease. Thus, it is not clear that the facets are the major pain generators in this degenerative process (10, 11, 44, 56, 57, 73).

Another hypothesis that has been suggested is that the overall loss of cervical lordosis from the disc degeneration may cause muscle spasm and subsequent axial neck pain (37, 49, 64). However, many successfully treated cases of cervical degenerative disc disease do not completely restore cervical lordosis, yet are associated with good patient outcomes (51). It is likely that the mechanical neck pain caused by cervical degenerative disease is multifactorial and that the discs, facets, and alignment all play a role.

Although the initial insult in disc degeneration is generally felt to be the result of increased mechanical stresses, new hypotheses have arisen regarding blood supply and disc nutrition as potential risk factors. Recent studies have demonstrated that the annulus receives more of a direct blood supply than does the nucleus, which is supplied via an ultrafiltrate of the plasma (48). Nonetheless, the nucleus seems to be more sensitive to changes in nutrient concentration and, thus, more dependent on blood supply, although indirect, than the annulus tissue. It is this sensitivity to nutrient supply from the bloodstream that may result in cell deterioration in the nucleus, subsequent disc dehydration, and degenerative disc disease (3).

Patients with cervical degenerative disc disease will typically complain of axial neck pain that is worsened by flexion, as this increases stress on the discs. Axial compression may also reproduce or exacerbate pain (5, 28, 35). As mentioned above, many of the same changes which are associated with degenerative cervical disc disease may also cause cervical radiculopathy and/or myelopathy; thus, the neurological examination may also be abnormal (8, 28, 70). Oftentimes, these patients will also have severe headaches that radiate into the occipital areas. These occipital headaches are presumably secondary to severe spasm in the paraspinal musculature and are often relieved when the cervical disc disease is treated (67).

C4 Radiculopathy

The C4 dermatomes include the proximal trapezial areas and the posterior scapular areas; thus, root impingement at the C3 to C4 level may cause apparent axial neck pain (Fig. 3) (26). It is important for the spine surgeon to be able to distinguish between C4 radiculopathy and true axial neck pain, as this may guide the correct operative treatment of the pain complex experienced by the patient. Unilateral neck or poste-
rior scapular pain should alert the possibility of C4 radiculopathy because axial pain from degenerative disc disease is usually bilateral.

A full sensory examination should always be performed in the C4 distributions in any patient who complains of axial neck pain (Fig. 4). The patient should always be asked whether or not he or she experiences paresthesias in these distributions as well. As the C4 nerve root does not have a distinct motor unit, strength and reflex testing is not possible in this distribution (45).

**Pseudoarthrosis**

Unfortunately, an increasingly common cause of axial neck pain is failed cervical surgery. Poor surgical technique or host factors, such as smoking, steroid medication, and noncompliance with postoperative immobilization, may predispose the patient to a postoperative nonunion. Many cases of fibrous union are stable and, thus, asymptomatic and do not require revision surgery. Occasionally, however, enough motion will be present at the nonunion site that axial neck pain will be present (20, 54, 63, 65).

Pseudoarthrosis is most frequently seen after failed anterior cervical discectomy and fusion, presumably because anterior cervical discectomy and fusion is the most common cervical operation; however with the advent of instrumentation and the widespread use of ventral cervical plates, the rate of nonunion has decreased (5, 7). In cases of pseudoarthrosis, graft collapse is often seen and it is not uncommon for the foramen to become narrowed. Thus, these patients may have radiculopathy in conjunction with neck pain (38). Other hallmarks of pseudoarthrosis are broken instrumentation or progressive deformity (22).

MRI scans can be difficult to interpret if instrumentation is present and shows poor bony detail. CT scanning is the most useful test in evaluating for pseudoarthrosis, as it gives the best bony definition. The use of myelography in conjunction with CT scanning is indicated if nerve root or cord compression is suspected. In addition, plain films, including flexion and extension laterals, are invaluable in determining instability. If the immediate postoperative images are available, it will also help the clinician determine the amount of graft collapse and increase in angular deformity (22, 38).

**Pathological Processes in the Cervical Spine (Tumors, Trauma, Infection)**

As mentioned above, the physician who evaluates the patient with axial neck pain must always keep in mind the possibility of a severe process, such as tumor, trauma, or infection. Any recent trauma, as well as any systemic signs such as weight loss, fevers, chills, or night sweats, must always be questioned. The clinician must also be very suspect of any patient complaining of severe, unrelenting pain that is getting progressively worse over a relatively short period of time (1, 6, 68, 81). A full neurological examination must be performed in all such patients to establish a baseline. Any patient in whom the above mentioned “red flags” go off should be immediately evaluated radiographically with both plain x-rays and canal studies (MRI or CT) (47).

**Rheumatological Disorders (Rheumatoid Arthritis, Ankylosing Spondylitis, Reiter’s Syndrome, Psoriatic Arthritis)**

The seropositive and seronegative spondyloarthropathy disorders are beyond the scope of this discussion. However, a clinician evaluating patients with axial neck pain must keep a rheumatological disorder in mind, especially if systemic or multiple joint complaints are present (68). Specific evaluation includes blood testing for HLA B27 or rheumatoid factor. However, these tests have a relatively high false negative rate. Thus, if the clinical suspicion is high enough, the onus is on the spine surgeon to make appropriate referral to a rheumatologist to rule out a seropositive or seronegative spondyloarthropathy. Unless spinal instability, neurological compromise, or severe deformity is present, it is generally wise to treat these patients nonoperatively with medication.

**Shoulder Pathology and Rotator Cuff Disease**

Patients with shoulder pain will often complain of associated neck pain or mistake his or her pain as coming from the cervical spine. Thus, particularly in the patient with more prominent complaints about the shoulder or proximal deltoid, a full shoulder examination should be performed to prevent treatment of the wrong problem.

Rotator cuff pathology can be tested with Neer and Hawkins' tests for impingement as well as with testing abduction from 0 degrees. If the physical examination is equivocal, injection of local anesthetic into the subacromial space may aid in the diagnosis. Imaging studies, such as MRI, can determine in detail the extent and location of a rotator cuff tear if one is present (32).
Acromial-clavicular joint arthritis will usually present with a lump and/or tenderness localized over the region. Degenerative arthritis in the glenohumeral joint will generally present with decreased range of motion in all directions. Imaging studies and injection of local anesthetic will aid in the diagnosis of these conditions (24).

Vascular Disorders

Vascular disorders as a source of mechanical neck pain and headache are rare but are very important in the differential diagnosis because of the potential severity of these diseases. Neck pain and headache may be the presenting symptoms in patients with internal carotid artery dissections, vertebral artery dissections, and even aortic dissections (13, 39–40, 74). The symptoms associated with these disorders are often severe and unrelenting and are associated with dramatic changes in vital signs (34, 82). With regard to patients in acute distress with sudden, severe onset of pain, the possibility of a vascular etiology should always be considered.

CONCLUSION

Mechanical neck pain and cervicogenic headache can be the presentation of many different disorders; often, the cause can be nebulous and difficult to sort out. As in any disease process, it is of utmost importance for the clinician to first make the correct diagnosis. As the differential diagnosis in the patient with axial neck pain is wide, a full history and physical examination, as well as appropriate imaging studies, are critical before implementing a treatment plan.

The most common cause of axial neck pain is cervical strain, which is a poorly defined soft tissue injury that may involve the disc, facet, and/or paraspinal ligaments and muscle. Fortunately, the majority of cases of cervical strain resolve within 6 weeks, and the treatment is always nonoperative.

Cervical degenerative disc disease is the most common cause of mechanical neck pain that has not responded to conservative treatment. Unless associated with a neural compression, the treatment for axial neck pain is generally conservative. The pain generator in cervical spondylosis has been difficult to identify. Thus, the ability to effectively relieve cervical discogenic pain, with or without surgery, has been limited.

Other potential causes of axial neck pain include C4 radiculopathy or cervical pseudoarthrosis. C4 radiculopathy should be suspected if the patient has paresthesias or numbness in this distribution or if the symptoms are unilateral. Oftentimes, it may be difficult to distinguish C4 radiculopathy from axial neck pain.

Cervical pseudoarthrosis should be suspected in patients with persistent symptoms despite previous fusion. Although rare, vascular disorders and pathological processes should always be ruled out, especially in patients with very severe symptoms.

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25. Deleted in proof.
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Cervical spondylosis is a term used to describe the degenerative aging process that encompasses a sequence of changes in the intervertebral discs, vertebral bodies, facet joints, and ligaments of the cervical spine. It is a common condition that occurs as a natural consequence of aging in the majority of the adult population. As a result, it is often difficult to distinguish normal physiological degeneration from pathological changes. Anatomic changes should only be considered pathological if they are etiologically related to specific clinical syndromes.

There are three main categories of cervical spondylosis: cervicalgia (non-radiating neck pain), cervical radiculopathy, and cervical myelopathy. This article concerns the pathophysiology, presentation, and clinical evaluation of cervical radiculopathy and the spectrum of radicular syndromes attributable to cervical spine degenerative disease. Cervicalgia and myelopathy, which are commonly associated with radiculopathy and the treatment of cervical radiculopathy, are covered elsewhere in this issue.

Cervical radiculopathy is a pathological process involving the cervical nerve root. It is the result of compression and inflammation of the nerve root or roots at or near the cervical neural foramen. This occurs annually in 85 out of 100,000 people. The most common causes for radiculopathy are cervical disc herniation (Fig. 1–3) (17), followed by cervical spondylosis (Fig. 1) (1, 35). Cervical radiculopathy is less commonly caused by intraspinal or extraspinal tumors, trauma with nerve root avulsion, synovial cysts, meningeal cysts, dural arteriovenous fistulae (19), or tortuous vertebral arteries (16). Cervical radiculopathy may also occur without an identifiable cause. Other conditions that can mimic cervical radiculopathy, which should be included in the differential diagnosis, are upper extremity nerve entrapment, primary shoulder disease, brachial plexus disorders, and peripheral neuropathies. This article focuses on radiating pain secondary to compression of cervical nerve roots by herniated disc material or pain that is associated with cervical spondylosis.

PATHOPHYSIOLOGY

The cervical intervertebral disc is taller ventrally than dorsally, and it is the cervical disc, not the vertebral body, that is responsible for the maintenance of cervical lordosis. The outer portion of the disc is made up of the anulus fibrosus. The latter is crescent-shaped, and, when viewed in the axial plane, it is thicker ventrally than dorsally. Ventrally, it is multilaminated with interweaving fibers of alternating orientation, but dorsally, it is only present as a thin layer of collagen fibers (23). Before the age of 20 years, few morphological changes occur in the cervical spine. Beginning in the third decade of life, a progressive decline in the water content of the intervertebral disc occurs and continues with age. The nucleus pulposus becomes an indistinct fibrocartilaginous mass (29). In patients younger than 30
The water content of the intervertebral disc approaches 90%, and it decreases to less than 70% by the eighth decade of life. The basic structural unit of the nucleus pulposus is glycosaminoglycan protein, which consists of a proteoglycan protein core and bulky, sterically active polysaccharide attachments of chondroitin sulfate and keratin sulfate. Because of their high molecular weight and overall negative charge, glycosaminoglycan proteins have a strong attraction for water molecules. With aging, these large, sterically active glycosaminoglycan proteins gradually diminish in size and number. As a result, the intervertebral disc’s ability to retain water also diminishes. These age-related changes in the chemical composition of the nucleus pulposus and annulus fibrosus cause the degenerated disc to become more compressible and less elastic (3). Consequently, the disc loses height and bulges dorsally into the spinal canal. As the vertebral bodies drift toward one another (i.e., subsidence), the ligamentum flavum and facet joint capsule fold in dorsally, causing a further decrease in the canal and foraminal dimensions. This approximation of adjacent vertebral bodies leads to a reactive process that produces osteophytes around the disc margins and at the uncovertebral and facet joints. However, the degenerative changes of the cervical intervertebral disc differ from those affecting the lumbar disc. In the cervical spine, true disc prolapse and herniation of the nucleus pulposus is uncommon (23).

The neural foramen is bordered ventrally by the uncovertebral joint and dorsally by the superior articular process of the caudal vertebra (2). Compressive radiculopathies occur as a result of mechanical distortion of the nerve root by either the hypertrophied facet joint or uncovertebral joints (Fig. 1), disc protrusion (Fig. 2 and 3), spondylotic spurring of the vertebral body, or a combination of these factors. Pressure on the nerve root may lead to sensory deficits, motor weakness, or radicular pain. Pain is related to mechanical compression and to an inflammatory response.

PRESENTATION

Radiculopathy can be divided into acute, subacute, and chronic. Acute cervical radiculopathy occurs in relatively young patients in the setting of a tear in the annulus fibrosus and subsequent prolapse of the nucleus pulposus. Subacute radiculopathy occurs in patients with pre-existing cervical spondylosis, without persistent symptoms except for occasional neck pain. Patients develop insidious symptoms, which are often polyradicular in nature. Chronic radiculopathies materialize from acute or subacute radiculopathies that have failed to respond to treatment. Pain is most prominent in acute cervical radiculopathy and diminishes as the condition becomes more chronic. It may be described as sharp, achy, or burning and may be located in the neck, shoulder, arm, or chest, depending on the nerve root involved. Classically, an acute radiculopathy presents with pain radiating in a myotomal distribution. For example, patients with a C7 radiculopathy often experience pain in the triceps region rather than the distal dermatomal region. Sensory symptoms, predominantly parasthesias and numbness, are more common than motor loss and diminished reflexes. The clinician should keep in mind that the sensory symptoms frequently do not match the dermatomes illustrated in medical textbooks. Henderson et al. (13) reviewed the clinical presentations of cervical radiculopathy in more than 800 patients and found arm pain in 99.4%, sensory deficits in 85.2%, neck pain in 79.7%, reflex deficits in 71.2%, motor deficits in 68%, scapular pain in 52.5%, anterior chest pain in 17.8%, headaches in 9.7%, anterior chest and arm pain in 5.9%, and left-sided chest and arm pain in 1.3%.

Radicular pain is often accentuated by maneuvers that stretch the involved nerve root, such as coughing, sneezing, Valsalva, and certain cervical movements and positions. Several clinical signs suggestive of radiculopathy have been described. Davidson et al. (9) described the “shoulder abduction sign” in
which the patient experiences significant relief of arm pain with shoulder abduction. The patient holds the arm over the head and typically rests the wrist or forearm on the top of the head. The Spurling test is a maneuver that provokes the patient’s arm pain with induced narrowing of the neural foramen. It is performed by extending the neck and rotating the head to the side of the pain and then applying downward pressure on the head. The test is thought to cause a narrowing of the intervertebral foramina and is considered positive if the limb pain or paresthesia is provoked with the maneuver. This test has been found to be specific, but not sensitive, for cervical radiculopathy (33).

The type and location of the radicular symptoms are determined by the level at which the cervical nerve root compression occurs (Table 1). Radiculopathy of the third cervical nerve root results from pathological changes between the C2 and C3 vertebrae and is not common. Patients may experience pain in the suboccipital region, often extending to the back of the ear, and in the dorsal or lateral aspect of the neck. This pain is often difficult to distinguish from other causes of headache. Numbness may be present along the occiput and in the distribution of the great auricular and lesser occipital nerves. Although the third cervical nerve root supplies, in part, the suboccipital muscles, the trapezius, the levator scapulae, the sternocleidomastoid, and the strap muscles, an isolated motor deficit generally cannot be detected clinically.

Radiculopathy of the fourth cervical nerve root results from pathological changes between the C3 and C4 vertebrae and is more common than a C3 radiculopathy. It may be a cause of unexplained pain along the base of the neck that radiates to the superior aspect of the shoulder and posteriorly to the scapula. The rhomboid, trapezius, and levator scapulae muscles are supplied, in part, by the fourth nerve root, but a motor deficit may be hard to detect. A sensory deficit may be present over the anterolateral aspect of the neck, along the distribution of the transverse cervical and supraclavicular nerves. The C3, C4, and C5 nerve roots innervate the diaphragm. Involvement of these three nerve roots may lead to diaphragmatic weakness (6, 7).

Radiculopathy of the fifth cervical nerve root results from pathology at the C4–C5 level. Patients often present with numbness and localized shoulder pain that can be confused with a pathological shoulder condition (Table 2) (2). When it is due to a rotator cuff tear, shoulder disease can present with weakness of abduction and external rotation. However, unlike pain from primary shoulder disease, radicular pain is not significantly affected by motion of the shoulder. The numbness follows the C5 sensory distribution, which is located over the top of the shoulder along its midportion, and extends laterally to the midportion of the arm. The principal motor deficit is supraspinatus and deltoid muscle weakness with impaired shoulder abduction. Weakness of the clavicular head of the pectoralis major, biceps, and infraspinatus muscles can also occur. The pectoralis reflex and the biceps reflex, which are innervated by the fifth and sixth cervical nerve roots, may be decreased.

Compression of the C6 nerve root is the second most common cause of cervical radiculopathy and results from disc herniations or spondylosis at the C5–C6 level. Patients present with pain

<table>
<thead>
<tr>
<th>Table 1. The cervical radicular syndromes</th>
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<tbody>
<tr>
<td><strong>Nerve root</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>C3</td>
</tr>
<tr>
<td>C4</td>
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<tr>
<td>C5</td>
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<td>C6</td>
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<td>C7</td>
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<tr>
<td>C8</td>
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<tr>
<td>T1</td>
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and/or numbness radiating from the neck to the lateral aspect of the biceps, the lateral aspect of the forearm, the dorsum of the hand at the web space between the thumb and index finger, and into the tips of those digits. Motor deficits in the wrist extensors and biceps are common. Weakness of the supinator, pronator teres, and triceps muscles may be present. The brachioradialis and biceps reflexes may be decreased or absent. The pain and paresthesias of C6 radiculopathy may mimic carpal tunnel syndrome, which is caused by median nerve entrapment at the wrist by the transverse carpal ligament.

Unlike cervical radiculopathy, upper limb nerve entrapments, such as carpal tunnel syndrome, are characterized by pain, paresthesia, and weakness in multiple nerve root distributions. Referred pain with entrapment neuropathy, however, is common and pain can radiate proximally to the site of entrapment. Compression of the median nerve at the wrist, for example, may cause referred pain to the arm and even to the neck. Carpal tunnel syndrome is characterized by nocturnal dysesthesias, weakness, and, occasionally, thenar atrophy. The thenar and first two lumbrical muscles are innervated via the median nerve by the C8 and T1 nerve roots. The symptoms of carpal tunnel syndrome are often reproduced with Phalen’s test, and Tinel’s sign may be present.

Electrodiagnostic studies may be necessary to evaluate peripheral nerve function to differentiate entrapment syndromes from cervical radiculopathies.

To complicate matters, entrapment syndromes may coexist with cervical radiculopathy. This is known as the “double crush” phenomenon and was first described by Upton and McComas (32) in 1973. According to this hypothesis, a proximal injury along an axon, such as a cervical root lesion, causes impaired axoplasmic flow, which predisposes affected axons to injury at a more distal site. Upton and McComas found that in 81 out of 115 cases of carpal tunnel syndrome, there was an associated cervical radiculopathy as well. However, more recently, Morgan and Wilbourn (26) retrospectively studied 12,736 cases of carpal tunnel syndrome and ulnar neuropathy at the elbow and found that 435 of these cases (3.4%) had a coexisting cervical root lesion. However, in only 98 (0.8%) of these cases were the lesions on the same nerve.

Most studies that employ clinical examination to diagnose cervical radiculopathy have demonstrated the seventh cervical nerve root to be the most frequently involved in cervical radiculopathy (12, 15, 30). It is caused by degenerative changes at the C6–C7 level. The patient may present with pain and/or numbness radiating across the back of the shoulder, over the triceps, the dorsolateral aspect of the forearm, and over the dorsum of the long finger. Triceps weakness can be significant, but may not be noticed by the patient until it becomes severe.

<table>
<thead>
<tr>
<th>Nerve root</th>
<th>Entity mimicking radiculopathy</th>
<th>Differentiating factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5</td>
<td>Rotator cuff tear</td>
<td>Both present with weakness of abduction, but the rotator cuff tear is not associated with weakness of other C5 innervated muscles. C5 radiculopathy not associated with painful shoulder movement or significant tenderness</td>
</tr>
<tr>
<td>C5</td>
<td>Suprascapular nerve entrapment</td>
<td>Suprascapular nerve entrapment is not associated with weakness of other C5 innervated muscles, such as the deltoid, biceps, and pectoralis major</td>
</tr>
<tr>
<td>C6 or C7</td>
<td>Carpal tunnel syndrome</td>
<td>Carpal tunnel syndrome is associated with nocturnal dysesthesias, and the hypoesthesia is present distally, over the palmar side of the hand and over the first three to three and one-half digits. There can be weakness and atrophy of the thenar and first two lumbrical muscles, which are innervated by C8 and T1. Phalen’s test may be positive, and Tinel’s sign may be present</td>
</tr>
<tr>
<td>C7</td>
<td>Posterior interosseus nerve compression</td>
<td>Posterior interosseus nerve compression is not associated with sensory findings and does not affect the triceps, pronator teres, and flexor carpi radialis</td>
</tr>
<tr>
<td>C8</td>
<td>Anterior interosseus nerve entrapment</td>
<td>Anterior interosseus nerve entrapment usually presents with pain over the proximal forearm and may have a positive “pinch sign” because of weakness of flexion at the interphalangeal thumb joint and at the distal interphalangeal joint of the index. There is no sensory loss with anterior interosseus nerve compression</td>
</tr>
<tr>
<td>C8</td>
<td>Ulnar entrapment at the elbow</td>
<td>Entrapment at the level of the elbow may cause clinical tenderness along the medial aspect of the elbow; may have positive Tinel’s sign. C8 radiculopathy is associated with weakness of the pronator quadratus and flexor digitorum superficialis and of the first two flexor digitorum profundus muscles, which are innervated by the median nerve. Sensory change does not extend proximal to the wrist in ulnar nerve entrapment</td>
</tr>
</tbody>
</table>
perhaps because gravity aids in extension of the forearm. The latissimus dorsi muscle, wrist flexors, and finger extensors may also be involved. The motor symptoms of C7 radiculopathy may be confused with entrapment of the posterior interosseous nerve, which may present with weakness in the extensor digitorum, extensor pollicis longus, brevis, and extensor carpi ulnaris muscles. Notably, entrapment of the posterior interosseus nerve does not cause sensory changes, and the triceps and wrist flexors are not affected. In C7 radiculopathy, the triceps reflex may be diminished or absent.

Nerve root compression at the C7-T1 level causes radiculopathy of the eighth cervical nerve root. This usually manifests with symptoms extending over the medial aspect of the arm and forearm and into the medial hand and the last two digits. Numbness usually involves both the dorsal and volar aspects of the digits and hand and may extend proximal to the wrist over the medial aspect of the forearm. Unlike a T1 radiculopathy, the sensory findings produced by the C8 nerve root syndrome do not extend to the axillary region (25). The C8 nerve root innervates the small muscles of the hand, particularly the interossei, and the flexors and extensors of the wrist and fingers (with the exception of the flexor carpi radialis and extensor carpi radialis muscles). Thus, patients complain of difficulty using their hands for routine daily activities. Compression of the C8 nerve root may initially be difficult to differentiate from ulnar entrapment at the elbow. C8 nerve root compression may affect the function of the flexor digitorum profundus in the index and long fingers, the flexor pollicis longus in the thumb, and the pronator quadratus, but these muscles are not affected by entrapment of the ulnar nerve. Also, the short thenar muscles, except for the adductor pollicis, may be involved with C8 or T1 compression but are spared with ulnar nerve involvement. Furthermore, sensory changes seen with ulnar neuropathies include numbness, tingling, and/or pain in the fourth and fifth fingers and the hand just below these fingers, but not proximal to the wrist (medial antebrachial cutaneous nerve distribution), as may be seen with C8 radiculopathy. Anterior interosseus nerve entrapment may also mimic C8 or T1 radiculopathy but lacks sensory changes, and thenar muscle involvement is absent.

T1 radiculopathy is uncommon but has been reported in association with T1-T2 disc herniations (25). Intrinsic hand muscle weakness is common because the T1 root is the main contributor to the adductor pollicis, the thenar muscles, and to the interossei and first two lumbricals. Axillary numbness is common, and Horner’s syndrome can occur ipsilaterally.

### CLINICAL EVALUATION

The diagnosis of cervical radiculopathy depends on the correlation of the history and physical examination with radiographic imaging studies. The value of these imaging studies as an adjunct to the diagnosis and treatment of patients with cervical radiculopathy depends on their accuracy associated with demonstrating the precise anatomic features of the nerve root compression.

### Plain Films

Historically, clinicians have used cervical spine plain films to infer nerve root compression by the presence of degenerative changes; however, it has been shown that degenerative changes within the cervical spine are age-related and present in asymptomatic as well as symptomatic individuals (4, 11, 14, 34). Despite the poor correlation between the clinical symptoms of patients and the degenerative cervical spine, plain films remain an important screening tool in the evaluation of patients presenting with neck and limb symptoms. They are inexpensive, readily available, and provide information regarding sagittal balance, congenital abnormalities, fractures, deformity, and instability. Flexion-extension lateral cervical spine radiographs can disclose occult instability that may be the cause of intermittent or positional symptoms. Because plain films cannot visualize neural structures, either directly or indirectly, other diagnostic modalities, including myelography, computed tomography (CT), and magnetic resonance imaging (MRI), are more commonly used in the evaluation of nerve root compression.

### Myelography

Neural compression is diagnosed indirectly with myelography by observing changes in the contour of a contrast-filled spinal canal. Today, water-soluble contrast agents are used. These are associated with less toxicity and enable improved visualization of neural structures compared with the original oil-based agents. The major disadvantage of plain myelography is its invasive nature. Because the diagnosis of neural compression is inferred only indirectly, the exact nature of the compression is not always clear. For example, myelography alone, it can be difficult to distinguish between a “hard disc” with bony osteophytes and a “soft disc” herniation. Because plain myelograms do not rely on the sagittal or coronal reconstruction of an axially acquired image, excellent spatial resolution is achievable with these images.

Accuracy rates for water-soluble nonionic cervical myelography in the diagnosis of clinical nerve root compression ranges between 67% and 92% when compared with intraoperative findings (8, 24, 31). Myelography was associated with no false-positive results, a 15% false-negative rate, and an overall accuracy rate of 85% in a study of 53 patients who had surgical confirmation of the cervical spine pathology (15).

### Computed Tomography

Unlike myelography, CT allows for the direct visualization of pathology causing compression of neural structures. Compared to myelography, CT emits less radiation, has improved visualization of lateral pathology, such as foraminal stenosis, has no significant adverse reactions, and can visualize structures above or below myelographic blocks (2). CT also has a high spatial resolution and is especially helpful in visualizing the foraminal region. Another important advantage of CT is that it can distinguish neural compression caused by soft tissue from compression related to bony structures, such as facet hypertrophy. This is a major advantage from a surgical planning per-
CERVICAL RADICULOPATHY

Electrodiagnostic Studies

Electrophysiological studies may play an important adjunctive role in diagnosing cervical radiculopathy by identifying physiological abnormalities of the nerve root and ruling out other neurological causes of the patient’s symptoms. However, in patients with well-defined radiculopathy and good imaging correlation, the pain and added expense of electrodiagnostic studies are usually not justified.

The electrodiagnostic study has two parts: the nerve conduction studies and the needle electrode examination (EMG). Nerve conduction studies are performed to exclude peripheral nerve pathology. The amplitude, distal latency, and conduction velocity can be measured. The amplitude corresponds to the number of intact axons. The distal latency and conduction velocity reflect the degree of myelination. The needle electrode portion of the EMG is performed by analyzing multiple muscles within the same myotome and in adjacent myotomes (28). The presence of fibrillation potentials and positive sharp waves at rest is indicative of denervation, but these changes may not occur until 3 weeks after the onset of neural injury. They are noted in the paraspinal musculature before they become apparent in the appendicular muscles. EMG may be normal in the presence of mild radiculopathy or a predominantly sensory radiculopathy and are less likely to be positive in patients with no demonstrable weakness (28). Nerve conduction studies and EMG have been shown to be useful in diagnosing nerve root dysfunction and distinguishing cervical radiculopathy from other lesions that are unclear on physical examination (22). They have also been found to correlate well with findings on myelography and surgery (35). A reference chart detailing the results of needle electrode examination of upper extremity muscles in patients with surgically proven solitary root lesions has been published (21).

Magnetic Resonance Imaging

Because magnetic resonance imaging (MRI) can detect the neural structures directly and non-invasively, it has become the most common method of imaging the cervical spine to detect significant pathology (22). The accurate assessment of disc herniations and spinal stenosis is due to the intrinsic contrast and good spatial resolution. Brown et al. (5), in a blinded, retrospective review, studied 34 patients who underwent MRI prior to surgery. MRI correctly predicted 88% of the lesions as opposed to 81% for CT myelography, 57% for plain myelography, and 50% for CT. Disc herniations are commonly observed with MRI scans of asymptomatic individuals (22). They may be observed in 10% of asymptomatic people younger than 40 years of age and 5% of those older than 40 years of age. Degenerative disc disease may be observed in 25% of asymptomatic people less than 40 years of age and 60% of those older than 40. Therefore, the imaging findings should be carefully correlated with the neurological examination. In difficult situations, MRI can be used in conjunction with CT or CT myelography to refine the diagnostic accuracy as these studies provide complementary information.

Conclusion

Cervical radiculopathy is usually the result of disc herniation or cervical spondylosis and is a common cause of upper extremity symptoms. A thorough history and neurological examination, combined with confirmatory radiographic and electrodiagnostic studies enable accurate localization of the pathology and allow the exclusion of other common causes of upper extremity dysfunction, such as shoulder pathology and entrapment neuropathies.

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Cervical Spondylotic Myelopathy: A Brief Review of Its Pathophysiology, Clinical Course, and Diagnosis

DEGENERATIVE DISEASE OF the cervical spine commonly occurs in the natural process of aging. This can lead to compression of the spinal cord and symptomatic myelopathy. We review the pathophysiological factors that lead to myelopathy and the controversial natural history of untreated myelopathy. Signs and symptoms at presentation, examination findings, differential diagnosis, and diagnostic studies are also discussed.

KEY WORDS: Cervical spondylosis, Myelopathy

Cervical spondylotic myelopathy (CSM) is the most common cause of spinal dysfunction in the elderly (77). It is also the most common cause of nontraumatic spastic paraparesis and quadriparesis. In one series, 23.6% of all patients presenting with nontraumatic myelopathic symptoms were found to have CSM (45). A basic understanding of its pathophysiology, presentation, and diagnosis is necessary before considering any surgical intervention for this very common degenerative condition.

PATHOPHYSIOLOGY

Spondylotic changes occur in the aging cervical spine as a result of disc degeneration. As discs age, they fragment, lose water, and collapse. This process starts in the nucleus pulposus, resulting in the central annular lamellae buckling inward and the external concentric bands of the annulus fibrosus bulging outwards. Degenerative disc changes observed on pathological specimens from patients with CSM include fibrillation, fissuring, brown degeneration, and narrowing and ossification of the disc (72). Because of disc degeneration, increased mechanical stresses are theorized to occur at the endplates of the adjacent vertebral body (39).

Subperiosteal bone formation occurs next, forming osteophytic bars that extend along the ventral aspect of the spinal canal and, in some cases, encroach on nervous tissue (42, 52). Osteophytic bars most likely stabilize adjacent vertebrae by increasing the weightbearing surface of the endplates, which are hypermobile as a result of lost disc material (31, 72). Additionally, uncinate process hypertrophy occurs, frequently encroaching on the ventrolateral portion of the intervertebral foramina (52). Nerve root irritation may also occur as intervertebral discal proteoglycans are degraded (59). Ossification of the posterior longitudinal ligament, observed predominantly in certain Asian populations, can result in severe anterior cord compression (20). Factors that have been associated with increased risk of spondylotic changes include repeated occupational trauma, such as carrying axial loads, genetic predisposition, and Down syndrome (36, 50, 74, 76). Smoking has also been associated with disc degeneration (29), and thus it is a risk factor for cervical spondylosis.

Myelopathy occurs as a result of three important pathophysiological factors. These are staticmechanical factors, dynamic-mechanical factors, and spinal cord ischemia. As ventral osteophytosis occurs, the cord space narrows. This is particularly problematic in patients with congenitally narrowed spinal canals (10–13 mm), who are predisposed to developing CSM (79). Agerelated hypertrophy of the ligamentum flavum and thickening of bone may result in narrowing of the spinal canal (22, 42, 77). Additionally, degenerative kyphosis and subluxation are fairly common findings that may contribute to neurological dysfunction in patients with CSM (20, 43).
Dynamic factors relate to the fact that normal flexion and extension of the spinal cord may aggravate spinal cord damage initiated by static compression of the spinal cord. During flexion, the spinal cord lengths, resulting in it being stretched over ventral osteophytic bars. During extension, the ligamentum flavum may buckle into the spinal cord, pinching it between the ligamentum flavum and ventral osteophytes (22, 77). In a patient with significant canal narrowing as a result of spondylosis, repeated hyperextension of the cervical spine results in intermittent acute compression of the spinal cord by buckling of the ligamentum flavum, and the posterior aspect of the cord is subjected to high shear stress comparable to that occurring in acute spinal cord injury. These episodic events may account for the clinical deterioration seen in many cases of CSM (33).

Spinal cord ischemia most likely also plays a role in CSM. Histopathological changes observed in CSM frequently involve gray matter and medial white matter—a pattern consistent with ischemic insult. This is corroborated by animal study models involving both combined compression and ischemic insults and studies measuring perfusion pressures (18, 22, 27). Most likely, ischemia occurs at the level of the impaired microcirculation (1). Ischemia may occur from reduced flow in the pial plexuses, but also from venous congestion and compression of larger vessels, such as the anterior spinal artery (43). Further, oligodendroglia may be particularly susceptible to the effects of ischemia, accounting for early demyelination of the corticospinal tracts, which is a pathological change seen with CSM (22, 26, 49). Other possible factors involved in the pathophysiology of CSM include impairment of intracellular energy metabolism, free radical-mediated injury, apoptosis, and cation-mediated cell injury (22).

**NATURAL HISTORY**

There are few studies regarding the natural history of CSM. Early reports on the course of CSM described progressive disability and neurological function that never returned to normal (13, 57, 65). Nurick (47), however, confirmed the earlier results of Lees and Turner (41) that, for the majority of cases of CSM, there is an initial phase of deterioration followed by a static period lasting for a number of years, during which the degree of disability does not change significantly for those mildly affected. The majority of patients in Nurick’s (47) series had a good outcome. Nevertheless, older patients were noted to deteriorate more frequently. Therefore, Nurick stated that surgery should be reserved for those with progressive disability and those older than age 60 years. Similarly, in a reanalysis of Lees and Turner’s (41) work, patients with CSM who had moderate to severe disability were more likely to improve with surgical therapy than nonoperative treatments, and those with moderate disability treated nonoperatively were more likely to deteriorate than those treated surgically. Patients with mild disability were unlikely to worsen (66). This supports the role of intervention for progressive myelopathy because the natural course seems to be continued deterioration.

Other authors maintain that patients treated medically show continual progressive neurological deterioration (21, 43). Additionally, patients with CSM may be at increased risk for spinal cord injury after minor trauma (23). These arguments have been used in support of early intervention for even mildly symptomatic patients. This is further supported by series demonstrating improved neurological outcomes with shorter duration of symptoms before surgery (43, 44, 54). Nevertheless, in their Cochrane review on the role of surgery for cervical myelopathy, Foyuras et al. (24) noted that the idea that progressive disability will necessarily develop in untreated individuals is not supported by reliable evidence. In addition, the disease can not only remain static for lengthy periods, but sometimes patients with severe disability can also improve without treatment. Foyuras et al. (24) found only one study meeting the criteria of “unconfounded or quasirandomized controlled investigations...allocating patients with cervical...myelopathy to...‘best medical management’ or decompressive surgery (with or without some form of fusion) plus best medical management” (6, p 736). In this small study, 49 patients with mild or moderate myelopathy were randomized to compare surgery versus conservative treatment. Although age and gender ratios were similar between the two groups, the conservative group had slightly better modified Japanese Orthopaedic Association (mJOA) scores, suggesting a possible bias in treatment allocation. At 6 months, mJOA scores and gain scores were better in the conservatively treated group. But at 2 years there were no differences. In addition, a subgroup with severe disability improved after surgical intervention (24).

Other recent studies have had conflicting results. Kadanka et al. (37) performed a 3-year prospective randomized study in patients with mild or moderate clinical myelopathy, studying conservative versus operative treatment. They noted “no significant deterioration in mJOA score in the two groups over the 3-years follow-up period,” and that, “the 3-years follow-up study did not show, on the average, that the surgery is superior to conservative treatment” (37, p 2205–2208). In their discussion, they noted that their results “could mean that the conservative approach can treat CSM with a degree of success similar to that of surgery for at least 3 years, supporting rather than proving the ‘wait and see’ (conservative treatment) strategy. On the other hand, excellent results for surgical management of CSM have been demonstrated in many studies. Most such studies, however, fall into a low-evidence category, and make no comparisons with the effects of the conservative approach.” Sampath et al. (62) published the results of a prospective trial of 503 nonrandomized patients and found significant improvements in the functional status of patients undergoing operative intervention over patients treated conservatively, even though the medically treated group was less symptomatic before assignment to treatment. They noted in their study of patients with probable moderate CSM that “medical treatment did not significantly alter neurological outcome, functional status, or overall pain but had a significant detrimental effect on ability to perform activities of daily living. Although surgical treatment was not found to improve
neurological outcome, overall pain and functional status improved significantly. When medical and surgical treatments were compared, surgically treated patients seemed to have better outcomes, despite exhibiting a greater number of neurological and nonneurological symptoms and having greater functional disability before treatment.” On the basis of these reports, the natural course of CSM for any given individual is variable, and a precise prognostication is not possible (40). Once moderate signs and symptoms develop, however, patients are less likely to improve on their own and would likely benefit from surgical intervention (20).

**SYMPTOMS AND SIGNS**

The hallmark symptoms associated with CSM are gait abnormalities and weakness or stiffness of the legs, which usually develop insidiously. In the early stages of myelopathy, patients may complain of subtle changes in their gait or balance (20). Additionally, they often present with neck stiffness because of the presence of advanced spondylosis. Patients may also present with stabbing pain in the preaxial or postaxial border of the arms (77). They can present with a loss of manual dexterity, difficulty writing, and abnormal sensations, which patients describe as “numb, clumsy hands” (42). They often complain about worsening of their handwriting or difficulty with buttons or zippers (20). Patients may also present with weakness, stiffness, and proprioceptive loss in the legs. These patients often exhibit signs of spasticity. Weakness or clumsiness of the hands may be observed in conjunction with proximal weakness of the legs. Motor loss in the hands with relative sparing of the legs, however, is a relatively rare syndrome. Symptoms are commonly asymmetric in the legs. Loss of sphincter control and urinary incontinence are rare. Some patients, however, complain of urgency, frequency, and urinary hesitancy (42, 77).

Patients with CSM may also present acutely with a central cord syndrome. This typically occurs when a patient experiences an acute hyperextension injury with preexisting acquired stenosis or myelopathy, resulting in acute spinal cord compression. Patients usually present with a history of a blow to the forehead. The syndrome consists of greater upper extremity weakness than lower extremity weakness, varying degrees of sensory disturbance below the lesion, and myelopathic findings, such as spasticity and urinary retention (63).

The most typical physical examination findings are suggestive of upper motor dysfunction. These include hyperactive deep tendon reflexes, ankle/patellar clonus, spasticity (especially of the lower extremities), Babinski’s sign, and Hoffman’s sign (77). The sensitivity of Hoffman’s sign may be increased by examining the patient during multiple full flexion and extension maneuvers of the neck, to a degree that they can comfortably tolerate (dynamic Hoffman’s sign) (17). A patient may exhibit Hoffman’s sign after this maneuver, although at rest they did not. Another reflex that occasionally is useful is the pectoralis muscle reflex. This is elicited by tapping the pectoralis tendon in the deltopectoral groove, causing adduction and internal rotation of the shoulder if hyperactivity is present. It is suggestive of compression in the upper cervical spine (C2–C4) (71). If the patient exhibits diffuse hyperreflexia, then the jaw jerk may be of use in distinguishing upper cervical cord compression from lesions above the foramen magnum (30). If the results are normal, this suggests a lesion below the foramen magnum, whereas, if it is exaggerated, intracranial and metabolic pathologies should also be considered. Another sign that is helpful, if present, is Lhermitte’s sign, which consists of electrical shock-like sensations running down the back and shooting into the limbs during flexion of the neck. This sign, however, is not specific for CSM and is classically attributed to dysfunction of the posterior columns (16).

In terms of the motor examination, in the upper extremities, patients with CSM most commonly exhibit triceps and/or hand intrinsic muscle weakness. Upper extremity weakness typically begins in these muscle groups (11). Wasting of the intrinsic hand musculature is a classical finding in CSM (19, 28, 51). The patients’ hand function should be assessed in addition to upper extremity strength assessment. A useful maneuver consists of having the patient make a fist and release it 20 times in 10 seconds. Impairment or clumsiness during this maneuver may suggest cervical cord dysfunction. Similarly, the finger escape sign may be indicative. In this maneuver, the patient holds his/her fingers extended and adducted. If the ulnar digits drift into abduction and flexion within 30 to 60 seconds, CSM may be present (20). Lower extremity motor examination most frequently reveals motor weakness in the iliopsoas, followed by the quadriceps femoris. Distal strength is reduced less frequently (11). The finding of lower extremity weakness and hyperreflexia, but no upper extremity symptoms and signs, should prompt investigation of the thoracic cord for other pathologies.

Gait should be examined whenever possible. Typically, patients exhibit a stiff or spastic gait, especially during the later course of their disease. Additionally, measuring walking times and the number of steps taken over 30 meters may be an objective, reproducible, and quantitative method of assessing the severity of CSM before and after surgical intervention (64). Nurick (48) developed a widely used grading scale for CSM, on the basis of the degree of patients’ difficulty in walking (Table 1). Gait assessment is also a part of the Japanese Orthopaedic Association assessment scale for evaluation of CSM, a scale that continues to be very useful in quantifying disability associated with CSM (12, 32). It is most widely used as the mJOA score, as modified by Benzol et al. (Table 2) (8). In comparison with the Nurick disability score, the Japanese Orthopaedic Association score more specifically assesses motor function, assesses sensation, and also evaluates urinary symptoms. It also has been demonstrated to have a high interobserver and intraobserver reliability (75). Other instruments used for measuring outcomes in patients with CSM include the Cooper scale and the Harsh scale. Additionally, the Medical Outcomes Study Short Form-36, a generic quality of life outcome assessment instrument, has been used to assess the quality of life among patients with CSM (38).
Sensory abnormalities in CSM have a variable pattern as revealed by an examination. Typically, symptoms start in the fingertips, are confined to the hand, and occur in a nonradicular distribution (11). Loss of vibratory sense or proprioception in the extremities can occur, particularly in the feet. Spinothalamic sensory loss may be asymmetric. The sensory examination can be confounded by the presence of diabetes mellitus or other metabolic causes of peripheral neuropathy (5).

RADIOGRAPHIC STUDIES

Magnetic resonance imaging (MRI) has become the imaging study of choice as the initial screening process for patients in whom CSM is suspected (2). MRI provides excellent imaging of the spinal cord and subarachnoid space and is a very sensitive method of determining their involvement by extradural pathology (Fig. 1) (67). Furthermore, MRI facilitates multiplanar imaging, excellent imaging of the neural elements, increased accuracy in diagnosing intrinsic cord disease, and is a noninvasive, radiation-free procedure (7). MRI, however, may detect pathology unrelated to a patient’s symptoms or may detect pathology in asymptomatic patients. Teresi et al. (67) observed that 57% of patients older than 64 years of age had disc bulging, and 26% of patients in this age group had evidence of spinal cord compression on MRI scans. Overall, the advantages of MRI significantly outweigh its problems. Thus, MRI has become the standard diagnostic study for spondylotic disease.

Computed tomographic (CT) scanning is an important additional imaging modality in the evaluation of cervical spondylosis. CT scanning is superior to MRI because of its definition of bony anatomy and the definition of the neural foramina (25). It may be more sensitive to osteophytes and other degenerative bony changes (Fig. 2) (34). Thus, CT scanning is often used to complement MRI by providing

TABLE 1. Nurick disability score

<table>
<thead>
<tr>
<th>Grade</th>
<th>Signs and symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Signs or symptoms of root involvement but no evidence of spinal cord disease</td>
</tr>
<tr>
<td>1</td>
<td>Signs of spinal cord disease but no difficulty walking</td>
</tr>
<tr>
<td>2</td>
<td>Slight difficulty in walking that prevented full-time employment</td>
</tr>
<tr>
<td>3</td>
<td>Difficult in walking that prevented full-time employment or the ability to do all housework, but that was not so severe as to require someone else’s help to walk</td>
</tr>
<tr>
<td>4</td>
<td>Able to walk only with someone else’s help or with the aide of a frame</td>
</tr>
<tr>
<td>5</td>
<td>Chair-bound or bedridden</td>
</tr>
</tbody>
</table>


TABLE 2. Modified Japanese Orthopaedic Association functional score

<table>
<thead>
<tr>
<th>I. Motor dysfunction score of the upper extremities</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inability to move hands</td>
<td>0</td>
</tr>
<tr>
<td>Inability to eat with a spoon but able to move hands</td>
<td>1</td>
</tr>
<tr>
<td>Inability to button shirt but able to eat with a spoon</td>
<td>2</td>
</tr>
<tr>
<td>Able to button shirt with great difficulty</td>
<td>3</td>
</tr>
<tr>
<td>Able to button shirt with slight difficulty</td>
<td>4</td>
</tr>
<tr>
<td>No dysfunction</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>II. Motor dysfunction score of the lower extremities</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete loss of motor and sensory function</td>
<td>0</td>
</tr>
<tr>
<td>Sensory preservation without ability to move legs</td>
<td>1</td>
</tr>
<tr>
<td>Able to move legs but unable to walk</td>
<td>2</td>
</tr>
<tr>
<td>Able to walk on flat floor with a walking aid (i.e., cane or crutch)</td>
<td>3</td>
</tr>
<tr>
<td>Able to walk up and/or down stairs with hand rail</td>
<td>4</td>
</tr>
<tr>
<td>Moderate to significant lack of stability but able to walk up and/or down stairs without hand rail</td>
<td>5</td>
</tr>
<tr>
<td>Mild lack of stability but walk unaided with smooth reciprocation</td>
<td>6</td>
</tr>
<tr>
<td>No dysfunction</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>III. Sensation</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete loss of hand sensation</td>
<td>0</td>
</tr>
<tr>
<td>Severe sensory loss or pain</td>
<td>1</td>
</tr>
<tr>
<td>Mild sensory loss</td>
<td>2</td>
</tr>
<tr>
<td>No sensory loss</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IV. Sphincter dysfunction score</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inability to micturate voluntarily</td>
<td>0</td>
</tr>
<tr>
<td>Marked difficulty with micturition</td>
<td>1</td>
</tr>
<tr>
<td>Mild to moderate difficulty with micturition</td>
<td>2</td>
</tr>
<tr>
<td>Normal micturition</td>
<td>3</td>
</tr>
</tbody>
</table>

additional bony detail to characterize the lesion responsible for neural encroachment.

Myelography is also useful in demonstrating nerve root and thecal sac compression. Myelograms demonstrate nerve root take off well (3). Myelograms are particularly useful in patients undergoing reoperation. Although some authors advocate CT myelography as having a lower rate of false-positive results than conventional myelography, CT myelography may provide greater specificity in evaluation of the intradural contents and the disc margins (34). Penning et al. (53) concluded that CT myelography provides additional data only when the results from a myelogram are positive-negative results from a myelogram followed by CT study in the case of suspected spondylosis is unlikely to show any clinically useful additional findings.

<table>
<thead>
<tr>
<th>TABLE 3. Differential diagnosis for cervical spondylotic myelopathy*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Condition</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>ALS</td>
</tr>
<tr>
<td>Primary lateral sclerosis</td>
</tr>
<tr>
<td>MS</td>
</tr>
<tr>
<td>Normal pressure hydrocephalus</td>
</tr>
<tr>
<td>Subacute combined degeneration (vitamin B12 deficiency)</td>
</tr>
<tr>
<td>Tumors</td>
</tr>
<tr>
<td>Rheumatoid arthritis</td>
</tr>
<tr>
<td>Spinal arteriovenous malformations and dural arteriovenous fistulas</td>
</tr>
<tr>
<td>Syringomyelia</td>
</tr>
<tr>
<td>Thoracic disc herniations and spinal stenosis</td>
</tr>
<tr>
<td>Epidural abscess</td>
</tr>
<tr>
<td>Tabes dorsalis</td>
</tr>
<tr>
<td>HIV-related myelopathy</td>
</tr>
<tr>
<td>Tropical spastic paraparesis</td>
</tr>
<tr>
<td>Hereditary spastic paraplegia</td>
</tr>
</tbody>
</table>

* ALS, amyotrophic lateral sclerosis; CSM, cervical spondylotic myelopathy; EMG, electromyelogram; MS, multiple sclerosis; MRI, magnetic resonance imaging; CSF, cerebrospinal fluid; VDRL, Venereal Disease Research Laboratory antibody assay; HIV, human immunodeficiency virus.
Given the widespread availability and noninvasive nature of MRI, myelography has been relegated to a secondary role in the evaluation of CSM. It is primarily used for evaluating patients who cannot undergo MRI study (e.g., those with cardiac pacemakers) or in whom MRI data is inconclusive.

Although plain films of the cervical spine are inexpensive and widely available, the nearly universal presence of spondylotic radiographic changes in the elderly, and the very similar appearance of a cervical spine x-ray film in a symptomatic patient and an asymptomatic patient limit their usefulness (3). Cervical spine x-rays can demonstrate disc space narrowing, osteophytosis, loss of cervical lordosis, uncovertbral joint hypertrophy, apophyseal joint osteoarthritis, and vertebral canal diameter (56). Sagittal view plain films may also be useful in assessing sagittal alignment, which may influence potential surgical procedures. Flexion-extension views may be used to diagnose instability, especially in the presence of degenerative subluxation in addition to spondylolisthesis (20). These can be performed safely in patients with CSM, providing there is no evidence of radiographic gross instability, by having the awake patient flex and extend their neck as much as they can comfortably tolerate.

**ELECTROPHYSIOLOGICAL STUDIES**

Electromyography is rarely useful in the workup of the majority of patients with CSM. It may be used to exclude specific syndromes, such as peripheral neuropathy. It also may be of great assistance when amyotrophic lateral sclerosis (ALS) is a concern. Somatosensory evoked potentials may also play a role in the evaluation of spinal cord dysfunction because they provide a more direct assessment of spinal cord function than electromyography (58). A combination of electromyography and somatosensory evoked potential evaluation may be useful in some patients exhibiting signs of upper and lower motor nerve root compression. These studies may help exclude ALS and multiple sclerosis (69).

**LABORATORY STUDIES**

Various laboratory studies may assist in differentiating cervical spondylotic disease as a cause of a patient’s symptoms from other causes of radiculopathy and myelopathy. Cyanocobalamin (B12) levels and a serum rapid plasma reagin assay may help distinguish metabolic and infectious causes of myelopathy from CSM.

**DIFFERENTIAL DIAGNOSIS**

Several other conditions may present in a fashion similar to CSM. It is important to exclude these because they may explain lack of neurological improvement after surgery (14, 60). In particular, the absence of sensory abnormalities on examination should alert one to the possibility of ALS. Extensive weakness and wasting in the hand muscles, especially in the presence of fasciculations, should also make one consider the possibility of ALS (61). Multiple sclerosis can also present with symptoms similar to CSM (78). If there is a lack of correlation between sensorimotor findings and spondylotic changes, suspicion of a demyelinating process should be raised. Other conditions to consider include normal pressure hydrocephalus, subacute combined degeneration (vitamin B12 deficiency), tumors, rheumatoid arthritis, spinal arteriovenous malformations, syringomyelia, thoracic disc herniations and spinal stenosis, epidural abscess, tabes dorsalis, tropical spastic paraparesis and hereditary spastic paraplegia (Table 3) (45, 77).

**CONCLUSION**

CSM remains a very common source of disability in the elderly. It is imperative for the spine surgeon to be familiar with its pathogenesis, presentation, and diagnosis. A detailed history and physical examination, combined with appropriate radiological evaluation, should minimize misdiagnosis and allow the spine surgeon to help patients with this potentially devastating degenerative disease.

**REFERENCES**


MEDICAL MANAGEMENT IS often the initial management of cervical spondylitic syndromes, including radiculopathy, myelopathy, and neck pain. This includes pharmacological and rehabilitation treatment. Prospective studies comparing the efficacy of surgical versus medical management are lacking. The indications and efficacy of pharmacological and rehabilitative treatments are reviewed. The use of anti-inflammatory drugs, muscle relaxants, analgesics, antidepressants, anticonvulsants, steroids, facet joint ablation, and physical therapy are reviewed. A rationale for the medical management of acute neck pain, chronic neck pain, radiculopathy, and myelopathy is presented.

KEY WORDS: Cervical spondylosis, Medical management, Myelopathy, Neck pain, Radiculopathy

DOI: 10.1227/01.NEU.0000215386.05760.6D

MEDICAL MANAGEMENT OF CERVICAL SPONDYLOSIS

Medical management of cervical spondylotic syndromes, including axial neck pain, radiculopathy, and myelopathy, typically includes pharmacological and rehabilitation components. Nonsteroidal anti-inflammatory drugs (NSAIDs), muscle relaxants, analgesics, antidepressants, and anticonvulsants are frequently used in nonoperative management of these conditions. The use of these agents is largely empirical because clinical studies of efficacy in cervical spondylosis are lacking. Similarly, studies evaluating the role of nonpharmacological therapies, including physical therapy exercises, traction, manipulation, and cervical collars in spondylitic syndromes, when available, are generally of poor quality, and frequently provide inconclusive results. A systematic review of 24 randomized controlled trials of pharmacological and nonpharmacological treatment of mechanical neck pain concluded that, “in general, conservative interventions have not been studied in enough detail to assess efficacy or effectiveness adequately” (3).

The natural history of untreated axial neck pain from cervical spondylosis is not known. With nonoperative treatment, approximately 75% of patients have complete or partial, but significant, relief of symptoms (15). Treatment studies of patients with cervical spondylosis with mixed symptoms of axial neck pain, radicular symptoms, or both, treated nonoperatively, suggest that 45 to 60% of patients have good resolution of symptoms, with the remainder continuing with moderate-to-severe residual pain (24, 33). No prospective randomized comparison of surgical and medical treatments has been performed in patients with purely axial neck pain from cervical spondylosis.

Nonoperative treatment of spondylosis with radiculopathy has not been compared with surgical therapy in randomized trials. A large epidemiological survey of cervical radiculopathy in Rochester, Minnesota, found that 75% of patients improved with conservative care and 20% were treated surgically (48). After 6 years of follow-up, 90% of patients were doing well. A more-recent longitudinal cohort study of 26 consecutive patients treated aggressively, but nonoperatively, reported “good or excellent” outcomes in 20 patients (54). Although 14 patients in this study had motor deficits before treatment, progressive neurological loss did not occur in any patient. Two of 26 patients required surgery.

The natural history of cervical spondylitic myelopathy is variable. Early studies suggested that most patients with myelopathy experience progressive neurological deterioration, most commonly in an episodic pattern (12, 59, 61). Conversely, another long-term study of myelopathic patients reported that long periods of nonprogression was the rule and progressive deterioration was the exception (33). A small cohort study of 24 patients followed for a mean duration of 6.5 years found that approximately one-third of patients
improved, one-third deteriorated, and one-third were stable (52). In general, older patients and those with motor deficits are more likely to develop progressive deterioration. Patients with milder disease may have a better prognosis (51). Direct comparisons of nonoperative and operative treatment in myelopathic patients are few. A nonrandomized cohort study comparing medical and surgical treatment in 43 patients, 23 of whom were treated nonoperatively, reported significantly greater improvement in function and pain in surgical patients (56). A more recent 3-year prospective randomized study of 68 patients with mild-to-moderate nonprogressive spondylitic cervical myelopathy, however, did not demonstrate a significant difference in outcomes between surgically and nonsurgically treated patients (30). Features suggesting a poor response to nonoperative treatment include advanced age, duration of symptoms, severity of myelopathy, and severity of stenosis (17).

**PHARMACOLOGICAL MANAGEMENT OF CERVICAL SPONDYLOSIS**

**NSAIDs**

Despite the lack of any clinical trials in patients with cervical spondylitic symptoms, NSAIDs are widely used in the management of axial neck pain and radicular syndromes. Conceptually, NSAIDs are used because of their combined analgesic and anti-inflammatory properties. There is no data demonstrating superior efficacy to pure analgesics in cervical spondylitic patients. A recent study, however, suggests a superior efficacy of an NSAID (diclofenac) over acetaminophen in patients with severe osteoarthritis of the hip or knee (19, 45). In patients for whom chronic use is anticipated, particularly the elderly, a major concern is NSAID toxicity (gastrointestinal, renal, and cardiovascular) with prolonged use. Newer NSAIDs that are selective inhibitors of cyclooxygenase-2 (COX-2) seem to offer the advantage of significantly lowered risk of gastrointestinal toxicity. However, accumulating evidence suggests that therapy with selective COX-2 inhibitors (coxibs) is associated with a significant increase in cardiovascular events, particularly at higher doses and in higher-risk patients.

**Efficacy**

No studies of NSAID efficacy in patients with cervical spondylosis are available. Two recent meta-analyses of NSAID efficacy in back pain concluded that there was sufficient evidence demonstrating that NSAIDs are more effective than placebo for short-term relief of acute low back pain (31, 63). These reviews were unable to find sufficient evidence to confirm NSAID efficacy in chronic back pain or in lumbar radiculopathy.

Despite this data, NSAID therapy is widely used in acute spondylitic cervical axial or radicular pain, on the basis of a presumed anti-inflammatory effect. If axial symptoms respond to NSAID therapy and long-term use is required, regular monitoring for adverse effects is required. In patients at high risk for NSAID toxicity, pure analgesics, opioid and nonopioid should be considered as an alternative therapy.

**Toxicity**

Gastrointestinal symptoms develop in 15 to 20% of patients taking NSAIDs for an extended period (58, 66). Two to 4% of these patients develop symptomatic ulcers, of which 1 to 2% perforate or bleed. Major risk factors for NSAID “gastropathy” are older age, previous peptic ulcer disease, concomitant use of glucocorticoids, and higher-dose therapy (25). Because most patients with cervical spondylosis are older than 55 years of age, risk of NSAID gastropathy (and renal toxicity) must be considered, particularly with long-term therapy. In higher-risk patients, newer COX-2-inhibiting NSAIDs (coxibs) should be considered. Two large trials comparing available coxibs with older NSAIDs demonstrated a 50% reduction in ulcers and ulcer complications in coxib-treated patients (8, 57). In very high risk patients (the very elderly and patients with recent serious ulcer disease), all NSAIDs should probably be avoided, and pain should be managed with nonopioid or opioid analgesics.

Renal adverse effects of NSAIDs are similar for both older agents and coxibs (22). These include acute renal failure, sodium and water retention, and hypertension. In patients with known cardiovascular disease, particularly those taking diuretic therapy, NSAID therapy significantly increases the risk of congestive heart failure (20). Spondylitic patients who are older and who have comorbid cardiac or renal disease require regular monitoring of renal function if treated with NSAIDs.

A recent analysis of a large trial studying rofecoxib use versus naproxen use in more than 8000 patients found increased cardiovascular events (myocardial infarction, sudden death, and ischemic events) with rofecoxib compared with naproxen. Although some studies have suggested that this data actually reflects a cardioprotective effect of naproxen rather than a prothrombotic effect of rofecoxib, the drug has been withdrawn from the United States market (6, 13, 50). At this time, it remains unclear whether increased risk of cardiovascular events is a class effect, common to other COX-2-selective NSAIDs. In patients with cardiovascular disease or risk factors for such, COX-2-selective NSAIDs should be avoided. Co-therapy with low-dose aspirin to reduce cardiovascular seems to negate the gastroprotective effect of the drugs.

**Nonopioid and Opioid Analgesics**

By providing effective pain control, analgesics may permit better compliance with active exercise programs used in nonoperative management of cervical spondylosis. Acetaminophen has been the preferred first choice for mild-to-moderate pain because of its apparent safety and efficacy comparable to NSAIDs. As noted above, the latter view has now been questioned. Furthermore, recent data has suggested an increased risk of adverse gastrointestinal events (i.e., ulcers and dyspe-
In addition to more potent analgesia, opioids offer other potential clinical advantages over nonopioid agents, including NSAIDs. No end organ toxicity (renal, hepatic, or otherwise) occurs with long-term opioid therapy (42). With opioid analgesics, no ceiling dose exists. For combination products containing acetaminophen, however, the total dose is limited by the nonopioid component. Neuropathic pain may be somewhat opioid-resistant (46). Impediments to the use of opioids for chronic pain have included fear of inducing addiction, potential adverse effects, including impaired cognitive function, fear of drug diversion, and fear of regulatory issues. True addiction, distinguished from physical dependence, is rare in patients with chronic pain treated with opioids if they do not have a previous history of substance abuse (47). Tolerance to drug effect and effects on cognition have not been well studied in patients with spinal pain treated with long-term opioids.

**Efficacy**

Randomized clinical trials assessing opioid efficacy in acute and chronic spinal pain, particularly cervical spondylosis, are few. However, a recent double-blind, placebo-controlled comparison of controlled release oxycodone or fixed combination oxycodone plus acetaminophen in osteoarthritis patients, 49% of whom had back or neck as the primary site of involvement, demonstrated significant improvement in pain intensity and quality of sleep in both treatment groups (11). Although further study is clearly required, the recent clinical practice guideline of the American Geriatric Society on management of pain in older persons, including those with spondylitic syndromes, endorses opioid analgesics for selected patients with moderate- to-severe persistent pain (2).

**Indications**

Opioids should be considered in the management of carefully selected patients with moderate-to-severe symptoms of axial neck pain, with significant underlying structural spondylosis, who have not responded to nonopioid agents and nonpharmacological modalities. Older patients with significant comorbidity are at higher risk for NSAID toxicity and a relatively low risk for opioid abuse. Patients with cervical spondylitic radiculopathy or myelopathy whose pain is a barrier to a trial of active physical therapy or who are not considered surgical candidates may merit a trial of opioid analgesics. The presence of significant psychosocial disorders, such as major depression and current or previous substance abuse, is a contraindication to opioid use. When cervical or arm pain is intermittent and predictable, shorter-acting drugs with a more-rapid onset of action may be effective when used intermittently and before the triggering activity. Oral administration of propoxyphene and meperidine are poor analgesics with risk of toxic metabolite accumulation at higher doses and should be avoided, particularly in the elderly (52). Mixed opioid agonist-antagonists, such as pentazocine and butorphanol, may precipitate withdrawal symptoms in patients already taking pure opioid agonists, and, likewise, should be avoided. For chronic pain, sustained-release preparations released during 12 to 24 hours may be considered, but patients must be warned not to crush or chew the tablets or capsules. Management of patients taking opioids requires frequent regular visits for careful assessment of pain control and improvement in functional status. If improvement is not observed, opioids should be discontinued.

**Muscle Relaxants**

The rationale for the use of muscle relaxants in patients with cervical spondylosis and neck pain is based on the assumption of associated reactive paraspinous and trapezius muscle spasm that may augment symptoms. In addition, available centrally acting agents, including baclofen, cyclobenzaprine, carisoprodol, and tizanidine, produce some degree of sedation, potentially improving pain-disrupted sleep. Randomized clinical trials of muscle relaxants in spondylitic neck or radicular pain are few. Two placebo-controlled trials of cyclobenzaprine reported significant improvement in mixed populations of neck and low back pain (3). Although flawed, studies of centrally acting muscle relaxants in acute back pain have reported improvement in pain, muscle spasm, tenderness, range of motion, and activities of daily living, with the greatest gains made in the first week of symptoms (10). In low back-pain patients, the addition of a muscle relaxant to an NSAID may provide a short-term additive benefit, particularly for relief of muscle spasm and tenderness (7, 9). Adverse effects occur in as many as 60% of patients taking these agents. The most common of these adverse effects are sedation and dry mouth (10, 14). Extrapolating from the low back literature, the use of muscle relaxants is appropriate in persons with cervical spondylosis with exacerbation of neck pain, particularly if palpable muscular tenderness or spasm is present. Because of diminishing efficacy and the risk of habituation with some agents (i.e., carisoprodol), use beyond 2 weeks is not advisable.

**Antidepressants**

Antidepressants may be of value in selected patients as adjuvant analgesics for chronic neck and/or radicular pain. The therapeutic efficacy of these agents may be related to either their antidepressant effect or, alternatively, their inhibitory effect on serotonin and norepinephrine uptake (23, 35, 64). No specific studies demonstrating efficacy of antidepressants in cervical spondylosis are available. However, studies of antidepressants in chronic low back pain demonstrate a modest improvement in pain severity in comparison with placebo, but minimal differences in functional status (4, 55). Common side effects with antidepressants include drowsiness, dry mouth, dizziness, constipation, urinary retention, weight gain, sexual dysfunction, and cardiac conduction changes. Tricyclic antidepressants should be avoided in patients with significant cardiac disease, particularly the elderly. Sedation is more common with amitriptyline, doxepin,
and trazodone, making these agents the first choice in patients with sleep difficulty.

Anticonvulsants

On the basis of experience in diabetic neuropathy, gabapentin is now widely used to treat other neuropathic pain syndromes, including radiculopathy. In studies with diabetic patients, gabapentin compares favorably with amitriptyline in reducing neuropathic pain (38). Another placebo-controlled trial, also in patients with diabetic neuropathy, demonstrated improved quality of life and reduced sleep interference in the gabapentin group (5). In these studies, approximately one-quarter of gabapentin-treated patients experienced an adverse effect, most commonly, dizziness or somnolence. No clinical trials of gabapentin in cervical spondylitic syndromes have been reported. Other newer anticonvulsants used to treat neuropathic pain include tiagabine and oxcarbazepine. None of these agents has received Food and Drug Administration approval for use in spinal syndromes.

Corticosteroids

In some patients with severe radicular symptoms refractory to NSAIDs, oral corticosteroids are sometimes prescribed for their potent anti-inflammatory effect. No data demonstrating the efficacy of this approach is available. Typically, a tapering course of methylprednisolone or prednisone is given during a 1- to 2-week period.

Cervical epidural steroid injection has been studied retrospectively in patients with cervical spondylisis (21, 53). Approximately two-thirds of patients with radicular symptoms and signs respond with significant reduction in pain for approximately 6 months. Patients with purely axial cervical pain are poor candidates for cervical epidural steroid injection.

NONPHARMACOLOGICAL NONOPERATIVE THERAPY

Nonoperative modalities used in the treatment of cervical spondylisis include physical therapy exercises, soft and hard collars, cervical traction, manipulation, other forms of manual therapy, thermal therapy, and acupuncture. Studies of these approaches vary considerably in quality. Studied populations are often heterogeneous, including patients with myofascial pain syndromes as well as spondylitic neck pain and radiculopathy. Myelopathic patients are not included in most trials. For some forms of therapy, blinding in controlled studies is difficult. For example, a recent comparison of acupuncture versus placebo in chronic mechanical neck pain failed to demonstrate a clinically significant benefit of acupuncture (65). However, the “placebo” control did not mimic the process of needling. Systematic reviews of nonoperative management of neck pain, presumably including spondylitic patients, have concluded that, for most of these interventions available, studies are inadequate to assess efficacy (3, 26).

Physical Therapy

Neck Pain

Physical therapy approaches to cervical spine disorders include active, exercise-oriented treatment and modalities, such as ultrasound, thermal therapy, and traction. Active exercise programs in cervical spondylisis patients have been studied primarily in patients with neck pain. A recent structured literature review found three randomized studies suggesting that supervised isometric exercises or proprioceptive reeducation (slow neck movements) produced clinically important improvement in pain and functional parameters (44). Another recent study in 183 patients with neck pain of more than 2 weeks duration compared physical therapy exercises, manual therapy, and continued care by a general practitioner in a randomized, controlled trial (27). Manual therapy consisted of hands-on mobilization using low velocity passive movement of facet joints within the normal range of motion. At the 7-week follow-up visit, manual therapy scored significantly better on most outcome measures than the other interventions. On the basis of patient age (mean, approximately 45 yr) and duration of symptoms (50% had symptoms for less than 6 wk), this study probably included patients with primarily myofascial pain in addition to spondylisis. Another similar trial comparing intensive exercise training, physiotherapy, and chiropractic manipulation in 119 patients with neck pain for longer than 3 months found no differences in any outcome measures, including pain level, range of motion, and disability (29). Thermotherapy may provide brief symptomatic relief, but has not been shown to affect eventual outcome. One small randomized controlled trial comparing therapeutic ultrasound with placebo in patients with myofascial neck pain found no difference in pain relief (32).

Radiculopathy

For spondylitic syndromes with radiculopathy, physical therapy recommendations have included active exercise movements, such as the McKenzie approach, traction, and immobilization using a soft or hard collar (18, 54). Conceptually, the McKenzie approach should be most helpful in persons with cervical disc herniation (“soft disc”) with an intact annulus. This approach uses repetitive test movements to identify a “directional preference” on the basis of “centralization” of the patient’s pain, i.e., movement of pain proximally from the distal extremity toward the neck. This phenomenon is attributed to displacement of the nucleus pulposus within the annulus. Although not well studied in cervical radiculopathy, this approach has been demonstrated to be effective in patients with lumbar disc herniation and radiculopathy (16, 43).

Although soft cervical collars do not significantly restrict neck movement, as many as 76% of patients report reduced pain with their use (40). Although the collar may be of symptomatic benefit, there is no evidence of effect on long-term outcome, i.e., on the need for surgical treatment (28). A hard collar that maintains the neck in a neutral or slightly flexed position may improve symptoms, particularly in patients with
facet joint pain (18). Wearing a soft collar during sleep may limit unconscious neck movement. Collars should be used for a limited time, 2 to 3 weeks, and isometric neck exercises are recommended during use (62).

Although a recent systematic review of mechanical traction for chronic neck pain found insufficient evidence of efficacy, this modality is widely used to treat axial and radicular spondylitic syndromes (44). Traction may be administered in the seated or recumbent position, intermittently or continuously. The traction force applied generally ranges from 10 to 20 pounds for 15 to 20 minutes with modest neck flexion of approximately 20 degrees. Studies of traction in cervical spondylosis are seriously flawed. A recent critical analysis of seven reviews of traction in cervical syndromes found agreement that evidence for efficacy was inconclusive (26). A recent uncontrolled retrospective trial of over-the-door home traction demonstrated pain relief in 81% of patients with mild-to-moderate cervical spondylosis syndromes (60). Of the 10 patients with radiculopathy, five had complete remission of objective manifestations. However, whether patients in this trial were simultaneously receiving other treatments is unclear. Traction is contraindicated in patients with cervical tumors, infection, or vascular disorders. Patients with temporomandibular joint syndrome may not tolerate the over-the-door traction harness.

Myelopathy

There is little information on nonoperative treatment of cervical myelopathy. Cervical collars have been recommended for symptomatic relief, but no effect on long-term outcomes, including neurological progression, has been demonstrated. Manipulation and traction are contraindicated because of the potential for aggravation of neurological injury (12).

INTERVENTIONAL PAIN MANAGEMENT

In selected patients with chronic refractory axial spondylitic neck pain, diagnostic injection may define one or more facet joints as the primary source of pain. Meticulous diagnostic technique, using comparative local anesthetic block or placebo-controlled block of the medial branch of the primary dorsal rami is crucial to reliable identification of facet joint pain. In carefully selected patients, radiofrequency ablation may produce significant relief of pain, lasting 9 to 12 months (34, 36, 37, 41).

SUMMARY: A RATIONAL APPROACH TO NONOPERATIVE MANAGEMENT OF CERVICAL SPONDYLOSIS

Acute Neck Pain

On the basis of the evidence presented, acute neck pain is best managed with an approach emphasizing symptomatic relief with either NSAIDs or acetaminophen, supplemented with a muscle relaxant in the first 2 weeks of symptoms. In rare cases, short-term opioid use may be necessary. Patients must be cautioned regarding sedation associated with these drugs. Brief use (<2 wk) of a soft cervical collar may provide additional symptomatic relief. Manual therapy may be of limited benefit in patients with acute neck pain. Likewise, though unproven, cervical traction may be a helpful adjunctive modality in some patients. As severe symptoms subside, therapist-guided active exercises emphasizing improvement in range of motion and strengthening of paravertebral muscles should be introduced. Isometric exercises may be performed in a soft collar if symptoms are too acute to permit movement.

Chronic Neck Pain

Symptomatic management of axial neck pain from cervical spondylosis includes adequate analgesia and gentle range-of-motion exercises. Long-term use of NSAIDs, particularly in an elderly population, must be carefully considered. If NSAIDs are used, regular monitoring for toxicity is mandatory. Alternatively, for mild pain, acetaminophen is probably safer. For moderate-to-severe pain in patients at high risk for NSAID toxicity, opioid analgesics are preferred. Careful assessment of comorbid psychosocial issues, including history of substance abuse, must be performed before initiation of treatment with these drugs. Furthermore, regular assessment of toxicity and efficacy must be performed. There is no evidence that muscle relaxants are of benefit in these patients. Tricyclic antidepressants may be useful adjuvant analgesics in patients without contraindications to these agents. There is no evidence that long-term use of manipulation, manual therapy, or traction improve outcome, although these therapies may be used intermittently to provide relief of symptom exacerbation. In carefully selected patients, radiofrequency ablation may provide extended relief of facet joint axial pain.

Cervical Radiculopathy

The vast majority of patients with nonmyelopathic cervical radiculopathy respond to nonoperative care consisting primarily of analgesic and anti-inflammatory therapy (NSAIDs) and therapist-guided physical therapy, most often using a McKenzie-based approach. For severe, refractory symptoms or in patients with contraindications to NSAID therapy, a brief course of corticosteroids may be beneficial. Cervical epidural corticosteroid injection may be used, with a similar rationale for symptomatic relief, but evidence of long-term effect on need for surgical intervention is lacking. Although the evidence is inconclusive, cervical traction may be helpful and can be performed at home with appropriate instruction. More study is required before anticonvulsants, such as gabapentin, can be recommended for routine use (Table 1).

Cervical Myelopathy

For patients with mild or subtle myelopathy, nonoperative treatment is appropriate. Careful, regular monitoring for neu-
logical deterioration is mandatory. Symptomatic relief of pain, as discussed, is appropriate. Traction and manipulation should be avoided. A soft or hard collar may be of use with isometric exercises.

**REFERENCES**


### TABLE 1. Medical management of cervical spondylosis

<table>
<thead>
<tr>
<th>Pharmacological</th>
<th>Side effects</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NSAIDs</strong></td>
<td>Ulcers, gastropathy, renal failure, hypertension, congestive heart failure, cardiovascular events</td>
<td>Demonstration of efficacy in cervical spondylosis lacking</td>
</tr>
<tr>
<td><strong>Nonopioid/opioid analgesics</strong></td>
<td>Ulcers, dyspepsia/addiction, impaired cognition</td>
<td>No ceiling dose. May improve pain and quality of sleep</td>
</tr>
<tr>
<td><strong>Muscle relaxants</strong></td>
<td>Sedation, dry mouth, risk of habituation</td>
<td>Few randomized trials. No evidence of long-term benefit</td>
</tr>
<tr>
<td><strong>Antidepressants</strong></td>
<td>Sedation, dry mouth, dizziness, constipation, urinary retention, weight gain, and cardiac conduction changes</td>
<td>No specific studies for cervical spondylosis. Useful as adjuvant analgesics</td>
</tr>
<tr>
<td><strong>Anticonvulsants (e.g., Gabapentin, oxcarbazepine)</strong></td>
<td>Dizziness, somnolence, weight gain</td>
<td>Useful in neuropathic pain. No clinical trials in cervical spondylosis</td>
</tr>
<tr>
<td><strong>Corticosteroids (oral prednisone)</strong></td>
<td>Steroid psychosis, peptic ulcer, congestive heart failure, osteoporosis, dyspepsia, mood swings, insomnia, hypertension</td>
<td>No clinical data show efficacy</td>
</tr>
<tr>
<td><strong>Epidural corticosteroid injection</strong></td>
<td>Dural puncture, spinal headache, facial flushing, stiff neck, hypertension, chemical arachnoiditis</td>
<td>Useful for patients with acute neck pain with radicular symptoms. Lack of randomized control studies</td>
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<table>
<thead>
<tr>
<th>Nonpharmacological</th>
<th>Side effects</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical therapy</strong></td>
<td></td>
<td>Useful in decreasing acute neck pain and radicular pain in short term. No difference in long term. No specific studies in cervical spondylosis</td>
</tr>
<tr>
<td><strong>Modalities (moist heat, ice pack, ultrasound, transcutaneous electrical nerve stimulation)</strong></td>
<td></td>
<td>Brief, symptomatic pain relief. No specific studies in cervical spondylosis</td>
</tr>
<tr>
<td><strong>Cervical collars (soft and hard)</strong></td>
<td></td>
<td>Decreased pain and improved sleep. No evidence for long-term effects</td>
</tr>
<tr>
<td><strong>Cervical traction</strong></td>
<td></td>
<td>Evidence for efficacy is inconclusive</td>
</tr>
<tr>
<td><strong>Manual therapy and chiropractic manipulation</strong></td>
<td></td>
<td>No difference in any outcome measures, including pain, range of motion and disability</td>
</tr>
<tr>
<td><strong>Interventional pain management</strong></td>
<td></td>
<td>Effective in axial neck pain with demonstrated response to medial branch block</td>
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**a** NSAIDs, nonsteroidal anti-inflammatory drugs.


Surgery for Neck Pain

Axial neck pain is a common finding that typically represents a spectrum of clinical Arlington Orthopedic Associates, disorders affecting the cervical spine. Controversy exists concerning the ultimate treatment of the patient who presents with cervical spondylosis and primarily axial neck pain without radicular symptoms or myelopathy and who has failed to respond to extensive nonoperative treatment methods. Cervical discography has been used to assist in determining the specific level or levels causing the neck pain and, potentially, which levels to fuse; however, controversy regarding the specificity of cervical discograms has also been debated in the literature. Los Angeles, California We recommend exhausting all conservative means of treatment of axial neck pain. Surgery is offered only after conservative treatment fails and appropriate psychological testing is performed, as well as diagnostic imaging and discography that confirm a specific level or levels as the pain source. Cervical fusion may demonstrate good results in appropriately chosen patients with cervical spondylosis and axial neck pain.

Key words: Cervical fusion, Cervical spondylosis, Natural history, Neck pain

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Pathophysiology of Neck Pain

Axial neck pain can be the result of a multitude of potential etiologies. Neck pain is often the result of muscular or ligamentous factors related to poor posture or ergonomics, stress, injury, and/or chronic muscle fatigue. Neck muscle pain can develop over time secondary to postural changes or to a primary source of pain, such as the shoulder, temporomandibular joint, or the craniovertebral junction (36). The true physiology of this muscle pain remains unclear. Free nerve endings in muscle serve as chemonociceptive and mechonociceptive units. Sensitization of these nerve endings may be the primary source of muscular neck pain.

Degeneration of cervical discs and/or facet joints is prevalent and seems to be a part of normal aging; therefore, attributing axial neck pain to these degenerative changes is a source of controversy. However, cervical discs and facet joints do seem to be a source of pain. Dwyer et al. (15) performed provocative zygapophyseal injections on normal volunteers and derived cutaneous maps of the different segmental pain patterns in the neck, head, and shoulder. This pattern of facet joint-induced pain can be effectively reversed by anesthetic injections in the facet joint or by blocking the dorsal primary rami (4). These findings support the idea that the facet joint plays a role in the development of axial neck pain.

The peripheral portion of the discs contain nerve fibers and nerve endings that may be responsible for generating pain from degenerative cervical discs (4, 5). The disc is innervated by the sinuvertebral nerve, which is formed by branches from
the ventral nerve root and the sympathetic plexus. Suboccipital pain with radiation into the neck and/or back of the ear is common with degenerative arthritis of the atlantooccipital and atlantoaxial joints. Dreyfuss et al. demonstrated a reproducible pain pattern with injection into the atlantooccipital and atlantoaxial joints. Irritation of the greater occipital nerve, which is formed by the posterior rami of the second, third, and fourth cervical levels, is presumed to cause occipital headaches in some patients.

Patients with rheumatoid arthritis often experience axial neck pain without radicular symptoms. Indications for surgery in rheumatoid spondylitis are better accepted and defined than in cervical spondylosis with predominantly axial neck pain. Atlantoaxial instability, superior migration of the odontoid, and subaxial instability/subluxation are the three most common indications for surgical intervention in the rheumatoid cervical spine. The pathophysiology of rheumatoid spondylitis is distinctively different from patients with cervical spondylosis. We have mentioned rheumatoid pathology for completeness, but a thorough description of neck pain associated with rheumatoid arthritis is beyond the scope of this article.

**NATURAL HISTORY**

Neck pain is usually self-limited and will resolve over time with conservative care. Axial neck pain is more common than often perceived. A recent study of a Saskatchewan adult population showed that 66% of adults experienced neck pain in their lifetime, with 54% having symptoms during the past 6 months and 5% significantly disabled by it (12). After 3 months of medical management for neck pain, DePalma et al. (13) reported that 21% of patients had complete relief, 49% had partial relief, and 22% had no relief. Another study demonstrated that 23% of patients with predominantly axial neck pain remained partially or totally disabled after 5 years (41). In this same study, Rothman and Rashbaum (41) found no significant difference between the patients treated operatively versus nonoperatively for predominantly axial neck pain. They concluded that nonoperative management is the best treatment for axial symptoms.

Gore et al. (20) reported the results of a minimum of 10 years of follow-up on 205 patients with neck pain without any surgical intervention. Seventy-nine percent had a decrease in pain, 43% were free of pain, and 32% had moderate-to-severe residual neck pain. The presence or severity of neck pain was not related to the amount of degenerative changes on x-ray films over time. They concluded that many patients with this condition will have residual symptoms that may be moderately disabling.

Degenerative changes in the cervical spine are the rule, not the exception, with aging. As part of the normal aging process, degenerative changes of the cervical spine include decreased hydration of the discs and mechanical wear of the osseous and ligamentous structures. Most degenerative changes will not produce symptoms. However, some changes can produce pain. The main problem of treating axial neck pain, similar to the treatment of low back pain, remains the appropriate diagnostic evaluation.

**DIAGNOSTIC IMAGING**

Imaging studies of the patient with axial neck pain must be evaluated critically because of the possibility that a significant percentage of symptomatic and asymptomatic patients can have false-positive imaging studies. In one study, plain x-rays of 200 asymptomatic patients demonstrated that 95% of men and 70% of women had at least one degenerative change by age 60 to 65 years (19). Fenlin (16) reported degenerative changes on plain x-rays in 70% of patients older than 70 years.

Plain x-rays should be the first imaging study performed during the evaluation of chronic axial neck pain (Fig. 1). It is valuable in the evaluation of degenerative arthritis, malignancy, infection, trauma, and inflammatory arthropathies. In cervical spondylosis, the C5–C6 level most commonly demonstrates degenerative changes on imaging studies, followed by the C6–C7 level (16, 37). Flexion and extension views of the cervical spine can be added to evaluate for subaxial instability secondary to degenerative changes or traumatic injury (45). Plain x-rays are useful in the evaluation of axial neck pain, but advanced imaging studies are necessary to assess soft tissue structures and neural elements.

Radionuclide imaging is occasionally used to further evaluate neck pain. It is a very sensitive, but nonspecific, examination to assess for changes in blood flow or bone metabolism. Degenerative joint disease, healing fractures, neoplasm, and osteomyelitis are all detected on radionuclide imaging (6). This makes it a useful screening tool to evaluate for generalized pathology. Further studies, such as magnetic resonance imaging (MRI) or computed tomographic (CT) scanning, with or without myelography, are needed to obtain a more-specific diagnosis.

**FIGURE 1.** A, lateral x-ray of a patient with degenerative disc disease and axial neck pain. Narrowing of the disc spaces at C5–C6 and C6–C7, as well as loss of the normal lordosis of the cervical spine, are seen. Osteophytes are seen on the endplates of the vertebral bodies of C5–C7. B, anteroposterior x-ray demonstrating degenerative changes in the facet joints of C5–C7.
MRI has become the imaging modality of choice for evaluation of chronic neck pain associated with cervical spondylosis. It provides excellent visualization of soft tissue structures, neural elements, sagittal alignment, as well as spinal cord and nerve root morphology, and signal changes in the intervertebral discs and vertebral bodies (Fig. 2) (29). Boden et al. (3) studied 63 asymptomatic volunteers and found that 19% had an abnormality on MRI scans. Herniated nucleus pulposus, foraminal stenosis, and degenerative disc disease were found in these asymptomatic patients. Hence, it must be emphasized that diagnostic imaging studies must correspond with clinical signs and symptoms to minimize the significance of false-positive studies. MRI has been unsuccessful in demonstrating a characteristic marker of cervical discogenic pain (23, 34), although it is suggested that cervical discs that demonstrate degenerative abnormalities on MRI scans are more likely to be painful than normal-appearing discs. CT scans with or without myelography are also useful for evaluating cervical degenerative spondylosis. If MRI is not possible, or if MRI findings are incompatible with clinical signs, CT scans with myelography may be indicated (1, 32). CT myelography is the study of choice if severe degenerative changes and endplate osteophytes are present. Modic et al. (31) found MRI to be less sensitive than CT myelography in terms of distinction of bony from soft tissue impingement.

**CERVICAL DISCOGRAPHY**

If surgical intervention is considered in patients with axial neck pain unresponsive to conservative measures, the importance of identifying the exact source of pain generation must be emphasized. Identification of the pain generator continues to be a clinical challenge. Controversy regarding the validity of diagnostic testing techniques, including MRI and discography, for cervical discogenic pain continues to appear in the literature (8, 42).

Cervical discography has been used by clinical practitioners in selected cases as both a provocative and morphological study to evaluate suspected discogenic pain (Fig. 3) (9, 11, 43). Carragee and Alamin (8) and others have questioned the validity of discography in the lumbar and cervical spine. They argued that the specificity of discography is dramatically affected by the psychological profile of the patient examined (2, 8). Some authors think that discography is not useful in elucidating the patient’s pain source or determining effective treatment (25–28, 30).

Conversely, there are authors who feel very strongly that discography can be used effectively in determining the source of a patient’s pain (9, 10, 35, 40, 44). Grubb and Kelly (22) reviewed their experience with cervical discography during a 12-year period and suggested that a reliable pattern of pain was produced by stimulation of each cervical disc. They reported a high percentage of patients that demonstrated multiple discs responsible for their axial neck pain.

The authors advocate the use of plain x-rays and MRI scans to screen for degenerated and potentially painful discs in these challenging patients with chronic axial neck pain. Cervical discography is used to ascertain whether the degenerative discs on imaging were painful and whether normal levels might have been pain generators. Control levels should always be used in discography. Discs that demonstrate moderate-to-severe concordant pain with adjacent controls on discography should be considered positive. These positive discs only should be considered for surgical management.

**SURGICAL TREATMENT OF AXIAL NECK PAIN**

Accepted criteria for operative intervention on patients with axial neck pain exist when concurrent conditions exist, such as rheumatoid spondylitis, subaxial subluxation/instability, fracture/dislocation, radiculopathy, and myelopathy. For patients with cervical spondylosis and isolated axial neck pain, surgery is generally not considered except for rare cases caused by one- or two-level degenerative discs, with severe and unrelenting pain after exhausting all conservative treatment options. As previously discussed, emphasis should be placed on patient selection criteria, including psychological profile, physical examination, radiographic imaging, and cervical discogram results.

Anterior cervical disectomy and fusion (ACDF) is accepted as an effective treatment for radiculopathy and/or myelopathy associated with cervical spondylosis. Several studies in the literature demonstrate that patients who underwent ACDF for radiculopathy and who also had axial pain often showed improvement in both symptoms. Riley et al. (39) demonstrated 72% good or excellent results in 93 patients who underwent ACDF for axial pain. Another study (7) described 43 patients who underwent ACDF for radicular...
symptoms; 36 of these patients also complained of axial neck pain. Eighty-nine percent of these patients had good or excellent relief of neck pain.

Several studies have specifically addressed ACDF for axial neck pain (Table 1). Whitecloud and Seago (47) reported on 40 patients treated with ACDF for axial pain syndromes with positive cervical discography (Fig. 4, A and B). They demonstrated a 70% good or excellent result and concluded that cervical discography is a valid diagnostic study. Palit et al. (33) reported on 38 patients who underwent ACDF for axial neck pain with a positive discogram. They recorded a 79% overall satisfaction with the procedure and a significant improvement in pain and function in their patients. These two studies are the only reports in the literature, to our knowledge, regarding operative treatment results for patients with axial neck pain who had a positive cervical discography.

Ratliff and Voorhies (37) retrospectively reviewed 20 patients with chronic axial neck pain who underwent surgery. Twelve patients underwent ACDF and eight patients underwent posterior fusion via either spinous process wiring or lateral mass plates. General outcome measures indicated that 85% of the patients reported satisfaction with pain relief and surgical result. Garvey et al. (18) retrospectively reviewed 87 patients who had undergone ACDF for neck pain. They reported significant pain relief in 93% of the patients.

Upper cervical spine degenerative arthritis can often be addressed posteriorly. Wertheim and Bohlman (46) demonstrated significant relief of upper cervical pain and headaches with occipitocervical fusion. Patients with atlanto-occipital osteoarthritis and neck pain have demonstrated good results with significant relief of their pain with posterior arthrodesis. Atlantoaxial degenerative arthritis has also successfully been treated with posterior arthrodesis (Fig. 5). These patients also complain of upper cervical pain and occipital headaches. Multiple techniques of arthrodesis of C1–C2 have been documented in the literature with good results. Surgeons should use the technique most comfortable for them.

Patients with adjacent segment disease after previous ACDF have also developed severe axial neck pain. However, there are currently no studies in the literature specifically addressing neck pain and adjacent segment degeneration.

### Table 1. Summary of reports on operative treatment for axial neck pain

<table>
<thead>
<tr>
<th>Series (ref. no.)</th>
<th>Description of study</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratliff and Voorhies, 2001 (37)</td>
<td>Retrospective review of 20 patients who underwent ACDF (12) or posterior fusion (8) for longstanding axial neck pain—an outcomes study</td>
<td>Authors suggest that anterior or posterior cervical arthrodesis for chronic axial neck pain can yield excellent clinical results (85%) with thorough evaluation preoperatively</td>
</tr>
<tr>
<td>Palit et al., 1999 (33)</td>
<td>Prospective outcomes study of 38 patients who underwent ACDF for neck pain</td>
<td>Authors demonstrate a significant decrease in pain, increase in function, and a high degree of patient satisfaction found after ACDF for neck pain</td>
</tr>
<tr>
<td>Garvey et al., 2002 (18)</td>
<td>Retrospective outcomes study of 87 patients who underwent ACDF for axial neck pain</td>
<td>Authors demonstrate that properly selected patients with chronic neck pain are significantly improved after ACDF. They conclude that ACDF is a reasonable option</td>
</tr>
<tr>
<td>Whitecloud and Seago, 1987 (47)</td>
<td>Retrospective review of 34 patients who underwent ACDF for axial neck pain after positive cervical discography</td>
<td>Authors report 70% good or excellent results after ACDF for neck pain after positive discography. They conclude that cervical discography is a valid diagnostic study</td>
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</table>

**FIGURE 4.** A, lateral x-ray of a patient with C4–C5 and C5–C6 degenerative disc disease with chronic axial neck pain. B, cervical discogram at C4–C5 and C5–C6 that positively reproduced the patient’s axial neck pain during provocative discography. C, lateral x-ray after the patient underwent C4–C6 ACDF with iliac crest bone graft and plate fixation. D, anteroposterior x-ray after C4–C6 ACDF. The patient was fused at 1 year, with good relief of neck pain.
after cervical fusions. The authors have had good results with fusion of adjacent segments if obvious degenerative changes have occurred, and results of discography further suggest that the adjacent level is the pain generator (Fig. 6).

Currently, there are no prospective, randomized, double-blind studies in the literature investigating the operative treatment of chronic axial neck pain. There exists a paucity of good studies addressing this topic. Controversy regarding the surgical management of axial neck pain persists because of the lack of good data addressing this topic. However, from the studies currently published in the literature (7, 18, 33, 37, 39, 46, 47), the data suggests that surgical intervention for neck pain can produce improvement in pain and function for patients with nonradicular cervical pain who have been appropriately screened and have failed extensive conservative care.

REFERENCES

38. Deleted in proof.
Earlier descriptions of cervical radiculopathy and its clinical manifestations include those by Elsberg (10), who described “ventral chondromata,” and Stookey (30), who described growths from the intervertebral discs. Arnold (3) described the clinical manifestations of spondylochondrosis, now commonly referred to as cervical spondylosis. The early surgical exposures often required dorsal approaches with dural incisions and dentate ligament resection to access the offending pathology. Surgical techniques included aggressive laminectomy and/or facetectomy to access anterior disc pathologies. Transdural excision of disc fragments with direct visualization of the spinal cord described by Fager (16) epitomized the early development of dorsal spine surgery. As dorsal surgical procedures developed, the modern laminoforaminotomy by Scoville (29) and others (11, 17) became popular. This procedure has a long and successful record of accomplishment, with longer than four decades of use.

The advent of ventral cervical procedures, such as those reported by Bailey and Bagdley (4), Cloward (7), and Robinson and Smith (28), allowed a ventral approach to decompress the cervical spinal elements. In many institutions today, ventral cervical fusions have overtaken the dorsolateral approach as the procedure of choice (2). However, the successful record of accomplishment of posterior laminoforaminotomy had been evidenced by Henderson et al. (19), Murphey and Simmons (22), and Zeidman and Ducker (35), who described significant case loads of successful clinical results after posteriolateral foraminotomy. Murphey and Simmons described the results of 648 patients, 90% of whom had more than 90% pain relief; Henderson et al. described 736 patients with 96% relief of arm pain; and the description by Zeidman and Ducker of 172 laminoforaminotomies showed a 97% success rate in improving radicular pain.

Clearly, the efficacy and safety of laminoforaminotomies were well established. In a prospective comparison of ventral and dorsal approaches, Herkowitz (20) found no significant statistical difference between the two approaches. However, Herkowitz concluded that, in the series of 44 patients, anterior fusion provided better long-term results. Herkowitz suggested that dorsolateral foraminotomy should be limited to patients with body habitus that limits ventral approach and/or patients with previous ventral surgery that restricts access. Of note, many of the patients in this study had concomitant cervical stenosis with myelopathy.

The number and variety of procedures available to treat cervical radiculopathy is evidence that there is no single technique that can best treat all types of pathology. Quite often, the surgeon’s practice is based solely on personal preference and not on the advantage of one procedure over another (12).
accomplished spine surgeon should be able to offer the patient the benefits of either approach, depending on the circumstances. Any surgeon who offers only one procedure is not providing the highest level of care. Clearly, both the ventral and dorsal approaches offer certain advantages and disadvantages. Ideally, the surgeon chooses the procedure best suited to the patient's needs, given their particular pathology. The advantages and disadvantages of these approaches are reviewed, it is clear that the dorsal procedure has a longer clinical history and the following advantages.

Laminoforaminotomy offers direct visualization of the nerve root and better exposure of the exiting nerve root (18, 30). In addition, the nerve can be adequately decompressed without fusion (15). With many techniques of laminoforaminotomy, the intervertebral disc space is not violated. In addition to the lack of fusion complications, which include graft site morbidity, graft dislodgement, and plate and implant complications, as well as pseudarthrosis, patients undergoing laminoforaminotomy typically wear a brace for comfort only, often for less than 1 to 2 weeks (13). Dorsolateral foraminotomy is ideal for dorsolateral sequestrations as well as paramedian disc protrusions. There are no risks to the trachea and esophagus, and there are no risks of cerebrovascular events caused by compression of the carotid sheath and its contents. Another significant advantage is that a laminoforaminotomy is less expensive than a ventral cervical fusion (24).

Disadvantages or risks of laminoforaminotomy include surgical complications, dural injury, cerebrospinal fluid fistula, air embolus (especially a risk in the sitting position), pneumocephalus, and subdural hemorrhage (27). Instability can occur if more than 50% of the facet is resected, resulting in hypermobility (9, 14, 22, 27). This risk of instability is also observed if bilateral procedures are performed at the same level.

Another potential disadvantage of the dorsal approach lies in the indirect method of decompressing the nerve root versus the ventral approach, which is more direct. Unless osteotomies are used to resect the lateral osteophytes of the uncinate process, as was advocated by Epstein et al. (11), the success of the laminoforaminotomy relies on the ability of the nerve root to move posteriorly away from the ventral compressive osteophyte.

Other risks include spinal cord and nerve root injury (6). Williams (32) described up to 10% of patients undergoing laminoforaminotomy experiencing transient symptoms of worsening radiculopathy and/or postsurgical paresthesias. This may be related to anatomic variation in which the dorsal sensory and ventral motor root can be apparent in either a single dural sleeve or separate dural sleeves. A surgeon confusing a tethered ventral sleeve with disc pathology may explain this postoperative complication (6). To decrease the risk of instability after laminoforaminotomy, some suggest a semicircular laminotomy at the caudal aspect of the lamina above as adequate bone removal to access lateral discs (32). Another potential cause for nerve root injury arises in the case of soft disc herniations, in which the root must frequently be manipulated to address the pathology; this manipulation is not necessary with the ventral approach.

The risk of air embolus and cardiovascular compromise is reported if patients are placed in the seated position (6, 30). Additionally, the incidence of wound infection (1–1.5%) seems to be somewhat higher with dorsal than with ventral procedures (30). Another reported risk of posterior laminoforaminotomy is surgical error of either wrong-level surgery, wrong-sided surgery, or missed pathology (6). This risk of surgical error would hold true for ventral procedures as well.

The list of potential complications with dorsal cervical procedures, in particular laminoforaminotomy, may seem daunting. However, the risks of ventral cervical surgical complications include: inadequate decompression, recurrent laryngeal nerve injury, thoracic duct injury, chylothorax, esophageal injury (which can frequently be determined intraoperatively by dilute indigo carmine solution), laceration of vital structures with retractors and/or burrs, graft donor-site morbidity, graft dislodgement, sympathetic chain injury and Horner’s syndrome, screw penetration of the dorsal cortex and spinal cord injury, plate failure, implant migration, pseudarthrosis, adjacent segment disease, and injury to the thyroid, thymus, carotid contents, ansa cervicalis, or larynx (1, 6, 18). For those who promote ventral cervical discectomy without fusion, the risks include the aforementioned exposure risks, as well as anterior column collapse, kyphotic deformity, and instability (5, 8).

Technically, posterior laminoforaminotomy requires that the surgeon be cognizant of a number of factors. Evidence of preoperative instability must be clearly excluded by evaluation of plain cervical films with flexion and extension (12). The offending pathology must be clearly identified, with imaging studies including computed tomography, computed tomographic myelography, and/or magnetic resonance imaging. Various exposure techniques, including an oblique muscle-splitting incision and minimally invasive procedures, have been described to decrease postoperative neck pain. The position of the patient during the procedure is also a debated topic. Some surgeons have used the lateral decubitus position or “park bench” position (21). More commonly, however, either the prone reverse-Trendelenburg (Concorde) position or the seated position is used (6). The seated position decreases venous engorgement, providing a drier surgical field, but adds an increased risk of air embolism and cardiovascular complications. Air emboli can be managed by central cardiac catheter placement with an atrial catheter to remove any air if an embolism occurs (12). If emboli are detected venous bleeding is coagulated and the wound packed as the patient is placed in the left lateral decubitus position, theoretically, to trap air in the right atrium (6). The risk of air embolism makes many surgeons strongly resistant to the seated position (23). However, in a review of 736 patients, no air embolisms were reported (35). In Zeidman and Ducker’s (35) study of 172 patients, all in the seated position, there were four air embolisms without any clinical sequelae (12).

Recent advances in laminoforaminotomy include minimally invasive techniques. Tomaras et al. (31) described 200 outpatient laminoforaminotomies, 92.8% with excellent or good results. Laminoforaminotomy clearly favors minimally inva-
Physiologic technologies (33). Adamson (1) described 100 microendoscopic cervical laminoforaminotomies with limited exposure and improved return to full activity. The author thought that this was attributed to leaving the muscles attached to the spinous process and avoiding subperiosteal muscular stripping. Fessler (personal communication), Pimenta (25) and Pimenta et al. (26) described a microendoscopic foraminotomy with the MetRx system (Medtronic Sofamor Danek, Memphis, TN). This system uses a specialized endoscopic tool for a tubular, muscle-preserving approach to the posterior spine. Theoretically, the technique minimizes patient pain and provides a shorter recovery time. The main disadvantage is that the surgeon is limited not only by the field of view, but also by the two-dimensional view that the tubular system affords. Regardless of the technique or technology applied, we know that surgical timing significantly influences patient outcome. Long-duration symptoms and neurological deficits are poor prognostic indicators for improvement with surgical decompression (34). In general, the best candidates for laminoforaminotomy are younger patients with soft lateral disc herniations, smokers who are at increased risk of nonunion with discectomy and fusion, and patients who, for technical reasons, are not candidates for the anterior procedure, either because of body habitus (i.e., short neck) or the location of the pathology below the T1 level or above the C3 level (1, 30).

LAMINOFORAMINOTOMY TECHNIQUES

Indications

The ideal indication for a laminoforaminotomy procedure, rather than a ventral cervical discectomy and fusion, is a patient who has reproducible symptoms with a Spurling’s maneuver that improves with forward flexion of the neck. In this type of patient, the nerve is being pinched between the uncinate and the facet, and resecting the dorsal aspect of the neuroforamen will yield a highly successful outcome. However, if the patient still has symptoms with maximum flexion of the neck where the neuroforamen widens, the patient is less likely to respond to a foraminotomy, and our preference is to proceed ventrally. A laminoforaminotomy is an excellent technique to resect lateral disc herniations that impinge on the nerve root, either at its axilla or further laterally. Although one can treat disc herniations even up to the lateral one-third of the disc space, we usually prefer to treat these lateral one-third herniations anteriorly. We also prefer to use a ventral approach for patients who have constant and significant numbness in their fingers. Even with a complete removal of a disc herniation, these patients may take several weeks or, sometimes, even months to recover. If laminoforaminotomy and discectomy are performed and the patient does not improve, the question of whether the patient is not improving because of permanent injury to the nerve root at the time of the discectomy or because of an inadequate foraminotomy and discectomy must be raised. If we operate ventrally, we remove all of the disc material and visualize the nerve root past the uncinate process. In this way, we can be positive that there is no further disc fragment and no uncovertebral impingement on the nerve root. We can then be more confident that the persistent numbness is caused by the original injury rather than by an inadequate decompression. In addition, stabilizing the nerve root with a fusion may provide a more favorable environment for the nerve to recover.

We usually perform laminoforaminotomies as outpatient procedures and allow the patient to return to their normal duties as quickly as they can tolerate. A soft cervical collar for comfort is used, and it is recommended that the patient removes the collar as quickly as possible and resumes normal activities, including exercise and work.

Patient Positioning

It is absolutely essential to position the patient properly to reduce blood loss and improve visualization (Fig. 1). We opt to place the patient prone on an open Jackson frame (OSI; Orthopedic Systems, Inc., Union City, CA). We prefer to place the patient in Gardner-Wells tong traction and then suspend the head with bivector traction. If only a foraminotomy is being performed, the neck is kept in a flexed position to open the facet joints. If a fusion is to be performed after the foraminotomy, we first keep the neck in a flexed position and then, before the fusion, we extend the neck by switching the weights. The head of the bed is placed in the top rung of the table, and the foot of the table is placed in the bottom rung. The patient is placed in a modified knee-chest position, with the legs supported in a sling and the thorax and abdomen on bolsters that allow the abdomen to hang free (Concorde position). A strap is placed behind the buttocks to keep the patient in place. The entire table is then tilted in a reverse Trendelenburg position to distribute the blood into the abdomen and the legs. A body-warming blanket is placed underneath the table on the ventral side of the patient, where the warm air can rise and heat the front of the patient.

Technique for a Foraminotomy

For a single level unilateral foraminotomy, a 3- to 4-cm incision can be made just off of the midline. A subperiosteal dissection is made to expose the lamina and the medial portion of the facet. The facet capsule should be preserved. To perform an adequate foraminotomy for foraminal stenosis, typically, approximately one-half of the facet joint needs to be removed (Fig. 2).

To perform an adequate foraminotomy, one must first have an understanding of the compressive etiology and the boundaries of the foramen (Fig. 3). Causes of foraminal stenosis include uncinate hypertrophy that results in foraminal compression from the ventral aspect, intraforaminal disc herniation, and, more rarely, facet hypertrophy caused by arthrosis. The ventral medial border of the foramen is bounded by the uncovertebral joint. The dorsal margin is the superior articular facet of the caudal vertebral segment. Rostrally and caudally, the neuroforaminal borders are the pedicles.
Compression of the nerve in a patient with spondylosis usually occurs between a hypertrophied uncovertebral joint and the superior articular facet in the anterior-posterior direction. It is rare that such extensive loss of disc height would occur and the pedicles cause compression in a cranial-caudal direction. Therefore, if one approaches a decompression of the foramen for uncinate hypertrophy posteriorly, one needs to decompress the neuroforamen in an anterior-posterior direction. This is most readily accomplished by resecting the medial portion of the superior articular facet. Although the uncovertebral joint can be drilled down from a dorsal aspect, this requires a fair degree of retraction of the nerve root and exposes the root to potential injury from the burr itself. As one proceeds more ventrally along the neuroforamen, there is also the risk of injuring the vertebral artery. For this reason, we prefer to simply resect the superior articular facet alone. To expose the superior articular facet, however, one must first remove the overhanging inferior articular facet of the cranial segment. This can be minimized by flexing the neck such that more of the underlying superior articular facet is exposed without resecting the inferior articular facet.

When Is a Laminoforaminotomy Adequate?

The principle of dorsal decompression is to resect the dorsal border of the neuroforamen such that the nerve root can displace dorsally in the neuroforamen and away from the uncinate spur. We think that a simple keyhole foraminotomy that resects the medial half of the facet can occasionally be inadequate in a patient with a large anterior spur. For this reason, we prefer to resect a small portion of the medial lamina of the rostral and caudal segments so that the root can displace dorsally all the way from its origin in the spinal cord to the lateral margin of the neuroforamen. After a simple keyhole foraminotomy, there can often be some curling of the dorsal root against the lateral aspect of the lamina. If a small portion of the lamina is also resected, such curling does not occur. A more common question is, “How far laterally should one decompress?” The decompression is complete when the dorsal roof of the lateral margin of the neuroforamen is decompressed. Therefore, if one can place a small probe lateral to the pedicle, adequate lateral decompression has been achieved. In addition, there should be no dorsal overhang. One should be able to palpate the rostral and caudal borders of the caudal pedicle and not feel any overhanging superior articular facet (Figs. 3 and 4). The root can then migrate dorsally without impediment. Resection of additional facets beyond the lateral margin of the pedicle is not only unnecessary but also contraindicated because it leads to greater instability (Fig. 5).

Foraminotomy for a Disc Herniation

The exposure is identical to that described above for cervical spondylosis and uncinate hypertrophy (Fig. 6). In this case, however, the nerve root must be manipulated to expose the
herniated disc fragment that is ventral to the nerve root. The easiest way to perform this is to drill down part of the caudal pedicle. Only the rostral 2 to 3 mm of the pedicle needs to be drilled flush with the vertebral body. One can then retract the nerve root caudally without injuring the nerve root. In addition, it is easier to dorsally retract the nerve root and extricate the disc fragment. The authors use small micro instruments, including a 1-mm Kerrison punch and micro probes. Two-millimeter and 3-mm right-angle ball-tipped probes are ideal to fish out the disc herniation and also to retract the nerve root. Before concluding the procedure, one should check both above and below the nerve root to make sure that all of the disc fragments have been adequately removed. The area is flushed with saline and we use a hemostatic agent, such as FloSeal (Baxter Healthcare Corp., Deerfield, IL) or Gelfoam (Pharmacia-Upjohn, Kalamazoo, MI). The wound is then closed in multiple layers. Depending on the amount of bleeding intraoperatively, a drain can be used. However, this is usually not necessary.

Retraction

When we make a midline incision, we most commonly use a microretractor, such as the McCulloch (V. Mueller, St. Louis, MO). An alternative is to use tubular retractors, such as the MetRx system. The tubular system requires a muscle-splitting
approach and is ideal for a unilateral foraminotomy at one or two levels. Hemostasis is achieved by placing in a thrombostatic agent, such as FloSeal. We then prefer to use microscope visualization to perform the decompression in the exact same manner as with a midline incision approach.

Mini-open Foraminotomy

For microendoscopic foraminotomies, we prefer to use the MetRx system. Exposure of the dorsal cervical spine can also be provided by using an illuminated three-bladed speculum, such as the Maxcess (NuVasive, San Diego, CA) (Fig. 7). The patient can be placed in two possible positions. In young and healthy patients, the best position is the semi-seated position, with the head fixed by a Mayfield head-holder (Integra Life Science, Plainsboro, NJ). This position minimizes blood loss, however, again, attention must be paid to possible air embolism. For older patients, we prefer to use the prone position, as previously described. A 2- to 3-cm incision approximately 1-in lateral to the spinous processes is made with fluoroscopic guidance. Dissection and opening of the muscle fascia is completed in the standard fashion. Three progressive tube dilators are directed obliquely through the muscle fibers to the facet joint using fluoroscopy. The triangular recess formed by the two lamina needs to be well identified after coagulation of the remaining muscle attachments. Once this exposure is complete, the laminoforaminotomy is performed as previously described.

Laminaplasty for Multilevel Spondylosis and Central and Foraminal Stenosis with Radiculopathy

We occasionally perform multilevel laminaplasties for relatively young patients who have multilevel central and foraminal stenosis with radicular symptomatology. The indications for the procedure are similar to those patients who undergo laminaplasties for myelopathy, in that the patients cannot have a kyphotic alignment or an unstable segment. In patients who have little to no axial neck pain, we prefer this approach to fusing three or more levels. Laminaplasties are covered in a different section of this issue, and a detailed account of the procedure is not covered within this article. We think that it is necessary to perform adequate foraminotomies at all levels that show radiographic stenosis. We perform an open-door laminaplasty and stabilize the opening with a laminoplasty plate. Although these plates are not approved for use by the Food and Drug Administration, we find that they are an effective means of keeping the laminaplasty open and provide immediate stability by restoration of the dorsal ring of the spinal canal.

CONCLUSION

Although anterior cervical discectomy and fusion are preferred by many surgeons, posterior procedures can be safer and more effective in the operative treatment of cervical radiculopathy. Dorsal decompression is an excellent option in patients with adequate alignment and who do not have evidence of instability. Not only does this preserve motion, but it also typically costs less than anterior procedures, avoids the potential complications related to grafts and implants, and spares patients from wearing a brace. Laminoforaminotomies offer more direct visualization of the nerve root and can be ideal for posterolateral disc herniations. Minimally invasive techniques can also minimize the postoperative pain typically associated with posterior procedures. Posterior techniques should remain an option in any cervical spine surgeon’s approach to cervical radiculopathy.

REFERENCES

The onset of cervical myelopathy is typically insidious (2, 3, 7). Its etiology is usually age-related degenerative spondylosis, hence the term cervical spondylotic myelopathy (CSM). Calcification of the posterior longitudinal ligament, progressive cervical spinal deformity, cervical disc herniation, trauma, spontaneous intraspinal hemorrhage, and infectious abscess represent less common causes of cervical myelopathy and may manifest clinically in a subacute or even an acute manner.

Once clinically apparent, CSM typically progresses, albeit at a variable rate, during an unpredictable time course (2, 3, 7). In some patients, symptoms and signs progress in a gradual step-wise fashion. In other patients, symptoms and signs, once present, may stabilize without obvious progression for years, only to “reactivate” and worsen months to years later (5, 7). Patients with CSM typically present in their sixth or seventh decades of life (1, 3, 5, 14, 20). Several series of patients with CSM have been described in the literature (1, 3, 5, 14, 20). Reported ages of affected patients range from the 20th to the 90th decades of life, with the median age in the mid-50s. Underlying congenital spinal stenosis, congenital cervical spinal anomalies, cervical spinal deformity, and seemingly “incidental” cervical trauma may result in an earlier-than-expected onset of CSM.

**PATHOPHYSIOLOGY**

CSM occurs because of spinal canal compromise and spinal cord compression (1, 8, 11, 20). Age-related disc degeneration results in collapse at the interspace, degenerative endplate changes, osteophyte formation, arthritis, and hypertrophy of the zygapophyseal and uncovertebral joints, thickening of the ligamentum flavum, and overlap and hypertrophy of the cervical facet complexes. The net effect of these changes is narrowing of the anteroposterior diameter of the cervical spinal canal and resultant spinal cord compression with flattening (1, 11, 12, 13, 17).

These degenerative cervical spondylotic changes tend to occur over multiple cervical spinal levels, centered at the C5–C6 level. Because of this combined ventral/dorsal, often concentric spondylotic pathology, CSM may result in spinal canal compromise and stenosis well beyond traditional “interspace” levels, particularly among patients with narrow spinal canal anteroposterior diameters. Other patients will present with disc compression and ventral osteophytes primarily localized to the endplates and interspaces. It is important to note this distinction on the imaging studies of patients with CSM. Degenerative cervical spondylotic stenosis may also be accompanied by progressive cervical deformity (typically kyphosis), and/or, less commonly, spondylolisthesis. The curvature and alignment of the cervical spine are important additional anatomic features to weigh when considering potential treatment options for patients with CSM.

Early on, CSM was thought to be primarily caused by spinal cord compression and mass...
Cervical Myelopathy Treatment via Anterior Cervical Approach

The interview and the examination make the diagnosis. The imaging (diagnostic) studies confirm it.

—James Garber Galbraith, III, M.D.

CSM is frequently underdiagnosed, and its findings may be subtle. A high index of suspicion, a keen interview, and a focused examination are essential to its discovery (2, 7, 8, 11, 20). During the interview, patients are questioned regarding numbness of the fingers, hands, and upper extremities. Careful questioning will discern bilateral, nondermatomal complaints, likely to be of cord origin. Dexterity of the hands, abilities with buttons and jewelry, or a change in handwriting should be explored. Stiffness of the extremities, clumsiness, and/or stumbling when ambulating, and bladder complaints, particularly urinary frequency, should be questioned. Occasionally patients will report odd dysesthesias or electrical-like sensations in their arms or torso with various neck positions, usually extension, or when working with their arms at or above head level. Patients should be questioned regarding weakness, particularly in their hands, and regarding muscle wasting, typically in their hand musculature.

The cervical spinal examination should focus on neck mobility, range of motion, and the potential of cervical spinal instability. The neurological examination may reveal diffuse sensory loss, particularly diminution in temperature and proprioceptive senses. Close observation may reveal weak hand grips with or without atrophy of the intrinsic musculature of the hands, particularly the first dorsal interossei. A careful reflex examination may reveal increased tone and reflexes and may reveal pathological findings, such as Hoffman’s sign in the upper extremities and clonus or Babinski’s responses in the lower extremities. The patient’s gait should be scrutinized for rigidity and spasticity, and the ability to stop, start, and turn easily without clumsiness should be examined. Toe walking, heel walking, and tandem gait should be tested.

The imaging study of choice for these patients is a good quality magnetic resonance imaging (MRI) study, preferably on a 1.5-T unit with both sagittal and axial views. MRI will define cervical spinal alignment and curvature and will document spinal canal stenosis and cord compression (9, 20). MRI scans will depict the extent of canal compromise and cord compression and will delineate the causative pathology and its primary compressive influence (ventral, dorsal, or circumferential). MRI scans will also document signal change within the cord substance, the presence of a potential syrinx, and will assist in distinguishing degenerative cervical spondylosis from other pathological processes (tumor, hemorrhage, infection, or renal spondyloarthropathy) that may cause similar symptoms and exam findings.

Anteroposterior and lateral cervical spine x-rays may be useful to define the patient’s cervical spinal curvature and vertebral column alignment. Lateral flexion and extension views may document abnormal translation of one cervical vertebra on another. Thin section computed tomographic studies may be useful in the imaging of bony anatomy not well defined on x-ray and MRI studies.

Clinical Decision Making

We base the decision to offer surgery to patients with CSM on several key factors. Patients must have appropriate clinical symptoms and signs and must have correlative imaging studies that confirm the presence of cervical spinal cord compression. They must be acceptable candidates for surgery from medical, surgical, and anesthetic comorbidity standpoints. It must be concluded that the patient’s cervical cord compression is the
Considerations include realignment of the cervical spine, stabilization of cervical spinal instability, and/or correction of cervical spinal deformity. The operative procedure of choice, rarely a combination of operative procedures, depends on individual patient pathology and the presence or absence of cervical instability and/or deformity. The operative procedure selected must make physiological and anatomic sense and must 1) decompress the entirety of the compromised spinal cord, 2) maintain physiological motion and biomechanical support as much as possible, 3) correct an existing spinal instability and/or cervical deformity, and 4) accomplish Steps 1 through 3 with the least morbidity to the patient.

In general, we prefer the anterior cervical surgical approach in the treatment of CSM patients if their compressive pathology is primarily ventral, primarily localized to an interspace or interspaces, and/or is associated with cervical instability, spondylolisthesis, or a kyphotic deformity best treated with anterior cord decompression and anterior reconstruction, internal fixation, and fusion.

In our opinion, primarily ventral pathology causing cord compression, particularly if it is focal rather than contiguous over multiple levels, is best treated via an anterior approach. We will proceed anteriorly for patients with deforming ventral cord pathology as distinguished from a congenitally narrow canal; concentric cord compression or broad-based ventral compression is treated by an osteophytic bar. We favor interspace decompression and resection of the disc and offending ventral osteophytes using interbody fusion and internal fixation at one, two, or three interspaces (and, rarely, four levels), in patients without a narrow spinal canal, who have ventral cord compression limited to one, two, three, or four interspaces (Figs. 4–7). In circumstances of kyphosis and angular interspace collapse with ventral cord compression as the cause of the neurological findings, as distinguished from cerebral ischemia, multiple sclerosis, amyotrophic lateral sclerosis, or other neurodegenerative disorders (2). Typically, patients must have failed medical therapy and have demonstrated progression of their symptoms and signs over time (Figs. 1–3).

Although there is little that “medical therapy” can offer patients with advanced CSM other than pain management, some patients with CSM symptoms and only modest physical findings may stabilize for extended periods of time (7, 8). Anti-inflammatory agents can alleviate pain complaints in many of these patients, and physical therapy can improve range of motion, muscle strength, and dexterity. Cervical traction may improve axial neck pain and radicular complaints associated with CSM. We offer serial follow-up to CSM patients with modest complaints and physical findings that seem to be clinically stable unless they have associated cervical spinal instability or MRI evidence of signal change within the spinal cord substance. Patients with these latter features, those with advanced neurological findings attributable to cervical spinal disease, and patients with progression of their symptoms and signs of CSM over time are offered operative spinal cord decompression.

The primary goal of the surgical management of patients with CSM is decompression of the spinal cord and elimination of the anteroposterior flattening and distortion of the cervical cord. Secondary surgical considerations include realignment of the cervical spine, stabilization of cervical spinal instability, and/or correction of cervical spinal deformity. The operative procedure of choice, rarely a combination of operative procedures, depends on individual patient pathology and the presence or absence of cervical instability and/or deformity. The operative procedure selected must make physiological and anatomic sense and must 1) decompress the entirety of the compromised spinal cord, 2) maintain physiological motion and biomechanical support as much as possible, 3) correct an existing spinal instability and/or cervical deformity, and 4) accomplish Steps 1 through 3 with the least morbidity to the patient.

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Patients are positioned supine on the operating room table. We do not place a bolster under the shoulders. We tape the chin to the head of the bed, allowing us to get the chin up in a position of modest extension. The head is slightly rotated, approximately 10 degrees off the midline, toward the left, exposing the right neck. Folded towels are then placed under the neck, packed under as tightly as possible, to help provide dorsal sinus process and/or musculature pressure to improve on or restore cervical lordosis. The towels also provide resistance, albeit modest, during the operative procedure, particularly if one is grafting within an interspace or during internal fixation, providing some counter to the downward pressure on the ventral aspects of the vertebral column, which occurs with screw insertion. This same strategy is used for patients who have been placed in a halo immobilization device after craniocevical traction to help reduce their deformity. Once positioned, we remove the anterior aspect of the halo immobilization device, tape the chin up toward the halo ring, and, again, pack towels under the dorsal aspect of the spine between the cushions on the operating room table and the patient’s neck. The patient’s arms are draped out to each side, respectively. We pull down on the shoulders and pull the arms in a caudal direction, toward the caudal end of the bed, using Kirlex (Tyco Healthcare/The Kendall Company, Mansfield, MN) around their padded wrists as needed to attempt to provide better fluoroscopic visualization of the more-caudal cervical interspaces to be treated during surgery. We use great care to avoid injury to the forearms, peripheral nerves, vasculature, wrists, and hands, by wrapping the hands and wrists in foam before placement of the Kirlex traction devices.

For one- or two-interspace procedures, a curvilinear skin incision 2 to 3 cm in length is made in a skin fold in the right neck, centered over the anterior border of the sternocleidomastoid muscle, at the level of intended surgery, as confirmed by intraoperative fluoroscopy. Three- or four-level interspace procedures require a modified sigmoid-shaped vertical incision along the anterior border of the sternocleidomastoid muscle. Dissection is performed down through the subcutaneous tissues and the platysma with unipolar cautery. Blunt dissection is used to dissect down to and expose the ventral aspects of the vertebral bodies. Intraoperative fluoroscopy is used to confirm the level. A handheld esophageal retractor assists with retracting the trachea and esophagus medially. The neurovascular bundles, the superior laryngeal nerve, and/or the recurrent laryngeal nerve, with associated vasculature, are preserved. Unipolar cautery is used to dissect the medial aspects of the longus colli musculature off of the ventral surfaces of the vertebral bodies. Dissection is performed high up the ventral surface of the superior vertebral level and low down the ventral surface of the inferior vertebral level, being careful to avoid dissection of the adjacent superiormost (or inferiormost) interspace. We are careful to avoid compromise of Sharpey’s fibers and the interspace immediately cephalad and immediately caudal to the intended levels of treatment.

There are two key times during the operative procedure that we stop to orient ourselves to the anatomic midline of the vertebral bodies and the lateral margins of the dissection. The goal, of course, is to know where the midline is and to work laterally and bilaterally within the spinal canal to fully decompress the spinal cord and/or exiting nerve roots at each level.

**OPERATIVE TECHNIQUE**

Patients are positioned supine on the operating room table. We do not place a bolster under the shoulders. We tape the chin to the head of the bed, allowing us to get the chin up in a position of modest extension. The head is slightly rotated, approximately 10 degrees off the midline, toward the left, exposing the right neck. Folded towels are then placed under the neck, packed under as tightly as possible, to help provide dorsal sinus process and/or musculature pressure to improve on or restore cervical lordosis. The towels also provide resistance, albeit modest, during the operative procedure, particularly if one is grafting within an interspace or during internal fixation, providing some counter to the downward pressure on the ventral aspects of the vertebral column, which occurs with screw insertion. This same strategy is used for patients who have been placed in a halo immobilization device after craniocevical traction to help reduce their deformity. Once positioned, we remove the anterior aspect of the halo immobilization device, tape the chin up toward the halo ring, and, again, pack towels under the dorsal aspect of the spine between the cushions on the operating room table and the patient’s neck. The patient’s arms are draped out to each side, respectively. We pull down on the shoulders and pull the arms in a caudal direction, toward the caudal end of the bed, using Kirlex (Tyco Healthcare/The Kendall Company, Mansfield, MN) around their padded wrists as needed to attempt to provide better fluoroscopic visualization of the more-caudal cervical interspaces to be treated during surgery. We use great care to avoid injury to the forearms, peripheral nerves, vasculature, wrists, and hands, by wrapping the hands and wrists in foam before placement of the Kirlex traction devices.

For one- or two-interspace procedures, a curvilinear skin incision 2 to 3 cm in length is made in a skin fold in the right neck, centered over the anterior border of the sternocleidomastoid muscle, at the level of intended surgery, as confirmed by intraoperative fluoroscopy. Three- or four-level interspace procedures require a modified sigmoid-shaped vertical incision along the anterior border of the sternocleidomastoid muscle. Dissection is performed down through the subcutaneous tissues and the platysma with unipolar cautery. Blunt dissection is used to dissect down to and expose the ventral aspects of the vertebral bodies. Intraoperative fluoroscopy is used to confirm the level. A handheld esophageal retractor assists with retracting the trachea and esophagus medially. The neurovascular bundles, the superior laryngeal nerve, and/or the recurrent laryngeal nerve, with associated vasculature, are preserved. Unipolar cautery is used to dissect the medial aspects of the longus colli musculature off of the ventral surfaces of the vertebral bodies. Dissection is performed high up the ventral surface of the superior vertebral level and low down the ventral surface of the inferior vertebral level, being careful to avoid dissection of the adjacent superiormost (or inferiormost) interspace. We are careful to avoid compromise of Sharpey’s fibers and the interspace immediately cephalad and immediately caudal to the intended levels of treatment.

There are two key times during the operative procedure that we stop to orient ourselves to the anatomic midline of the vertebral bodies and the lateral margins of the dissection. The goal, of course, is to know where the midline is and to work laterally and bilaterally within the spinal canal to fully decompress the spinal cord and/or exiting nerve roots at each level.
underlying ligament and thecal sac with the use of microsurgery. While elevating the ligament and thecal sac, we must be careful not to injure the lateral vertebral bodies. These are, nonetheless, dissected down to remove approximately 1 mm of the top of the superior endplate of the level to be treated, then place three clicks of distraction on the vertebra below the interspace to be treated. We incise the annulus at the vertebral body to be preserved and the inferior, caudal-most interspace levels, providing appropriate and adequate decompression of the ventral thecal sac and underlying cord and roots, followed by bony reconstruction to provide stability and restoration of a more normal lordotic curvature, hopefully restoring sagittal balance to the cervical spine.

Oftentimes, particularly on multilevel or reoperative procedures, we will identify a prespinal neurovascular bundle in the field traversing from lateral to medial. It may include the superior laryngeal nerve or the recurrent laryngeal nerve. We will preserve and work rostral and caudal to these structures, carefully retracting them as necessary to avoid injury and to complete the interspace work described in the previous paragraphs. An internal fixation plate is then measured, contoured as necessary, and applied. For more than two interspace levels, we prefer to use a translational plate system. Intraoperative fluoroscopy is used to be certain that the plate is appropriate in length. The early dissection and exposure of the entirety of the ventral aspect of the vertebral bodies being treated, as described earlier, allows us to place the plate more accurately in the midline, helping to avoid a plate that might be angled to one side or the other. Long-segment internal fixation, in which neurovascular bundles have been preserved in the field of dissection, is accomplished by sliding the plate under the neurovascular bundles and then working above and below the neurovascular bundle, as appropriate, to secure segmental screw fixation. We always place a drain over the ventral aspects of the plate in the deep tissues before closing. The drain is typically removed on the first postoperative day. If the patient has been placed in a halo for craniocervical traction and distraction before the surgical procedure and has been operated on in the halo, we replace the anterior portion of the halo vest and secure it before moving the patient from the operating table to the hospital bed. We maintain patients in the halo immobilization device from several days to 6 to 8 weeks postoperatively, depending on their presenting pathology and our ability to provide spinal realignment, correction, and internal fixation and fusion. Patients who do not require halo vest placement for distraction, realignment, and immobilization before surgery and who have had more than two interspace levels treated are managed in a rigid cervical col-
far enough to the patient’s left and to the patient’s right, using the techniques and landmarks described in the preceding paragraphs. We use direct visualization and blunt dissection of the pedicles bilaterally to be certain. We measure the length required of the interposition strut graft and cut an allograft whole fibular shaft to the appropriate length. We typically sawtooth the upper and lower ends of the graft to help accomplish purchase into the inferior portion of the superior ventral level and the superior portion of the inferior ventral level. We usually leave a very thin lip of cortical bone anteriorly on the graft, which allows us to hook it under the anterior-most portion of the ventral-most portion of the vertebral body to which the graft is being interposed, both superiorly and inferiorly. The distraction device allows us to distract the remaining vertebral levels and allows us to tamp this graft into an appropriate position to eliminate the preexistent kyphotic deformity and to restore relative lordosis. An internal fixation plate, typically a translational plate, is then measured and secured in a similar fashion as described in the preceding paragraphs for the multiple interspace dissection, fusion procedure, and internal fixation.

CONCLUSION

In summary, cervical myelopathy tends to be a process resulting in progressive spinal cord compression and ischemia with resultant, often permanent, neurological injury. In appropriately selected patients, spinal cord decompression procedures can arrest the progressive process and optimize the patient’s opportunity for neurological improvement and recovery. The choice of the operative procedure with the best chance to benefit an individual patient depends on multiple features of the pathology responsible for the myelopathy, including the primary direction of cord compression; the presence of focal disease or diffuse, multisegment, or concentric cord compression; and the presence or absence of associated cervical spinal instability and/or deformity (Figs. 8–10). We explain our thought processes on each of these difficult and often confounding issues. We favor the anterior approach to cervical cord compression and resultant myelopathy, particularly if the cord compression is primarily ventral, is localized to an interspace or three (rarely four) interspaces and/or is associated with cervical spinal instability or a kyphotic deformity requiring anterior cervical spinal realignment, reconstruction, internal fixation, and fusion.
REFERENCES

DORSAL SURGERY FOR MYELOPATHY AND MYELORADICULOPATHY

OBJECTIVE: To review the dorsal approaches to the cervical spine for myelopathy and myeloradiculopathy.

METHODS: The literature was reviewed in reference to dorsal approaches for cervical myelopathy and myeloradiculopathy.

RESULTS: There are a variety of surgical approaches in the management of cervical myelopathy and myeloradiculopathy. Deciding which is the best method for any individual requires the surgeon to be aware of the advantages of each technique, as well as the complications and limitations of each approach.

CONCLUSION: Laminectomy is the traditional technique used for multilevel cervical stenosis. The complications related to laminectomy, such as late neurological decline, kyphosis, instability, and postoperative radiculopathy, led to laminectomy with fusion. In Japan, dissatisfaction with both laminectomy and laminectomy with fusion led to the development of laminoplasty for dorsal treatment of multilevel cervical stenosis. This article highlights the salient features of preoperative evaluation in this patient population as it pertains to dorsal surgical approaches. Additionally, the techniques of laminectomy, laminectomy with fusion, and laminoplasty are compared, and the results are reviewed.

KEY WORDS: Fusion, Laminectomy, Laminoplasty, Myelopathy, Myeloradiculopathy, Surgery
the patient’s general condition, and the static and dynamic sagittal spine balance. Appropriate patient selection maximizes the chance of optimal neurological outcomes and minimizes complications.

**CLINICAL EVALUATION**

Clinical symptoms depend on the amount, location, and duration of neural compression. A thorough and complete history and physical is important to exclude other causes of spinal cord dysfunction, such as amyotrophic lateral sclerosis, cerebrovascular disease, demyelinating disease, intracranial lesions, hydrocephalus, syringomyelia, tabes dorsalis, myopathy, peripheral neuropathy, and metabolic or alcoholic encephalopathy (7). The physical examination should confirm signs of myelopathy, such as positive Hoffman’s reflex, inverted radial reflex (spontaneous flexion of the digits with the brachioradialis reflex) (82), Lhermitte’s sign, or clonus. The inverted radial reflex is virtually pathognomonic of cervical spondylotic myelopathy (CSM) (82), whereas Babinski’s sign is usually not present until late in the disease.

**RADIOGRAPHIC ANATOMY AND BIODYNAMICS**

In considering dorsal surgery for a patient with cervical disease, it is necessary to assess the extent of compression and the overall sagittal balance. Magnetic resonance imaging (MRI) is useful in determining the extent of compression and location of compression. Lateral x-rays with dynamic flexion extension studies determine the overall sagittal balance and any evidence of instability. Occasionally, 36-inch long cassette x-rays are obtained to assess the relationship of the cervical sagittal balance compared with the rest of the thoracic and lumbar spine. The Pavlov ratio (the anteroposterior diameter of the spinal canal divided by the anteroposterior diameter of the vertebral body at the same level) (Fig. 1) (74) is a guide to diagnosing congenital cervical canal stenosis. A ratio of 1.0 is normal; a ratio of less than 0.8 indicates a developmentally narrow canal.

In addition, the lateral x-ray shows the overall sagittal balance. Figure 2 illustrates the importance of sagittal balance in determining the optimal approach for treating cervical pathology. Cervical spinal cord decompression after laminectomy will not be obtained in patients with a straight or kyphotic cervical spine because the spinal cord will remain draped over the anterior pathology despite a satisfactory dorsal decompression. Preservation of lordosis is needed to allow adequate room for the spinal cord to migrate dorsally off any ventral compression. The cervical spine usually has 14.4 degree of lordosis from C2 to C7 (98). If the patient has a straight or kyphotic cervical spine, either a ventral approach or a laminectomy combined with dorsal segmental instrumentation used to reconstitute cervical lordosis is recommended because of the risk of postoperative kyphosis (especially in children). If translational or rotational instability is present (even in the lordotic cervical spine), dorsal instrumentation and arthrodesis at the time of cervical laminectomy should be considered.

The compression ratio (Fig. 3) is a useful measurement that can be made on axial MRI or postmyelographic computed tomographic scans (30). The compression ratio is measured by dividing the smallest anteroposterior dimension of the spinal cord (the sagittal diameter) by the broadest transverse diameter at the same level. A compression ratio of 0.4, especially after decompression, is associated with a poor recovery (30). Conversely, a compression ratio greater than 0.4, or an increase to greater than 40 mm² in the transverse area of the spinal cord, correlates with improved clinical recovery (55, 98). The measurement of the transverse area of the spinal cord at the affected level has been shown to be an accurate predictor of neurological recovery.

**FIGURE 1.** The Pavlov ratio is the anteroposterior diameter of the spinal canal (A) divided by the anteroposterior diameter of the vertebral body at the same level (B), as measured on a lateral x-ray. The ratio is normally approximately 1.0. A ratio of less than 0.8 is indicative of a developmentally narrow cervical spinal canal (from, Wiggins GC, Shaffrey CI. Laminectomy in the cervical spine: Indications, surgical techniques, and avoidance of complications. Contemp Neurosurg 21:1–10, 1999).

**FIGURE 2.** A, illustration showing normal lordotic curve of the cervical vertebral column that permits dorsal migration of the spinal cord after laminectomy. B, illustration showing cervical vertebral column with loss of normal lordotic curvature preventing reduction of anterior spinal cord compression by laminectomy (from, Wiggins GC, Shaffrey CI. Laminectomy in the cervical spine: Indications, surgical techniques, and avoidance of complications. Contemp Neurosurg 21:1–10, 1999).
NONOPERATIVE THERAPY

Although the natural history of CSM has been investigated, it is difficult to accurately predict the clinical course for a single patient. In 1956, Clarke and Robinson (15) published a review of 120 patients with CSM, in which they noted that spontaneous regression was clinically observed in two patients, but no patient ever returned to a normal state. They noted that 75% of their patients had recurring episodes and 66% had new symptoms of myelopathy and neurological deterioration. Five percent of their patients had rapid onset of symptoms followed by a long period of neurological plateau. Other studies have reported clinical improvement as high as 36 to 50% in patients managed with nonoperative treatments (11, 60). This must be compared with improvement rates of 68 to 95% and cure rates of 33% that have been reported in surgically treated patients (11). The prognosis for the recovery of spinal cord function postoperatively is variable and depends on the duration and severity of symptoms. The best results have been obtained for those patients who were decompressed within 6 months to 1 year after the onset of symptoms, those who had early, mild myelopathy (55, 61), and those in whom the transverse area of the spinal cord increased postoperatively to greater than 40 mm² (30, 55).

INDICATIONS FOR SURGICAL TREATMENT

The primary considerations in selecting patients for surgical therapy are the extent to which the patient’s symptoms affect the patient’s lifestyle and the surgeon’s confidence that the symptoms are secondary to cervical compression. Operative treatment is recommended for patients who have either substantial or progressive impairment of neurological function without sustained remissions (59). Failures of operative therapy may be secondary to poor patient selection or poor operation selection for the patient.

A variety of factors affect the timing of surgical intervention. Indications for more expedient intervention include progressive muscle weakness caused by a coexisting radiculopathy, significant gait instability, urinary frequency or incontinence, loss of coordination of the hands, difficulty in performing activities of daily living, or other significant signs of spinal cord compression causing myelopathy. Relative indications for operative intervention on a less urgent basis include pain, mild weakness, or sensory deficit that is not disabling, but causes unacceptable lifestyle changes because of the need for medication or restriction of activities.

Absolute contraindications to surgery are rare. There are few situations in which some type of appropriate decompressive surgery cannot be undertaken, especially if spinal cord compression is the issue. There are some relative contraindications, including advanced age with osteoporosis, severe pulmonary disease making it difficult to wean a patient from mechanical ventilation, and severe cardiac disease. Surgery can be performed in all but the most ill patients if careful attention is paid to minimizing the blood loss and operative time, maintaining the blood pressure to prevent cardiac and spinal cord ischemia, and, in some cases, keeping patients intubated until they no longer need large doses of narcotics for pain control. In general, multilevel posterior decompressions can be performed more rapidly and with less morbidity than multilevel anterior procedures. However, multilevel laminectomies without fusion are contraindicated in patients with preoperative cervical kyphosis because of the high rate of postlaminectomy kyphosis (51, 66). Similarly, patients with preoperative instability or anterior column incompetence should not undergo isolated posterior cervical decompression secondary to the risk of kyphosis. Some patients with focal, flexible kyphosis or limited instability can undergo laminectomy with the use of posterior instrumentation, such as lateral mass fixation, to help maintain or even create some lordosis.

LAMINECTOMY

Historically, laminectomy has been the procedure of choice for the treatment of multilevel cervical myelopathy. The patient is placed under general anesthesia, with fiberoptic intubation to avoid passive neck extension, and placed in three point fixation. The actual technique used for laminectomy probably does not affect patient outcome, but it is advisable to avoid placing any instrument under the midline lamina in an area of severe spinal cord compression because of the risk of worsening any neurological injury. A Kerrison punch with a low-profile footplate
can be used safely to begin the laminectomy, working along the lateral aspect of the lamina. We prefer to use a high-speed drill to create a gutter at the junction of the lamina and medial aspect of the lateral mass through the outer cortical bone and the cancellous bone, and to thin the inner cortical bone bilaterally (Fig. 4). Using a 1-mm Kerrison rongeur, transection of the lamina and ligamentum flavum is performed bilaterally in this lateral area in which the spinal cord is not compressed. Alternatively, the trough in the lamina can be drilled completely through the lamina and the ligament transected with scissors. Next, two Kocher clamps are used to lift the dorsal elements by the spinous processes en bloc, and the remaining attachments are transected (Fig. 5). Care is taken not to rock or tilt the lamina and create impingement on the cord.

DORSAL CERVICAL SEGMENTAL INSTRUMENTATION

In cases of flexible kyphosis, of focal instability, or in which potential instability is created by aggressive bony resection needed for decompression, posterior cervical segmental instrumentation can be considered. Cervical laminectomy with bilateral nerve root decompression including greater than 50% facet resection can lead to cervical instability and deformity (98). Proper instrumentatation at the time of an initial decompression in patients with abnormal segmental motion or absent lordosis markedly decreases their risk of developing postlaminectomy kyphosis, can help maintain sagittal alignment, and can help prevent future neurological decline or delayed pain.

The goal of any fixation system is to provide structural stability until a solid bone fusion forms. Several techniques of posterior cervical stabilization have been described. Many intraspinous or sublaminar wiring techniques have been developed, but most require the presence of intact posterior elements for fixation. These techniques are not useful in a patient after laminectomy. Cervical spine stabilization techniques available after laminectomy include interfacet wiring, wiring the bone onto the facet, and lateral mass fixation with plates or rods.

Interfacet wiring was described by Johnson (50) in the 1970s. The advantage of this technique is that it is effective in achieving stability against rotational and shear forces. The disadvantage is that it requires violation of an intact and unfused facet, which can lead to postoperative pain. Figures 6 and 7 demonstrate the technique. Facet fusion with wiring onto the bone graft can also be used to prevent postlaminectomy instability, as shown in Figure 8.

Both of these techniques have waned in popularity since lateral mass fixation was described (3, 14, 16, 63, 78, 89). Lateral mass fixation involves fixation of a small plate or rod to the lateral masses with screws. These devices provide superb flexural stability and resist torsion and extension significantly better than spinous process wiring (79). Lateral mass fixation with screws requires significantly less operative time than segmental facet fixation with wire. The enhanced stability can decrease or eliminate the need for postoperative orthosis. Disadvantages of lateral mass plates include cost and the potential injury to the exiting nerve root and vertebral artery.

Several screw placement techniques have been described. In an anatomic and biomechanical study, the Magerl technique
was observed to avoid the neurovascular structures better than the Roy-Camille technique (68). Because the Magerl technique parallels the facet, longer screws were able to be placed (20 mm versus 14 mm) and the instrumentation was able to accommodate a greater load before failing (68). A recent biomechanical evaluation performed in 21 adult cadavers compared the two screw placement techniques and did not find a statistical difference in pullout forces associated with the Roy-Camille and Magerl techniques (4). At C2, a pars screw can be placed and, at C7, a pedicle screw is placed because of the small lateral mass at this level. Newer top-loading cervical instrumentation systems permit precise placement of both lateral mass and pedicle screws in an ideal entry site and trajectory. Because the screws are not put through a plate, the screw holes can be drilled and tapped before performing a laminectomy or exposing the neural elements, thus, diminishing the risk of neural injury. The older lateral mass plates dictate screw entry sites on the basis of the spacing of the holes in the plate. Additionally, the top-loading systems are constrained and, therefore, allow for a more rigid fixation compared with non-constrained lateral mass plates. The top loading systems accommodate variations of the cervical anatomy without excessive rod contouring or compromising screw positioning.

Complications with lateral mass screw fixation include neural injury, vertebral artery injury, and hardware failure leading to pseudarthrosis. Heller et al. (40) performed the most complete analysis of complications after lateral mass fixation with screws and plates. They found a 0.69% incidence of nerve root injury per screw placed. There was a 1.1% incidence of screw loosening, which had no effect on their 98.6% fusion rate. Infections occurred in 1.3% of patients. They observed 3.8% adjacent segment degeneration with neck pain. No vertebral artery injuries or spinal cord injuries were reported in this series. In 1998, Wellman et al. (90) reviewed 43 patients who had 281 screws placed. The operations were mainly performed for posttraumatic instability and instability after multilevel laminectomy. After an average of 25 months of follow-up, they observed no screw-related complications (i.e., root injury or vertebral artery injury); however, they did document two superficial wound infections, one epidural hematoma and one patient requiring anterior surgery for progressive kyphosis. Both of these series demonstrate the overall safety of lateral mass screw fixation.

**LAMINOPLASTY**

Historically, laminectomy has been regarded as the standard posterior procedure for the treatment of multilevel cervical myelopathy. A prospective study comparing surgical management of CSM found superiority of laminoplasty and anterior decompression compared with laminectomy (41). A variety of laminoplasty techniques exist, but many are modifications of the “open-door” technique. This technique uses a high-speed burr to create a gutter at the junction of the lamina and medial aspect of the lateral mass (Fig. 9A). The cancellous bone on the “opening” side of the laminoplasty is removed, and the inner cortex is thinned. Using a 1- or 2-mm Kerrison rongeur, transection of the lamina and ligamentum flavum is performed. A “greenstick osteotomy” is performed by carefully displacing the spinous processes toward the closing osteotomy side and elevating the opening side of the lamina with a nerve hook (Fig. 9B). Allograft tricortical iliac crest or premanufactured bone spacers can be used for graft segments that are placed in the open-door portion of the laminoplasty, between the opened lamina and the lateral mass (Fig. 9C). Stabilization of each level is then performed using a 2.0-mm titanium miniplate or precontoured cervical plates (Figs. 9D and 10).

Figure 11 shows a preoperative sagittal T2-weighted MRI of a 58-year-old patient with progressive myelopathy. The Patient underwent laminoplasty. Figure 12 shows a postoperative T2-
weighted MRI scan, an axial computed tomographic scan, and a lateral x-ray of the same patient, demonstrating the miniplate reconstruction (Fig. 13).

COMPLICATIONS

A variety of complications associated with dorsal cervical approaches have been reported (10–13, 20, 21, 26, 34, 37, 62, 65, 66, 87, 92, 93, 95, 96). Paying strict attention to detail and operative technique can prevent most of the complications. The complications can be grouped into three categories: general, neurological, and biomechanical. The general category includes air embolism, infection (37), epidural hematoma (95), cerebellar hemorrhage (13), deep venous thrombosis, dural tear (21), and adhesive arachnoiditis (66). For most surgeons, avoidance of the sitting position for surgery is emphasized to lessen the operation preparation time, risk of hypotension, risk of positional and pressure-related peripheral nerve injury, and risk of air embolism (84). However, some surgeons think that the benefits of the sitting position can be realized while minimizing complications through careful preoperative evaluation to exclude patent foramen ovale and through close intraoperative monitoring with precordial Doppler (2, 76).

Neurological complications generally are caused by failure of technique or conceptual failure in planning. These failures often are predictable. Complications include injury to the spinal cord during the positioning or the operation (28, 95, 96), residual compression of the neural elements (11, 26, 34), delayed central spinal cord syndrome (62), and syringomyelia (65). Unacceptable results may occur because of inappropriate operation selection, intraoperative spinal cord or nerve root trauma, inappropriate width of decompression, or inappropriate length of decompression. The risks of inappropriate operation selection cannot be overemphasized. If the patient has preoperative kyphosis or focal anterior pathology, a dorsal approach is unlikely to help the patient improve.

The extent of decompression after cervical laminectomy may also contribute to the rate of C5 nerve root paresis. Yonenobu et al. (95) reviewed both ventral and dorsal cervical approaches. They noted 13 instances of C5 nerve root paresis or plegia without sensory involvement in a group of 384 patients. Paresis of the deltoid was the most common weakness. They thought that the weakness was caused either by tethering of the nerve root by fibrosis or by spondylotic changes at the foramen and root canal. Dorsal shift of the spinal cord could exert traction on the nerve root, which results in loss of motor function (85, 87, 95). The C5 nerve seems to be the most affected nerve because it is usually at the midpoint in a cervical laminectomy and would be at the point of maximum displacement of the cord. Dai et al. (20), in a review of 287 patients with cervical laminectomy, identified
37 patients (12.9%) with postoperative radiculopathy. Although C5 radiculopathy was the most common type, they thought that this could be predicted preoperatively with electrophysiological studies. Local trauma to the nerve root is another possible explanation for postoperative paresis. No matter what the etiology, postoperative C5 paresis usually resolves with time.

Postoperative spinal deformity is often an iatrogenic disease. In most instances, it can be prevented or predicted preoperatively and treated with stabilization at the time of decompression. To prevent postoperative instability, the surgeon must identify the factors (preoperative kyphosis, hypermobility, or need to perform greater than 50% bilateral facetectomies for neural decompression [98]) that place a patient at higher risk. Instability after cervical laminectomy usually falls into one of two types. Postoperative kyphosis is most common, but hyperlordosis and segmental instability also can occur.

Laminoplasty is one method of preventing postoperative instability after laminectomy. Some reports (47, 80) suggest that laminoplasty provides greater stability and greater range of motion compared with laminectomy, thus may be protective against postoperative instability (51). It is known that open-door laminoplasty reduces cervical spinal motion from 50 to 62% (44, 53, 54). Reduced motion may prevent the progression of cervical spondylotic disease. A prospective study by Herkowitz (41) compared anterior cervical decompression and fusion, laminoplasty, and laminectomy. Anterior cervical decompression and fusion and laminoplasty provided superior results, with no statistical difference between them, whereas laminoplasty did retain some cervical motion.

The mechanism for postoperative instability lies in the amount of facet resection, the age of the patient, and the length of laminectomy. A cervical kyphotic deformity refers to a reversal of five degrees or more of the natural cervical lordosis. During cervical laminectomy, the erector spinae muscles are partially denervated and weakened. The spinous processes, lamina, and ligamentum flavum are removed. The head's center of gravity usually is slightly anterior to the cervical spine. Weakening of the posterior tension band favors a kyphotic deformity. The risk of postoperative kyphotic deformity is greater in children because they have a relatively more flexible cervical spine. The epiphyses in the growing spine respond to asymmetric forces by causing a ventral wedging of the vertebral bodies. In addition, the orientation of the facet joints in the immature spine is more horizontal than the 45 degree angle in the mature spine, thus leading to less resistive force to flexion (91).

The exact incidence of postoperative kyphosis after cervical laminectomy is not known. It seems to occur more often in children than in adults (12, 13, 92, 93). Studies vary with respect to the type and significance of deformity. It seems that the overall incidence of adult postlaminectomy (without facetectomy) deformity is between 6 and 52% (13, 41, 46, 49, 66, 67, 96). Rarely (0–3%) do these patients develop symptoms directly related to their deformity. The extent of laminectomy seems to be one factor in determining postoperative kyphosis. Cusick et al. (19) looked at the biomechanics of cervical laminectomy without facetectomy and concluded that laminectomy alone induces significant increases in total cervical spine flexibility. If the C2 or C7 lamina or spinous processes are removed, the risk seems to be increased (13, 35, 46). Removal of the C2 lamina damages most of the musculus semispinalis cervicis and musculi suboccipitales, which are
attached to the spinous process of C2. Because they are damaged, the posterior tension band is weakened.

The width of the laminectomy and, more importantly, the width of the facetectomy are critical in determining the risk of postoperative kyphosis. Several studies in vitro have shown that the extent of facet resection can destabilize the cervical spine and can potentially contribute to accelerated degenerative changes (19, 97, 98). Using a multilevel cervical laminectomy model, Nowinski et al. (71) concluded that concurrent arthrodesis should be performed if bilateral facetectomy of more than 25% is performed in conjunction with a multilevel laminectomy. In a study of cervical spine mechanics, Panjabi et al. (73) demonstrated a progressively increasing degree of cervical instability to flexion loads with sequential removal of posterior supporting elements of the spine.

Zdeblick et al. (98) studied the effect of progressive facet resection after laminectomy in human specimens. Facetectomy of more than 50% caused a statistically significant loss of stability in flexion and torsion. In a similar study, Zdeblick et al. (97) found a significant loss of stability after 55% capsular resection. Recently, two finite element studies looked at the effect of graded facetectomies (57, 88). Their mathematical models suggest that the greatest change in stability occurred between 50 and 75% facet resection bilaterally. Functional unit studies demonstrate a 30% decrease in flexion-compression load with unilateral facetectomy (18). Relative mobility increased twice as much for bilateral facetectomies versus the same amount of unilateral facet resection (88). In fact, they concluded that unilateral cervical facet resection may not destabilize the spine. Thus, resection of greater than 50% of the bilateral facet complexes can lead to pronounced increases in angular rotation and intervertebral disc stresses.

Munechica (70) studied the relative contribution of the facets and the lamina to spinal stability in monkeys. Laminectomy alone did not lead to deformity, but a gibbus developed when laminectomy was combined with resection of one facet. In clinical studies, Epstein (23) has emphasized the importance of the facet joint contribution to stability and has advocated that not more than one-quarter to one-third of the facet is removed during foraminal decompression. In a comparison of treatment modalities for multilevel spondylotic radiculopathy, Herkowitz (41) noted a 25% incidence of postoperative kyphotic deformities within 2 years after cervical laminectomy with partial bilateral facetectomies. Therefore, the facetectomy should be limited to 25 to 50% or less to limit the risk of postoperative instability. Otherwise, stabilization must be considered.

**COMPARISONS/OUTCOMES**

Laminectomy has been regarded as the standard dorsal procedure for the treatment of multilevel cervical myelopathy outside of Japan. A review of the literature regarding the efficacy of cervical laminectomy indicates a 40 to 78% incidence of resolution of the myelopathy associated with cervical spondylosis or stenosis (1, 8, 10, 25, 28, 31, 32, 34, 49, 58, 72). Improvement rates of 68 to 95% and cure rates of 33% have been reported in some surgically treated patients (11, 22, 24). Although a few series suggest that prelaminectomy malalignment of the cervical column is not associated with subsequent clinical improvement, most reviews indicate that alteration of spinal curvature may be an important determinant of a poor clinical outcome (1, 5, 25, 66, 67). Therefore, attention to maintaining lordosis and anatomic alignment is indicated to improve patient outcomes. Some patients develop immediate or delayed impairment of neural function after laminectomy (17, 33). Brain et al. (9) found impairment of neural function in 19% of patients who had been treated with laminectomy. Crandall and Gregorius (17), after long-term follow-up, reported that 9 of 15 patients treated by laminectomy were worse postoperatively. Loss of neural function with cervical laminectomy can be attributed to errors in positioning, intraoperative manipulation of the spinal cord, failure to treat the causes of anterior compression, and loss of stability of the spine.

Many of the studies of laminectomy were performed in the late 1970s. Since then, attention has been placed on atraumatic cervical spine surgery. A recent long-term study by Kato et al. (52) of laminectomy for cervical myelopathy caused by ossification of the posterior longitudinal ligament revealed that the neurological recovery rate using the Japanese Orthopedic Association score was 44.2% after 1 year and 42.9% after 5 years. The surgical outcome was maintained at 5 years, but worsened between 5 and 10 years after surgery. Most patients’ neurological decline was secondary to falls. In the appropriately selected patient, neurological recovery is expected, with maintenance of this recovery during 5 years.

Laminectomy has fallen into disfavor because of the known sequelae. The frequency of instability and loss of normal cervical lordosis after laminectomy prompted some authors to advocate prophylactic fusion of decompressed cervical levels (27, 31, 56, 64). Advocates claim that the fusion adds only a small amount of time and morbidity risk, and that the fusion may also arrest the progression of spondylosis at the affected levels. The published experience includes a 12 to 40% incidence of complications with no cases of late neurological deterioration. In addition, each series reports fusion at each level in all patients. Houten and Cooper (45) retrospectively reviewed 38 patients after laminectomy with lateral mass plating for CSM. After a mean follow-up of 30 months, they documented a 97% increase in two neurological scales, with no change in spinal alignment. Heller et al. (39) reported a matched cohort retrospective analysis comparing laminectomy with fusion and laminoplasty. In this study, functional improvement was greater with laminoplasty, but the improvement was not statistically significant. Both groups showed a trend toward decreasing lordosis, although a majority of their complications (nonunion, instrumentation failure, and persistent autograft harvest site discomfort) were in the laminectomy with fusion group. These findings led to a recommendation for laminoplasty in this patient population.

In Japan, complications of laminectomy led to the development of laminoplasty. Proponents claim that the procedure
preserves motion relative to fusion techniques, reduces adjacent segment degeneration, and preserves the insertion points of the extensor muscles (42–44, 80, 86, 94). Laminoplasty is commonly performed for cervical stenosis secondary to spondylosis and ossification of the ligamentum flavum, with similar results (80). Yonenobu et al. (94) reported a comparison between laminoplasty and subtotal corpectomies. Their retrospective comparison demonstrated similar rates of functional recovery, but suggested that laminoplasty had fewer complications. In 1988, Herkowitz (41) compared anterior cervical fusion, laminectomy, and laminoplasty in the management of multilevel cervical spondylotic radiculopathy. This retrospective review of 45 patients revealed successful outcomes in 92% of anterior cervical discectomies, 86% for laminoplasty, and 66% for laminectomy. Complications were much higher in the anterior group (70%) than in the laminectomy (25%) or laminoplasty (13%) groups. The retrospective cohort study by Heller et al. (38) demonstrated slightly better, but not statistically significant, functional outcome in a laminoplasty group compared with laminectomy plus fusion. They also noted similar rates of postoperative axial neck pain and loss of lordosis.

Laminoplasty has been studied for long-term outcomes. Iwasaki et al. (48) reviewed patients with more than 10 years of follow-up after laminoplasty for ossification of the posterior longitudinal ligament. The mean neurological recovery for the first 10 years was 64%, and declined to 60% at the final follow-up. They attribute deterioration in many of their patients to neural compression outside the original surgical site. They did have two patients with deterioration caused by progression of the ossification of the posterior longitudinal ligament.

**CONCLUSION**

Dorsal cervical approaches for the treatment of degenerative disc disease are successful and have been performed since the 1950s. As with any operation, it is important to select the appropriate operation and tailor the operation to each individual patient. It is critical to evaluate a patient’s pathology (location and type) in addition to the static and dynamic sagittal spine balance. Complications can be avoided with careful attention to detail. The success of the operation ultimately depends on the surgeon’s judgment, experience, and patient selection.

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The treatment of cervical spondylotic myelopathy and myeloradiculopathy is important for patients with moderate-to-severe neurological impairment. In this article, we discuss the indications, techniques, and complications of combined ventral and dorsal surgery for the treatment of cervical spondylotic myelopathy and myeloradiculopathy. In addition, the advances in surgical technique and instrumentation in cervical spine surgery are explored. Finally, complication avoidance and management strategies are discussed. Combined ventral and dorsal decompression, reconstruction, and instrumentation procedures are viable options in the treatment of a select group of patients with complex cervical myelopathy or myeloradiculopathy.

**KEY WORDS:** Cervical fusion, Cervical instrumentation, Cervical myelopathy, Cervical spondylosis, Myeloradiculopathy

Cervical Alignment

Combined ventral and dorsal approaches should be considered if there is both ventral and dorsal compression on the thecal sac, or if the patient has developed a kyphotic deformity (Fig. 1).

In patients with either a straight cervical spine or with cervical kyphosis, a dorsal decompression alone may not be satisfactory because the spinal cord remains draped over ventral cervical osteophytes or disc herniations instead of being displaced away from these pathological lesions.

Number of Segments Involved

Studies have shown that patients with normal cervical lordosis who have ventral compressive pathology that extends less than two vertebral body segments can be treated adequately with a ventral cervical approach only (10, 21). However, patients requiring three or more levels of cervical corpectomy for the treatment of ventral compressive pathology probably should undergo a combined ventral and dorsal approach. There exists a very high graft failure rate and pseudoarthrosis rate with three levels or greater ventral cervical corpectomy, especially if an anterior plate with unicortical screws is used (21).
Causes of Stenosis

Many patients with diseases such as diffuse idiopathic skeletal hyperostosis, cervical tumors, and cervical traumatic instability with myelopathy are better treated with combined ventral and dorsal surgery. Patients with diffuse idiopathic skeletal hyperostosis who have both ventral and dorsal compressive osteophytes that contribute to myeloradiculopathy may not have adequate decompression with a single-stage ventral or dorsal surgery. Patients with primary or metastatic cervical tumors involving both the ventral and dorsal vertebral elements often require combined ventral and dorsal surgery to facilitate total tumor resection, neural element decompression, and stabilization. Patients with cervical myelopathy from traumatic injuries who have ventral and dorsal vertebral element fractures and instability with stenosis are also best treated with a combined ventral and dorsal decompression and fusion (Fig. 2).

Metabolic Factors

Metabolic factors also affect the decision to use a combined ventral and dorsal approach. Patients who are severely osteoporotic or diabetic, who have poor bone quality as a result of renal disease, or who are heavy nicotine users, have a very poor rate of spinal fusion with ventral surgery alone. In these patients, even if normal cervical lordosis is maintained, if one or more levels of corpectomy are planned, a combined approach should be considered to avoid pseudoarthrosis (24).

FACTORS THAT AFFECT TECHNIQUE SELECTION

There currently exist numerous surgical techniques available to decompress and stabilize the ventral and dorsal cervical spine. These include: ventral cervical discectomy (single level or multilevel with fusion), cervical corpectomy (single level or multilevel with fusion), cervical laminectomy, cervical laminectomy with fusion, and cervical laminoplasty.

Selection of the appropriate combination of ventral and dorsal techniques depends on several factors, including the...
patient’s age, the presence of comorbidities, the severity of the patient’s neurological deficit, the preservation of cervical lordosis, the surgeon’s experience, and the surgeon’s familiarity with the technique. The “art” of surgery is to identify the optimal surgical technique for an individual patient in a particular surgeon’s hands. Different highly skilled surgeons may choose an alternative approach for a particular patient, on the basis of personal experience and results.

**PREOPERATIVE CONSIDERATIONS**

Preoperatively, we attempt to optimize factors that promote wound healing and spinal fusion. Patients are asked to cease using nonsteroidal antiinflammatory medications and to cease the use of nicotine as well. Nutritional status is assessed. If the patient is malnourished, nutritional supplementation is given before surgery. The possible use of hyperalimentation after surgery is discussed with the patient.

In patients with a borderline hematocrit level of 30 or less, we consider the use of erythropoietin with iron supplementation to elicit improvement. For elective surgery in patients with higher hematocrit levels, autologous donor blood for use during or after surgery may be employed.

**TECHNIQUE**

Three questions must be answered when considering a combined ventral and dorsal surgery for the treatment of cervical spondylotic myelopathy or myeloradiculopathy.

**Question 1: Should the Ventral or the Dorsal Side Be Treated First?**

Generally, we decompress the side that has the greatest spinal canal compression. Consequently, if significant osteoarthritic change ventrally is the major contributor to spinal canal stenosis or the neural foraminal stenosis, the ventral side is approached first. Conversely, if ligamentous infolding and dorsal osteophytic change are the primary components of the stenosis, a dorsal approach is used first.

Another factor to consider when answering this question arises in patients with significant cervical kyphosis. In these patients, a three-stage operation may be required to correct the deformity.

**Question 2: Can the Surgery Be Performed with a Single Ventral and a Single Dorsal Approach?**

This question arises in patients who have severe cervical kyphosis and who may require a front-back-front or a back-front-back operation. We use the back-front-back approach if a dorsal decompression is performed first with osteotomies and wide foraminotomies (for osseous release) with placement of polyaxial lateral mass screws. This approach is performed in preparation for correction of the deformity with the subsequent ventral approach. After the ventral reconstruction is completed, a second dorsal approach is performed to secure the rods to the polyaxial screw heads, after compressing the screws on the rod to help restore cervical lordosis and permanently maintain it.

With a front-back-front approach, we first perform a ventral cervical discectomy and release, with consideration of a unilateral pediculectomy (Fig. 3). A dorsal release with osteotomies is then performed (Fig. 4) to further correct the kyphosis, by extending the patient’s head slowly with the temporary rods in place. The dorsal aspect is locked with permanent rods, and the ventral side is readdressed to complete the fusion procedure (Fig. 5). We have described this technique previously in detail in the literature.

When using three-stage procedures, one may consider intraoperative monitoring with motor evoked potentials and somatosensory evoked potentials. In addition, one may use intraoperative fluoroscopy to monitor the change in kyphosis during the correction.

**Question 3: Should All Approaches Be Performed in a Single Day or Should They Be Staged?**

Generally, we prefer to complete all surgery in a single day, with three exceptions. The first exception is a patient who is debilitated, poorly nourished, and who has numerous medical comorbidities (severe coronary disease, chronic obstructive pulmonary disease, etc.). The second exception is a patient in whom significant blood loss is anticipated because of problems with coagulation or because of highly vascular cervical spinal tumors. The third exception is a patient in whom the operative time is expected to be more than 10 hours. If a multistage surgery cannot be completed comfortably during daylight hours, we prefer to stage such complicated procedures (24).

**VENTRAL STRATEGIES**

The primary considerations in performing a ventral approach are whether a single-level or multilevel discectomy should be performed and whether cervical corpectomies should be performed. The answers to these questions...
are controversial (2, 8). Usually, if compressive lesions are present at the level of the disc only, either a single-level or a multilevel ventral discectomy should be performed. However, if the lesion is behind the vertebral body, a corpectomy should be performed.

The exception to this rule is multisegmental ossification of the posterior longitudinal ligament (OPLL). Treatment is controversial (9, 21, 23). A ventral decompression and fusion procedure directly addresses the pathology, but risks leakage of cerebrospinal fluid and spinal cord injury because of the occasional absence of the dura mater underlying the regions of ossification. Dorsal decompressive procedures do not directly remove the ossified ligament, but do allow for spinal cord decompression. In general, we tend to perform ventral decompression and fusion in cases in which OPLL extends for two or fewer segments. In cases in which OPLL extends for more than two segments, a dorsal decompressive procedure, such as laminoplasty or laminectomy with or without fusion, is performed. For long-segment OPLL (greater than two vertebral segments) with a focal area of ventral severe compression or kyphosis, we perform a ventral decompressive procedure to remove the focal lesion and restore ventral height and cervical lordosis. A dorsal long-segment decompressive procedure is then performed.

The advantages of performing a multilevel ventral cervical discectomy and fusion instead of a single-level or multilevel corpectomy and fusion is that, with the multilevel discectomy, postdecompression segmental fixation can be achieved by placing screws into the intervening vertebral bodies. Using this strategy, it is easier to restore sagittal balance after a multilevel ventral cervical discectomy as opposed to a cervical corpectomy (16).

The advantages of performing a single-level or multilevel cervical corpectomy versus multilevel ventral cervical discectomy include the ability to decompress lesions behind the vertebral bodies. In addition, there are only two points that must fuse in a corpectomy, versus multiple surfaces that must fuse with multilevel cervical discectomies.

The next factor to consider with a ventral cervical decompression and fusion is the choice of strut or spacer. Options include autograft iliac crest, allograft fibula, PEEK or carbon fiber cages, titanium mesh (i.e., Pyramesh) cages (Medtronic Sofamor Danek) or Harms cages (Depuy Acromed, Raynham, MA).

**Autograft Iliac Crest**

Traditionally, autograft iliac crest was the spacer of choice for ventral cervical surgery. It was associated with an excellent fusion rate. However, it has recently fallen out of favor because of reported patient morbidity rates of greater than 20% (14, 22).

One problem with iliac crest harvest is donor site complications, including pain (usually resolves within 1 yr, but may last longer), hernia, and lateral femoral cutaneous nerve injury. Second, there is limited availability of iliac crest bone, especially in people with a very thin pelvis. Third, the angulation of the iliac crest becomes an issue if it is used for the replacement of more than two levels of corpectomy. Finally, there is a risk of infection at the harvest site.

**Allograft Fibula**

Allograft avoids several of the complicating factors related to the use of autograft iliac crest. There is no problem with harvest site morbidity. It can be used for more than two levels of corpectomy. It is available in multiple sizes and shapes and can accommodate most ventral cervical decompressions. One problem with allograft is that the rate of fusion is not as high...
as autograft in stand-alone ventral constructs. However, when a ventral allograft construct is supplemented with a dorsal instrumented construct, the rate of allograft fusion has been reported to approach 100% (24).

Allograft provides a sufficient rate of fusion for up to two levels of corpectomy. However, when a third level of corpectomy is added, studies have shown that dorsal instrumentation is required to avoid graft failure and pseudoarthrosis (7, 10, 21).

Titanium Cages

Titanium cages, such as the Pyramesh cage (Medtronic Sofamor Danek) or the Harms cage (Depuy Acromed), are another option for vertebral body replacement after cervical corpectomy. These cages come in a variety of sizes. They are readily available, there is no limitation in supply (unlike allograft), they avoid donor site morbidity (unlike autograft), and they avoid the risk of infection from a donor cadaver (unlike allograft). When combined with ventral plate fixation, titanium cages perform well biomechanically in resisting flexion, extension, and lateral bending (17).

One disadvantage of using titanium cages is their high modulus of elasticity, which contributes to subsidence through the endplates of the vertebral bodies. This problem can be limited by endcapping the titanium cages. The endcaps (small titanium circular caps that snap onto the protruding spikes at the ends of the cage) increase the bone-metal surface area and help the cage to resist subsiding through the softer vertebral body endplate.

Another disadvantage of using titanium cages is the difficulty of assessing fusion. In addition, magnetic resonance imaging artifact from the titanium cage degrades the image and makes it difficult to assess the spinal canal and the neural foramen.

A third disadvantage of using the cages is that they are extremely difficult to revise. If a cage requires extraction from a corpectomy site, a significant amount of drilling and destruction of the vertebral bodies above and below are required. A fourth disadvantage is the cost that is typically associated with the cages.

In general, we prefer to restrict the use of titanium cages to ventral cervical constructs in patients with cervical metastatic tumors who have a limited life expectancy.

PEEK and Carbon Fiber Cages

PEEK and carbon fiber cages are an enticing alternative to bone. PEEK is readily available with an unlimited supply (unlike allograft and autograft). It has a modulus of elasticity that approaches normal bone (unlike titanium cages). It causes minimal inflammatory response, and there is no associated donor site morbidity. It is radiolucent. Therefore, it is easy to assess a fusion status (unlike titanium cages) (Fig. 1D) (4, 5).

Intracompartamental and Extracompartamental Bone

In cases in which titanium cages or PEEK/carbon spacers are used, we pack the central cavity of the interbody spacers with autograft bone and surround the spacers with more autograft bone, if there is space available. The autograft bone placed within the spacer is referred to as intracompartamental bone, and the bone packed outside the spacer is referred to as extracompartamental bone.

There are several options for obtaining intracompartental and extracompartamental bone. In cases in which a single-level discectomy is performed, the endplates above and below the discectomy can be scraped with a Number 1 Penfield. These bone shavings can be placed inside the interbody spacer as the autograft intracompartamental bone. Another option is to harvest the autograft bone from the iliac crest. This can be performed through a small window opening into the iliac crest without taking a large tricortical crest graft. Minimal morbidity is associated with this procedure (significantly less than taking a tricortical iliac crest wedge), although it does involve a separate incision on the iliac crest. In cases in which a corpectomy is planned, another good option is to perform the corpectomy with a large rongeur and to save the corpectomy bone fragments for use as autograft to place within and around the spacer.

In cases in which there is insufficient intracompartamental bone, mixing the available bone with a bone morphogenic protein (rh-BMP2) sponge may be used as the intracompartamental filler (this is an off-label use of rh-BMP2) (3, 4). We avoid using rh-BMP2 with titanium mesh cages because they are porous. It is our practice, if we choose to use rh-BMP2, to place the sponge within either a nonperforated PEEK cage or a fibula allograft to better contain the sponge (Fig. 1) (4).

Ventral Cervical Plates

Ventral cervical plate fixation has gained wide acceptance to enhance cervical arthrodesis. There have been significant advances in plate design during the past decade. To follow the evolution in plate design during the past decade, a classification scheme has been developed. In the Cervical Spine Study Group classification, the early ventral cervical plate designs are categorized as “unrestricted back out designs,” and the later designs are all categorized as “restricted back out designs.” The restricted back out designs have a mechanism to prevent screw back out.

During the 1990s, inventors recognized the importance of biomechanics and plate design. It was noted that bone heals better when subjected to some loading stress (Wolff’s Law). Early designs of ventral cervical plates were not dynamic and shielded the bone graft from load bearing. Consequently, these designs did not exploit Wolff’s Law to achieve fusion. More recent plate designs, designated the “semi-constrained, rotational” category, which include the Atlantis (Medtronic Sofamor Danek), A-line (Medikon Ltd., Germany), and Codman Systems, resolved the stress-shielding problem by providing variable-angle screws, which allow for rotational...
pivoting at the screw-plate interface (Fig. 6A). As a result of this rotational pivoting, these plates allow for increased loads to be placed on the disc space (rotational subsidence), thereby exploiting Wolff’s Law to achieve fusion across the disc space or the corpectomy defect (18).

The latest variation of dynamic ventral cervical plate, designated the “semi-constrained, translational” category, includes the Premier plate (Medtronic Sofamor Danek), the DOC system (Depuy Acromed), and the ABC plates (Aesculap, Tuttlingen, Germany), which are now being marketed. The semiconstrained, translational plates allow for translational subsidence of the cervical spine after anterior cervical decompression and fusion (Fig. 6B). These systems allow for the screws to translate rostrocaudally within a slot or along a rail (which allows for the translational subsidence). It is not known whether the rate of fusion after single-level or multilevel anterior cervical decompression and fusion using a translational plate is different from that of a rotational plate. It is our preference to avoid the use of translational plates in longsegment corpectomies, for fear of providing too much subsidence.

In difficult reoperation cases with significant scar tissue, not placing a ventral cervical plate after a multilevel cervical discectomy or corpectomy is acceptable if dorsal segmental fixation is to be applied. We do not favor buttress plates for the ventral cervical spine because the mode of failure of a buttress plate is to slip out anterior to the graft, which may lead to more esophageal and tracheal compression than if the graft slips out alone (19).
the ability to use offset connectors to accommodate more medially or laterally placed screws, ease of extension across the occipitocervical or cervicothoracic junction, and the ability to correct cervical kyphosis via compressing the screws on the rods. The systems that are currently available for this purpose include the Vertex system (Medtronic Sofamor Danek), the Summit system (DePuy Acromed), the Axon system (Synthes USA, Paoli, PA), the Oasys system (Stryker Spine, Allendale, NJ), and the Ascent System (Blackstone Medical, Springfield, MA). It is our practice to perform arthrodesis on the lateral masses and lay autograft harvested from the dorsal iliac crest beneath and around the instrumentation.

Laminoplasty: Cervical Fixation without Fusion

Laminoplasty is well described in the Japanese literature as a surgical option for the treatment of OPLL and for the treatment of cervical stenotic myelopathy. The open-door technique has gained the most popularity in the United States and in Europe. With this technique, the lamina is completely drilled through on one side and partially drilled through on the contralateral side. The first side is then lifted open (the open door) to increase the spinal canal diameter. The elevated lamina can be held open with a piece of bone, a carbon spacer, or a small titanium miniplate (6).

If multilevel cervical corpectomies are performed, we do not perform laminoplasty. In such cases, dorsal cervical fusion with a polyaxial screw-rod system is used to supplement the ventral cervical fusion.

However, when single-level or two-level ventral cervical discectomies or a single-level cervical corpectomy is performed, a viable option is to perform a combination posterior cervical laminoplasty to provide for further decompression of the spinal canal. In these cases, the likelihood of an anterior cervical fusion is quite high, and a supplemental posterior cervical fusion is not necessary.

Cervical Orthosis

For one- or two-level anterior procedures with an anterior plate, we place patients in a soft foam collar for comfort. After multilevel cervical surgery has been performed, immobilization with a padded hard cervical collar may be considered for 6 to 8 weeks. If the cervicothoracic junction is crossed with an instrumented dorsal fusion, a cervicothoracic orthosis that incorporates the upper thoracic spine and torso is used. The halo brace is seldom used.

COMPLICATIONS

The short-term morbidity rate after combined ventral and dorsal surgery for cervical myelopathy may be as high as 32%. However, the long-term morbidity rate has been shown to be only 5% (24).

The complications of combined ventral and dorsal approaches include neurological deterioration, dysphagia, hoarseness (recurrent laryngeal nerve injury), hardware failure, pseudoarthrosis, cerebrospinal fluid leak, and graft harvest site infection.

These complications can be minimized with meticulous surgical planning techniques. During the ventral cervical operation, our experience is that problems with dysphagia or injury to the recurrent laryngeal nerve may be avoided by performing a wide release of the cervical fascia and soft tissues. This maneuver may reduce the tension on the tissues during retraction. In addition, some authors have advocated temporarily releasing the cervical retractors periodically to avoid constant tension on the soft tissues (1). To access ventral C7–T1 lesions, we prefer a left-sided approach because the recurrent laryngeal nerve is anatomically located more medially on the left and is less likely to be injured. The speed with which the surgeon operates may also make a difference in these cases. Shorter operating times can decrease problems with tracheoesophageal injury and edema because there is a reduced overall compression of these structures by retractors. Patients undergoing a reoperation should be evaluated pre-operatively by an otolaryngologist to assess vocal cord function. If one vocal cord is already injured from the first operation, surgery should be performed on the side ipsilateral to the vocal cord paralysis. Bilateral vocal cord injury is a difficult problem, often requiring a tracheotomy, and should be avoided. It is infrequent for a patient to require a tracheotomy for a combined ventral and dorsal surgery.

Injury to the thoracic duct with a left-sided cervical spine surgery is a potential, rarely reported complication (13). The thoracic duct may extend into the left anterolateral cervicothoracic region before it empties into the junction of the left internal jugular vein and subclavian vein. The potential for thoracic duct injury is probably greater with exposure of the left side of the T1 vertebral body. Consequently, if we plan to perform corpectomies that include T1, we occasionally choose a right-sided approach to avoid the duct. Such approaches often require a partial sternal split (11).

Hardware failure and pseudoarthrosis have not been problems when ventral and dorsal fusion procedures are performed together (24). However, infection does remain a lingering concern and can be minimized with the use of perioperative and postoperative antibiotics and postoperative drain placement (20).

Neurological deterioration and cerebrospinal fluid leak may occur in cases in which OPLL is present and a ventral decompressive procedure is performed. For this reason, with long multisegmental OPLL, we use only a posterior decompression via laminoplasty or laminectomy with or without fusion if the patient has retained cervical lordosis.

CONCLUSION

Combined ventral and dorsal decompression, reconstruction, and instrumentation procedures represent viable options for the treatment of a select group of patients with cervical myelopathy or myeloradiculopathy. Advances in spinal instru-
mentation and surgical techniques have reduced morbidity associated with combined ventral and dorsal surgery during the past decades. The long-term durability of a combined ventral/dorsal cervical spine fusion has yet to be proven. Much remains to be learned regarding the optimum biomechanical environment for arthrodesis of the cervical spine.

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Cervical Deformity Correction

SUBAXIAL CERVICAL DEFORMITIES most often occur in the sagittal plane, primarily as kyphosis. Kyphosis may develop secondary to advanced degenerative disease, trauma, neoplastic disease, or after surgery. Whatever the cause, the development of cervical deformity should be avoided and corrected when appropriate because the greater the deformity, the greater the probability of an associated neurological deficit or chronic pain. Patients usually present with mechanical type cervical pain, with or without neurological deficit (i.e., myelopathy). They may also be relatively asymptomatic. Work-up includes appropriate imaging studies, such as radiographs, including dynamic images, and magnetic resonance imaging or computed tomography myelography. The deformity may be accurately assessed and an appropriate surgical strategy undertaken. Depending on flexibility of the deformity and the presence or absence of facet ankylosis, a dorsal, ventral, or combined approach may be used. All approaches are unique in their ability to correct a deformity and in their associated complications. A comprehensive discussion of each is undertaken.

KEY WORDS: Cervical spine, Deformity correction, Kyphosis, Osteotomy

Subaxial cervical deformities most commonly occur in the sagittal plane, primarily as kyphosis. Kyphosis may develop secondary to advanced degenerative disease, trauma, neoplastic disease, or after surgery. Whatever the cause, the development of cervical deformity should be avoided and corrected when appropriate. In the authors’ experience, the greater the kyphosis, the greater the probability of an associated neurological deficit or chronic cervical pain. Cervical kyphosis is biomechanically unfavorable for the cervical musculature. Axial loads tend to cause further kyphosis via the application of the axial load through a moment arm induced bending moment (Fig. 2) (4). It may be said that “kyphosis begets kyphosis.” Further, and often excessive, degeneration of the cervical intervertebral disks may occur. Both phenomena often lead to cervical pain that is mechanical in nature (18). If the kyphosis becomes severe (the magnitude of which is different in each patient) forward gaze (i.e., ability to see the horizon), swallowing, and respiration may be adversely affected.

A brief discussion of “normal lordosis” is prudent at this point. The definition of normal lordosis is unknown and has not been clearly defined in the literature. Gore et al. (13) measured mean lordotic angles in the cervical spine of osteoarthritis patients from C2 to C7. They observed a 16 to 22 degree lordosis in men and a 15 to 25 degree lordosis in women. The values of “normal” vary in the literature, depending on the measurement scheme used.
**CLINICAL PRESENTATION**

Patients with cervical kyphosis typically present with mechanical neck pain. More specifically, cervical pain is usually worse with activity and relieved by rest. Because of the advanced degeneration observed in this patient population, patients may also present with radiculopathy, with or without an associated myelopathy. Myelopathy typically occurs and progresses because of increased stress on the ventral spinal cord. These stresses adversely affect the spinal cord vasculature and most likely lead to local ischemia (5, 20). Despite the progressive nature of the disease, patients may also be asymptomatic.

**CLINICAL EVALUATION**

The deformity should be evaluated by anterior/posterior and lateral cervical radiographs along with dynamic lateral flexion, extension views. The deformity is then accurately measured (i.e., sagittal angle determination) and any other abnormalities noted (e.g., subluxation and pseudarthrosis). The authors also include standing long-cassette radiographs. This permits one to assess the overall sagittal balance of the spine. The goal of treatment is to obtain balance. Dynamic (i.e., flexion/extension) radiographs permit an assessment of the overall flexibility of the cervical spine, which is paramount when designing a treatment strategy. Fine-cut computed tomographic (CT) scans of the cervical spine are also useful in determining the presence of fusion or ankylosis of the facet joints. The knowledge of such should persuade the surgeon to perform a combined ventral/dorsal surgical strategy.

All patients should be evaluated with preoperative magnetic resonance imaging or computed tomography myelography. These image modalities permit the evaluation of compressive pathology (Fig. 3). If significant ventral compressive pathology (disk, osteophyte) is present, a ventral decompressive procedure must first be performed before the correction of the deformity.

When planning a ventral approach, magnetic resonance imaging allows the surgeon to evaluate the cervical spine for an intervening or intermediate vertebral body that may be used during the reconstruction procedure. An intermediate vertebral body is one that does not require resection and that may be left in situ after performing a decompression above or below this vertebral body. This prevents the need for multiple consecutive sequential corpectomies and may then permit adequate decompression via multiple interbody discectomies or discectomy combined with corpectomy. The intervening vertebral body provides intermediate points of ventral implant fixation, which significantly aids in ventral deformity correction and stabilization after surgery. An intermediate vertebral body may be retained or used if a cerebrospinal fluid signal on a T2-weighted magnetic resonance image is present dorsal to the vertebral body (Fig. 4). This denotes an absence of compression at this level and that it is safe to leave this vertebral body.

**SURGICAL INDICATIONS**

Well-defined indications for the correction of cervical kyphotic deformities do not exist. It is the authors’ opinion and practice to correct cervical deformity for patients who present with a neurological deficit, have severe mechanical pain, or functional disability, such as chin-chest deformity, swallowing difficulty, etc. If the deformity is mild (i.e., does not lead to a functional deficit), surgery is not indicated. The deformity often does not progress. Progression of deformity, in the authors’ opinion, is an indication for correction and fixation. In the authors’ experience, these patients are symptomatic.
Pain and neurological deficits are most often directly related to the kyphotic deformity. Therefore, the deformity correction should be performed along with decompression. The authors do not advocate fusion in situ without correction in the majority of cases.

**DEFORMITY CORRECTION**

Before a discussion of deformity correction strategies is undertaken, one must first consider how much correction of the deformity is required. As previously discussed, a clear, unequivocal definition of a normal cervical lordosis does not exist. Furthermore, the extent of acceptable kyphosis is also not known. This most certainly varies from person to person. Theoretically, a kyphotic deformity should be completely corrected. This, however, may be unrealistic and, at times, unnecessary. The authors think that the kyphosis should be corrected to at least a straight spine (i.e., no kyphosis or lordosis).

Sagittal plane deformity in the cervical spine may be addressed ventrally (6, 9, 15, 27), dorsally (1, 7), or both (1, 14, 21, 23). The surgical strategy is usually based on the results of imaging. In general, if there is imaging evidence of ventral compression, a ventral decompression procedure should be included in the overall strategy. In addition, if the anterior column is structurally insufficient (e.g., tumor, trauma, severe degeneration), its integrity should be reconstituted. The relative flexibility of the cervical spine is determined from the dynamic cervical radiographs. If the deformity is fixed (i.e., no reduction of the kyphosis on extension cervical radiographs), and there is no facet joint ankylosis (evaluated on fine-cut CT scans), the deformity may be addressed via a ventral alone strategy. If the deformity is fixed, but facet ankylosis is observed on CT scans, a combined ventral/dorsal strategy will most likely be required. A dorsal osteotomy may be required to correct the deformity. Lastly, if the kyphosis is reducible on extension radiographs (i.e., nonfixed), the deformity may be corrected posturally or with traction and fused in the desired position with a dorsal alone strategy (Fig. 5).

**Traction**

Traction is often used as an initial tool in the evaluation of the surgical approach to correct cervical kyphosis. Often, the deformity may be corrected via cervical traction. The authors occasionally use traction before surgical intervention. In their experience, if traction is to be useful in reducing a kyphotic deformity, 3 to 5 days is generally the duration of traction required. If no reduction is observed after 5 days, success with further traction is unlikely. Muscle relaxants may also be used to aid in the reduction process. If correction of the kyphosis is attained, a dorsal fixation and fusion may then be used to hold the correction and prevent deformity progression.

**Ventral Alone Strategies**

This strategy may be used when the deformity is fixed, yet there is no ankylosis of the facet joints. The ventral approach to the cervical spine is familiar and is associated with acceptable morbidity. It permits decompression of ventral pathology as well as reconstruction (deformity correction) with strut grafting and instrumentation. This strategy provides optimal ventral decompression of the spinal cord and permits the attainment of a lordotic cervical posture. In addition, it provides “superior surgical leverage” compared with dorsal surgery for deformity correction.

A ventral alone strategy uses both posture and biomechanical principles to correct cervical deformity. These principles are paramount in attaining lordosis after surgery. Patients should be positioned supine with the neck only slightly extended via the placement of a doughnut under the head and a blanket roll under the shoulders. The cervical spine is approached in a standard fashion along the sternocleidomastoid muscle. Distraction posts are placed in a convergent fashion. After the ventral release has been performed, distraction against the posts provides segmental extension and, therefore, lordosis (Fig. 6). It is emphasized that the ability to reduce deformity with distraction posts is only possible if the facet joints are not ankylosed and the uncinate processes (joints) have been completely released. If this is not the case, distraction against the posts may result in cut-out of the posts and damage of the vertebral bodies available for fixation. Optimally, decompression is performed via multiple discectomies or corpectomy combined with discotomies. This then avoids long-segment contiguous corpectomies and provides intermediate points of implant fixation (Fig. 7, A and B). After the appropriate decompression has been performed, the doughnut is removed from underneath the patient’s head, which places the cervical
spine in further lordosis. Autograft, which is fashioned in a trapezoidal manner (i.e., larger ventrally), aids in maintaining the deformity correction.

An implant, contoured in lordosis, is placed next. Screws are first placed at the cranial and caudal ends. Screws are then placed into the intervening vertebral bodies. When these screws are tightened, the spine is “brought to the implant” (Fig. 8).

There are many advantages to using multiple points of fixation with the ventral construct. This strategy not only achieves lordosis but also provides three or four point bending forces to maintain the sagittal alignment after surgery. It also minimizes the chance of terminal screw-bone interface degradation.

When this ventral strategy is used, consideration should be given to using a dynamic ventral implant. These implants permit controlled deformation in the axial plane (axial subsidence), yet prevent deformation in the sagittal plane (kyphosis) (4). The controlled subsidence allows the bone graft(s) to absorb most of the axial forces, which should encourage bone healing via Wolff’s Law (4). The construct also off-loads stresses at the screw-bone interface. This further contributes to a diminished incidence of structural failure.

Zedeblick and Bohlman (27) and Herman and Sonntag (15) both reported their series of cervical kyphosis correction via corpectomy. Ventral instrumentation was used in the latter series but not in the former. In both series, there was a reduction in kyphosis, yet, overall, a residual kyphosis was observed. Steinmetz et al. (25) have shown that the aforementioned ven-

FIGURE 6. Distraction posts are placed in a convergent manner (A). Arrows indicate the direction of the force applied. After a release has been performed via diskectomy or corpectomy, distraction against the posts results in segmental lordosis deformity correction (B).

FIGURE 7. A, decompression performed via multiple diskectomies plus corpectomy or corpectomy alone. C3 (3) and C7 (7) are left in place. Complete decompression of spinal cord may be performed while still leaving an intermediate vertebral body to be used during instrumentation. B, use of multiple diskectomies, skip corpectomies, or diskectomy combined with corpectomy avoids long, multisection corpectomies. This would require a long strut graft (a) and a long implant only affixed to the most rostral and caudal vertebral bodies (b). This is referred to as a bridging implant and is good at resisting axial loads but poor at resisting rotational and translational forces, thus resulting in high construct failure rate. By leaving and using an intermediate vertebral body (c), three or more points of construct fixation may be attained, resulting in a three- or four-point bending construct, which is able to resist axial, rotational, and translational forces.

FIGURE 8. Lordotic construct is first affixed to rostral and caudal vertebral bodies. Next, screws are placed into intermediate vertebral bodies (A and B). As intermediate screws are tightened, the spine is brought to the implant (C).
If dorsal elements are fused, a combined approach is required. This patient had a prior C4-C5-C6 laminectomy and resultant kyphosis (A). Deformity was rigid as assessed on dynamic radiographs, and facets were confirmed ankylosed on fine-cut CT scans. The patient underwent dorsal osteotomies of facets of C3-C4, C4-C5, C5-C6, and C6-C7 bilaterally. Inferior aspect of spinous processes of C3, C4, C5, and C6 were resected to permit extension. The patient then underwent C3-C4, C4-C5, C5-C6, and C6-C7 discectomies. The deformity was reduced, and interbody grafts and ventral dynamic instrumentation placed (B and C). Note that one intermediate screw has been left out because of poor bone quality (C).

Complications of Ventral Approach

Common complications of a ventral approach include vocal cord palsy, dysphagia, tracheal or esophageal injury, graft failure (displacement), hardware failure (fracture), and wound complications (infection, hematoma). These complications are well known and are familiar to all spine surgeons. Because patients with cervical kyphosis have undergone multiple prior procedures and the deformity often involves multiple spinal segments, the incidence of these complications is often greater in this patient population.

Sound biomechanical principles are crucial to lessen potentially avoidable complications, such as pseudarthrosis or construct failure. Examples include using multiple discectomies instead of multiple sequential corpectomies. This provides intervening vertebral bodies that may be used as multiple points of implant fixation. This not only aids in deformity correction but also provides three or four point bending forces that help maintain sagittal alignment.

Ventral construct failure may be observed after extensive deformity correction because of excessive stresses placed on the construct (i.e., screw or implant breakage, graft kick-out). Using an axially dynamic implant off-loads stresses on the implant and may significantly decrease the incidence of such construct failure.

Combined Ventral and Dorsal Approach

When the deformity is fixed and the dorsal elements are ankylosed, a combined ventral and dorsal approach is often required (Fig. 9). If the deformity involves the cervicothoracic junction, strong consideration should be given to a combined approach. In general, this approach permits ventral lengthening and dorsal shortening and, therefore, kyphosis reduction. It permits ventral decompression and release, with or without instrumentation, combined with dorsal instrumentation. The addition of the dorsal construct provides a long moment arm strategy to aid in deformity prevention (4). Furthermore, it provides multiple points of construct fixation if only a bridging implant is used ventrally (Fig. 10).

When planning a combined approach, the goals of the operation should be clearly defined. This will aid the surgeon in choosing the order of the procedure. If ventral compression exists and the dorsal procedure is solely for supplemental instrumentation, the ventral decompression (discectomy or corpectomy) and grafting should be performed first, often with use of a ventral implant. Next, the dorsal procedure is under-
taken. This most often consists of instrumentation and fusion. Dorsal decompression (i.e., laminectomy) is often not required. Instrumentation is most often via lateral mass fixation with or without C2 isthmus and C7 pedicular fixation. Interspinous wiring may also be used, but lateral mass fixation has been shown to provide greater rigidity than wire fixation alone (11).

In complicated cases, such as ankylosing spondylitis with kyphosis, a more extensive (e.g., 540 degrees) combined procedure may be warranted. A dorsal osteotomy may be performed first to release the fused dorsal elements before ventral decompression. This then permits the surgeon to manipulate the cervical spine (using the aforementioned ventral techniques) to correct the deformity. The authors usually place a ventral implant because of the large moment arm above and below the level of the fusion. Dorsal instrumentation may also be used, thus aiding in the prevention of further deformity progression. Obviously, the order in which the stages of the operation are performed depends on the situation.

At times, kyphosis may be corrected with cervical pedicle screws, thus obviating the need for a ventral implant or corrective forces. If this strategy is chosen, the ventral decompression and release should be performed first without grafting or instrumentation. After the release is performed, the patient may be placed prone in a Mayfield head holder (Integra Life Science, Plainsboro, NJ). If a dorsal release is required, it should be performed next. The cervical spine may then be manipulated by adjusting the three-point head holder. Because ventral decompression has been performed, the reduction is safe. A lateral, cervical radiograph confirms the correction attained. The dorsal construct (lateral mass fixation, pedicle screw construct) may then be placed to secure the deformity correction. Iliac crest may then be harvested to provide morselized bone for the dorsal fusion and material for the ventral fusion. The patient is again placed supine, and the ventral graft is placed. Abumi et al. (1), using a combined ventral/dorsal approach with cervical pedicle screw instrumentation, were able to improve an average preoperative kyphosis of 30.8 to 0.5 degrees of kyphosis at the final follow-up.

Dorsal Strategies

If the deformity is correctable with traction or posture (i.e., neck extension), a dorsal alone strategy may be used, although this is uncommon. If spinal cord decompression is required, it should be performed ventrally, and consideration should be given to a combined ventral/dorsal procedure.

Traction should be used to reduce the deformity, and the traction should be continued into the operating room. The patient’s head is placed into a Mayfield type head holder to maintain the reduction. A lateral preoperative cervical radiograph should be taken to ensure adequate deformity correction. A standard dorsal subperiosteal approach to the cervical spine is used. Interspinous wiring, lateral mass fixation, and pedicle screw fixation may be used to maintain the deformity correction (Fig. 11). If a laminectomy is performed, interspinous wiring may not be used because of removal of the spinous processes.

Cervical pedicle screws may be biomechanically superior to ventral plate or dorsal lateral mass instrumentation as a stand alone fixation construct. Abumi et al. (1), using only cervical pedicle screws, was able to correct kyphosis from 28.4 to 5.1 degrees of kyphosis, with all patients achieving a solid arthrodosis. It should be emphasized that lordosis was not achieved with the dorsal alone procedure because the kyphotic deformity was only reduced. Kotani et al. (19) have shown that cervical pedicle screw fixation is equivalent to combined ventral plate and dorsal wiring, although the procedure is technically challenging. Although cervical pedicle screws may be biomechanically superior, lateral mass fixation is familiar to most spine surgeons and may be performed with minimal morbidity. Despite the ease of placement, reports have shown that the lateral mass may not be an optimal stabilizing anchor for internal fixation in some patients (3, 11, 14). Ventral release and fusion may be required for the optimal deformity correction when using lateral mass plate fixation (1).

Complications of Dorsal Approach

Complications from the dorsal approach include spinal cord or nerve root injury, hardware failure or fracture, nonunion, vertebral artery injury, and wound complications (infection, hematoma). In the authors’ experience, the dorsal approach results in greater discomfort after surgery compared with a ventral approach. The combined approach obviously has the combined morbidity of both procedures.

Osteotomy

Ankylosing spondylitis may produce an extreme fixed flexion deformity at the cervicothoracic junction. This extreme deformity may place the chin in close proximity to the chest, which may interfere with eating and respiration. Some have advocated treating this deformity by extension osteotomy at the cervicothoracic junction (24, 26). Essentially, the procedure, as initially described, is performed under local anesthesia with
the patient awake and sitting. After osteotomy, the deformity is corrected externally either by an articulated plaster jacket incorporating the head and neck (26) or by manual extension (intraoperatively). Stability is maintained by a halo jacket (24).

McMaster (22) reported on 15 patients with ankylosing spondylitis and a cervical flexion deformity; all were treated by a dorsal extension osteotomy and external fixation using either a halo (12 patients) or internal fixation (three patients). In this procedure, the cervicothoracic spine is exposed dorsally from C6 to T1. A wide laminectomy is performed at C7, with partial laminectomies of C6 and T1. The spinous process of C6 is also removed. The ankylosed C7-T1 facet joints are removed bilaterally to expose the C8 nerve roots beyond their intervertebral foramina. A portion of the C6 and T1 pedicles are removed to avoid impingement of the C8 nerve roots during the deformity correction. Under electrophysiological monitoring, the head is extended to correct the deformity (Fig. 12). The correction is maintained in a halo vest or with internal fixation. The average correction obtained was 54 degrees. There were three neurological complications. Four patients had subluxation of C7 on T1.

Recently, Duff et al. (10) reported on a patient in whom a fixed flexion deformity was corrected using a single-stage, two-level midcervical osteotomy. Internal fixation was used in this case. Using the reported technique, the authors were able to achieve a correction of approximately 90 degrees of lordosis. Technically, they are correcting 90 degrees of kyphosis.

Complications of Osteotomy

Dorsal wedge osteotomy for the correction of flexion deformity has a potential high incidence of morbidity (22). Complications include infection, respiratory, and cardiovascular problems. There is a potential for vertebral artery injury during the osteotomy or neurological injury during deformity correction. The resultant neurological injury may range from minor nerve root irritation to spinal cord compression and quadriplegia. After deformity correction, there is risk of subluxation of C7 on T1, with resultant bony nonunion.

CONCLUSION

Cervical deformity is rare but may occur as part of the aging process or after surgery. Although it may be asymptomatic, it often leads to mechanical neck pain or progressive neurological deficit. If the deformity is symptomatic, correction should be considered. Preoperative imaging should aid the surgeon in deciding which surgical strategy should be used. The authors think a ventral approach is optimal in most cases. It permits decompression, and it provides a “better surgical leverage” than dorsal surgery for deformity correction while providing solid fixation points if intermediate points of fixation are used. In cases when there is a fixed deformity (e.g., ankylosing spondylitis), a combined approach may be used. Emphasis should also be placed on deformity prevention, such as restoring lordosis, after a ventral decompressive procedure or using dorsal fusion or instrumentation after an extensive dorsal decompression. Correction of cervical deformity is rewarding, and the majority of patients have relief of their mechanical symptoms and an improvement of neurological function.

REFERENCES


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Before 1950, cervical spine surgery was primarily performed via a dorsal approach. Bailey and Bagley (3) performed the first ventral cervical spine stabilization with an onlay fusion in 1952. In 1955, Robinson et al. (20) published their operative technique using an interbody graft. In 1958, Cloward (8) described his modification of the anterior cervical decompression and interbody fusion (ACDF). The advantages of the ventral approach were quickly evident. The approach was easy to perform and provided a wide exposure. The ventral spine could be decompressed and stabilized in one operation.

Initially, ACDFs were performed using the patient’s own iliac crest bone (autograft). A separate incision was made over the patient’s iliac crest and the surgeon harvested a tricortical piece of bone to replace the removed disc. A 3-cm incision is made 3 cm dorsal to the anterior superior iliac spine and 2 cm inferior to the crest prominence. Subperiosteal dissection exposes the crest, and an oscillating saw or osteotome is used to take the appropriately sized graft. The wound is then closed in a standard fashion. Alternatively, bone from the middle third of the fibula was harvested.

Cloward (8, 9) pioneered the use of allograft and reported excellent arthrodesis rates (Fig. 1). Today, allograft use has outpaced autograft use for many ventral cervical procedures. The relative merits of allografts compared with autografts have been widely debated. The decision whether to use allograft or autograft is dependent upon three central considerations: 1) clinical efficacy, 2) graft harvest morbidity, and 3) cost and availability.

THE DECISION-MAKING PROCESS: ALLOGRAFT VERSUS AUTOGRAFT

Graft Incorporation

The long-term goal of bone grafting is graft incorporation without deformation. Autograft has a significant advantage compared with allograft in this regard. Autografts contain endogenous bone morphogenetic proteins (BMPs), which are important in osteoinduction. BMPs help recruit osteoprogenitor cells and cause them to differentiate into osteoblasts. Fresh-frozen allografts contain some BMPs, whereas freeze-dried allografts lack BMPs (2).

Biocompatibility is highest with autografts. The host’s immune system works against allografts. Fresh-frozen allografts invoke a host’s inflammatory immune response, resulting in delayed graft incorporation (19, 26).

Current research is focusing on the use of recombinant human BMP (rhBMP; i.e., InFuse; Medtronic Sofamor Danek, Memphis, TN) with either allograft or synthetic material to overcome freeze-dried allograft’s lack of BMP (4, 27). Preliminary data indicates that rhBMP-2 incites an early and robust fusion when used in the cervical spine. BMP has also been associated with some local swelling and swallow-
less osteoconductive than iliac crest allograft (18). The addition of ventral cervical plate fixation decreases the rate of graft collapse and reduces the risk of graft extrusion and spine angulation (22, 26).

Clinical Studies

Multiple studies comparing the use of allografts and autografts have been published. These studies have generally found high fusion rates for single-level arthrodesis with either allograft or autograft (6). In a meta-analysis of ventral cervical arthrodesis, Floyd and Ohnmeiss (11) reviewed four prospective studies with 310 patients and 379 intervertebral levels. For both one- and two-level ACDF, autograft demonstrated a higher rate of radiographic union and a lower incidence of graft collapse (11). Zdeblick and Ducker (26) compared the use of freeze-dried allografts and autograft without a ventral cervical plate in 87 patients. They found similar fusion rates for one-level surgeries (95%), although allograft patients required a longer time to fuse. Greater than 2 mm collapse occurred in 30% of allograft patients versus 5% of autograft patients. For two-level cases, the allograft nonunion rate was 63% versus 17% for autografts. Clinical results were similar in both groups.

An et al. (1) prospectively evaluated the use of autograft versus allograft with a demineralized bone matrix composite (Grafton) in 77 patients. For single-level fusions, 47.4% of allograft patients developed a pseudarthrosis at 1 year compared with 26.3% in the autograft group. Graft collapse of more than 3 mm was noted in 11% of autograft patients versus 19% of allograft patients. Bishop et al. (5) compared 49 patients who underwent grafting with allogeneic, freeze-dried iliac crest with 83 patients who underwent autogeneic iliac crest grafting. At a mean follow-up of 31 months, the single-level fusion rate was 87% for allograft bone and 97% for autograft bone (5).

The introduction of ventral cervical plating has made the use of allograft more appealing. Ventral cervical plates function to improve fusion rates and decrease subsidence (7, 24). Kaiser et al. (16) retrospectively reviewed 522 patients undergoing one- or two-level ACDFs with cortical allografts. The fusion rates for one- and two-level arthrodesis with allograft and ventral plate fixation were 96% and 91%, respectively, compared with 90% and 72% for one- and two-level arthrodesis with allograft spacers without plating (16).

Clinical studies indicate that autograft is superior to allograft regarding both graft incorporation and maintenance of disk height. The superiority of autograft is especially evident when two or more levels are fused. However, with the introduction and use of ventral cervical plate fixation, in combination with allograft, the fusion rate of allograft has increased and now approaches the fusion rate of autograft for ACDF procedures (Fig. 2). Consideration should be given to use autograft in ACDF procedures extending three or more levels.

Smoking leads to a significant reduction in the rate of successful arthrodesis after ACDF (5). The detrimental effect of smoking on fusion is more pronounced with allograft than with autograft (1). Therefore, some surgeons use autograft in smokers.
Posterior Cervical

The use of allograft only in the posterior cervical spine is not well accepted or reported in the literature, to our knowledge. Structural allograft is not generally necessary in the posterior cervical spine. Allograft can be used in the context of a bone extender. No specific clinical data exists on this application in the cervical spine exists. Posterolateral lumbar fusion data indicate that graft extenders are effective when used in conjunction with autograft. The lack of load applied across the graft and decreased cancellous bone surface area provide a poor environment for bone healing in contrast to the anterior interbody space.

**GRAFT MORBIDITY**

The primary problem with autograft is the complications associated with graft procurement. Many studies show that more than one-third of patients experience some degree of pain at the donor graft site after 1 year. Severe pain requiring intervention occurs in less than 3% of patients. Complications occur in up to 20% of patients and include wound hematomas, infection, nerve injury, and iliac fractures (13, 15). Iliac crest harvest can result in meralgia paraesthetica from injury to the lateral cutaneous femoral nerve. Graft-related pain may persist long term and be under-assessed by surgeons at follow-up.

The principal advantage of allograft is the avoidance of autograft harvest morbidity. Allografts are bone grafts obtained from cadavers that are sterilized. Donors are screened according to the strict guidelines of the American Association of Tissue Banks and the Food and Drug Administration (17). Donors are excluded if they are positive for human immunodeficiency virus (HIV), Hepatitis B, Hepatitis C, or autoimmune disease. The graft may be obtained under sterile conditions or sterilized using radiation or ethylene glycol. There have been two reported cases of HIV transmission with fresh-frozen allografts and both occurred in the early days of the acquired immunodeficiency syndrome epidemic before routine screening techniques were used (2).

To freeze-dry the allograft, the graft is cooled to −70°C and then water is extracted until the graft has less than 5% water content. This lyophilization process destroys any remaining viral deoxyribonucleic acid and all the endogenous BMPs (14). One case of freeze-dried tissue obtained from an HIV-positive donor cadaver being transplanted into a non-HIV positive patient has been reported. The recipient of this tissue did not develop HIV (2).

**COST AND AVAILABILITY**

To avoid donor-site complications, the use of allograft has increased substantially, resulting in a shortage of available allograft in the United States. Outside the United States, allograft has not been widely accepted for a variety of reasons. A comprehensive cost analysis regarding the use of autograft versus allograft is not available. Initial operating room costs are probably higher for allograft. There is a cost for processing the allograft. Operating room costs are further increased if a ventral cervical plate is used specifically to remedy the deficiencies of using allograft. On the other hand, more operating room time is required to harvest autografts. Costs are incurred in treating donor site morbidity associated with autograft harvest (wound debridements, prolonged recuperation times, etc.).

**FUTURE DIRECTIONS**

New technology, including synthetic interbody devices and BMP, may change ventral cervical arthrodesis practices in the future. The use of BMP to augment ventral cervical fusion has been reported to achieve arthrodesis rates approaching 100% (4, 23). The use of BMP in conjunction with a synthetic interbody device, such as poly-ether-ether-ketone (PEEK) (nonabsorbable spacer) (Fig. 3A) or Macropore (Hydrasorb; Medtronic Sofamor Danek, Memphis, TN) (absorbable spacer) (Fig. 3B) also promises to introduce "bone-free" arthrodesis in the future.

These synthetic devices have several advantages compared with the use of allograft and autograft. They are available in unlimited quantities, unlike allograft and autograft. They do not risk the transmission of diseases from a donor cadaver. They are not associated with any donor-site morbidity. They are machined perfectly to fit into the differing sizes of interbody spaces. The drawback of such spacers is their cost,
especially when they are combined with rhBMP. The authors have used PEEK and rhBMP in more than 25 cases of ACDF and have obtained a 100% fusion rate regardless of the number of levels fused or the patient’s use of tobacco (Fig. 3C). Further study will determine whether the costs incurred by the use of synthetic spacers and BMP are justified by their benefits.

CONCLUSION

The literature clearly indicates the superiority of autograft in ventral cervical arthrodesis. Autografts are less likely to subside and more likely to become incorporated. It is also evident that using allograft spares patients autograft donor site harvest morbidity. With the introduction of ventral cervical plating, the advantages of autograft versus allograft have narrowed. With ventral cervical plating, subsidence is diminished and allograft incorporation rates are higher. Many surgeons today consider the use of allograft more desirable than autograft in most cases. Either option is acceptable for a one-level arthrodesis, and often the surgeon and patient decide together. Allograft use in two or more level arthrodesis should probably be supplemented with ventral instrumentation. To maximize fusion rates, it is the authors’ practice to use ventral cervical plate fixation in all cases in which allograft is used as the interbody spacer.

Consideration is given to using autograft in patients at high risk for a pseudoarthrosis. High-risk patients include smokers, end-stage renal disease, and patients undergoing three or more levels of arthrodesis. Autograft is also favored in posterior cervical applications because the lack of graft loading results in a poor environment for arthrodesis.

REFERENCES


TECHNIQUES OF POSTERIOR C1–C2 STABILIZATION

INSTABILITY OF THE atlantoaxial complex may result from inflammatory, traumatic, congenital, neoplastic, or degenerative disorders and often requires surgical stabilization. Initial dorsal wiring techniques allow safe fixation but require rigid external immobilization and have been associated with high fusion failure rates. Rigid screw fixation techniques including transarticular screw fixation and C1–C2 rod-cantilever fixation offer higher fusion rates and less need for rigid immobilization but are more technically demanding. C1–C2 fixation using crossing C2 laminar screws offers rigid fixation but without the technical demands of C2 pars placement. The history and techniques of dorsal fixation of the atlantoaxial complex are reviewed, and the success rates and complications of each are discussed.

KEY WORDS: Atlantoaxial joint, Cervical spondylosis, Outcome, Rheumatoid arthritis, Spinal fusion, Trauma, Treatment

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The atlantoaxial complex is a complicated structure composed of the upper two vertebrae of the cervical spine, their articular surfaces, and several crucial ligaments. Because of this intricate relationship, its architecture allows flexion, extension, lateral bending, and rotation (45). It is because of these characteristics that atlantoaxial instability can occur when any part of the components are damaged by trauma, inflammation, neoplasm, or congenital defects (17). Several techniques have been described to address this problem, ranging from external immobilization to ventral and/or dorsal surgical fusion and internal fixation procedures. All of these have their different advantages, risks, and success or failure rates.

The atlantoaxial complex accounts for more than half of the rotatory movement of the head with respect to the thoracic spine (45). Because of this, a higher failure of immobilization (external of surgical fusion) in this region, compared with the remainder of the cervical spine, is encountered in clinical practice and described in the literature (17). The different techniques for stabilization of the atlantoaxial complex, including their proper indications, techniques, and their success and complication rates, are reviewed.

ANATOMY OF THE C1–C2 JUNCTION

The first cervical vertebra is named atlas because it supports the globe of the head. It has no body and no spinous process; it is ring-like and consists of an anterior arch, a posterior arch, and two lateral masses. The anterior arch presents the anterior tubercle for the attachment of the longus colli muscles at its anterior center surface; posteriorly, it hosts the fovea dentis, which serves as the articulation point for the odontoid process of C2. The posterior arch ends behind in the posterior tubercle and provides a rounded edge for the attachment of the posterior atlanto-occipital membrane. Behind each superior articular process is the sulcus arteriae vertebralis, which is a groove that represents the superior vertebral notch and serves for the transmission of the vertebral artery and also transmits the first spinal nerve. On the undersurface of the posterior arch, behind the articular facets, are the inferior vertebral notches. The lower border provides the attachment surface for the posterior atlantoaxial ligament. Each lateral mass carries an inferior and a superior articular facet, the superior facet surface being directed upward, medially, and backward, forming a cup for the corresponding condyle of the occipital bone. The inferior articular facet surfaces are circular and directed downward and medially, articulating with the axis and permitting the rotatory movements of the head. Just below the medial margin of each superior facet, the transverse atlantal ligament attaches, stretching across the atlas ring, dividing the vertebral foramen into an anterior part, which receives the dens, and a pos-
rior part, which transmits the spinal cord. The transverse processes are large and serve for attachment of the muscles that assist in rotating the head (23).

The second cervical vertebra is also known as epistropheus or axis because it forms the pivot in which the first vertebra rotates. In its front is a median longitudinal ridge that separates two lateral depressions for the attachment of the longus colli muscles. The dens has a neck, at which it joins the body, and an oval facet on its anterior surface, at which it articulates with the atlas. The neck is the insertion site of the transverse atlantal ligament, which retains the process in position. The apex gives attachment to the apical odontoid ligament and, caudally, on either side, presents an area for the attachment of the alar ligament, which connects the process to the occipital bone. The pedicles coalesce with the sides of the body and the root of the odontoid process and are covered by the superior articular surfaces. The transverse processes are very small and end up in a single tubercle, each perforated by the foramen transversarium. The superior articular surfaces are directed upward and laterally, whereas the inferior articular surfaces have the same plane as the other cervical vertebrae. The spinous process is large and presents a bifid, tuberculated extremity (23).

The vertebral artery typically enters the foramen transversarium at C6 and ascends rostrally. After exiting the foramen on the superior aspect of the axis, the artery courses laterally to pass through the foramen of the atlas. The vessel then courses postero-medially along the superior aspect of the atlas to enter the dura near the midline before traveling through the foramen magnum. The left vertebral artery is dominant in 35.8% of patients, hypoplastic in 5.7%, and absent in 1.8%. The right is dominant in 23.4% of patients, hypoplastic in 8.8%, and absent in 3.1%. Equivalent right and left vertebral arteries are present in 40.8% of patients (54, 55).

The risk of injury to the vertebral artery during placement of screws for atlantoaxial fixation has been calculated to be 4.1% per patient or 2.2% per screw inserted (60). These are considered to be highly associated with screw malpositioning. The typical course of the vertebral artery places the vessel in proximity to the ideal screw trajectory, and the incidence of anomalies of the artery in the atlantoaxial region has been calculated to be 2.3% (55). Eighteen percent of individuals have a high-riding C2 foramen transversarium (44). In addition, there have been reports of erosion on the C2 lateral mass and pars by the artery itself, and asymmetric grooving of the C2 pars. According to Abou Madawi et al. (1), 52% of their specimens were asymmetric, and the difference between the left and right sides was calculated by Igarashi et al. (30). They reported that the differences of the pars width on the superior surface averaged 1.2 ± 0.9 mm; the pars width on the inferior surface averaged 1.0 ± 0.8 mm; and the pars height averaged 1.2 ± 1.0 mm. The vertebral artery that showed differences in pars greater than a standard deviation were 15% for the superior surface, 20% for the inferior surface, and 16% for pars height. Forty-one percent of these vertebrae were asymmetric (30). At the level of the axis, studies performed by angiography or cadaver dissection have shown that the vertebral artery groove is an angulated canal with an inferior and lateral opening, which deviates the artery laterally before ascending into the atlas (1, 34, 55).

**BACKGROUND**

Until the past few decades, the mainstay of treatment for cervical instability was external immobilization. However, the nonunion rate and morbidity associated with its use in certain populations preclude its use in some instances. In 1910, the first description of surgical treatment for atlantoaxial instability appeared in the literature. Mixter and Osgood (39) reported securing the posterior arch of the atlas to the spinous process of the axis with a heavy silk thread. Since then, other techniques have been developed. These include the Gallie type in 1939 (19), the Brooks and Jenkins in 1978 (5), the interlaminar clamp (29, 37), the Magerl transarticular screw (36), the C1–C2 rod-cantilever technique (20, 21, 28, 48, 52a), and the C2 laminar technique (33, 57, 58).

**INDICATIONS**

**Traumatic Fracture**

Traumatic damage to the C1–C2 complex can lead to significant instability. Fracture of the dens is the most common traumatic injury requiring stabilization; however, multiple options exist for the management of this fracture (59). Anderson and D’Alonzo (2) divided the dens fracture into three groups. Type 1 fractures involve fractures through the upper dens, and, although they are generally considered stable, a recent report suggested that this stability is not absolute (50). Type 2 fractures occur at the junction of the dens and the body of C2, and Type 3 fractures extend into the C2 body. Although anterior interior fixation with the odontoid screw technique is considered a simpler procedure, it is contraindicated in multiple situations. These include disruption of the transverse atlantal ligament, associated comminuted fracture of one or both atlantoaxial joints, unstable Type 3 fractures, atypical Type 2 fractures with oblique of comminuted fracture lines, irreducible fractures, associated thoracic kyphosis, and pathological fractures among other situations (40).

The indications for dorsal fusion in the setting of odontoid fractures include an associated fracture to one or both of the atlantoaxial joints; associated Jefferson fractures of the atlas may place the C1–C2 joint at risk for subluxation (31). In patients with extensive, multisystem trauma who require constant access to the chest and neck, sometimes the use of a halo vest immobilization device is not recommended. In these patients who have experienced a Type 3 dens fracture, surgical fusion provides an acceptable alternative and facilitates earlier mobilization (10).

Type 2A fractures are considered those that have significant comminution at the base of the dens and behave differently from other Type 2 with a high rate of nonunion with external immobilization (25). Posterior displacement of the dens leads to nonunion rates of 70 to 89% (10, 49). Anterior displacement of more than 6 mm leads to nonunion in 67% of cases, compared
with 9% in those displaced less than 6 mm (26). However, significant displacement in either direction prevents adequate placement of ventral screws through the body and into the dens if the fracture cannot be reduced. In these cases, dorsal stabilization is required.

Patients with marked thoracic kyphosis and Type 2 or shallow Type 3 fractures often cannot be approached ventrally because the rib cage prevents obtaining the angle for correct screw trajectory. Patients with prominent posterior osteophytes and an associated fracture cannot undergo cervical hyperextension to obtain the perfect angle because of the risk of spinal cord injury from compression. In pathological fractures from neoplastic disease of the dens, ventral fixation screws are contraindicated, and dorsal fusion techniques provide a viable option that avoids placement of instrumentation into the diseased odontoid (59).

Traumatic Ligamentous Laxity

Flexion of the upper cervical spine is limited by the tectorial membrane and cruciform ligament, including the transverse ligament, and the alar ligaments (12, 43). If the atlantodental interval (normal value, 2–4 mm) has a value greater or equal to 5 mm, ligamentous laxity should be suspected; and an interval of more than 10 to 12 mm indicates complete destruction of the ligamentous complex (16). Axial rotation of the upper cervical spine is limited by the alar ligaments, and damage to these increases rotation in the contralateral side by 30% (11). Failure of any of the components of the atlantoaxial ligament complex requires dorsal surgical fusion.

Rheumatoid Arthritis

Rheumatoid arthritis (RA) is a systemic disease that often affects the cervical spine, both the atlantoaxial junction and the subaxial spine. In as many as 49% of patients with RA, symptomatic atlantoaxial subluxation is encountered (15), with 20% of these becoming myelopathic (56). As many as 88% of RA patients have radiographical evidence of C1–C2 involvement, and postmortem studies have shown atlantoaxial dislocation to be the cause of death in as many as 10% of patients with RA (15, 38).

RA progression in the cervical spine causes pain and symptoms of cord compression, and multiple authors advocate surgery, regardless of the presence of neurological symptoms, if the posterior atlantodental interval is equal or less than 14 mm (4). Dorsal fusion has been more successful than ventral approaches for stabilizing the rheumatic atlantoaxial complex (46).

Congenital Disorders

A failure of the tip of the dens to fuse with the main odontoid process results in persistent ossiculum terminale. Although it is often confused with a Type 2 dens fracture, this process is stable, and the height of the dens is unaffected. Os odontoideum is the failure of the dens to fuse with the body of the axis. Both os odontoideum and odontoid agenesis may lead to incompetence of the cruciate ligament and subsequent atlantoaxial instability (42). The evidence-based indications and treatment options for os odontoideum have previously been reported (2a).

TECHNIQUES: DORSAL WIRING

Beginning with Mixter and Osgood (39), the initial techniques of dorsal atlantoaxial fusion involve variations of wiring together of the posterior elements of the axis and atlas. These techniques are technically simple and require no special intraoperative equipment, such as fluoroscopy or surgical navigation. These techniques all require rigid postoperative immobilization for successful fusion.

Gallie Fusion

In 1939, Gallie (19) first described the stabilization of subluxed vertebrae with “fine steel wire passed around the laminae or spines . . . and . . . by bone grafts laid in the spines of the laminae and articular facets.” The Gallie-type fusion (Fig. 1) involves a median bone graft notched over the spinous process of C2, with a sublaminar wire placed around the posterior arch of C1 and looped around the spinous process of C2 to hold the graft in place.

Although this is the simplest dorsal fusion with minimal technical hazards, it remains the poorest biomechanical construct. The Gallie-type fusion offers minimal stabilization in rotation, with comparable anteroposterior translation in response to flexion with other techniques (24). This contributes to its rate on nonunion as high as 25%, and patients require longer periods of external immobilization postoperatively (7). The placement of an onlay graft also reduces the fusion rate compared with grafts placed under compression. Because it requires an intact posterior arch of C1, the Gallie-type fusion cannot be used if there is an associated Jefferson fracture or rheumatic involvement of the atlas. Posterior rachischisis, with an incidence of 4% (51), also prevents stabilization by this approach. The Gallie-type fusion is often used to supplement other techniques.

Brooks-Jenkins Fusion

In the Brooks-Jenkins fusion (Fig. 2), the posterior arch of the atlas and the laminae of the axis are exposed, and doubled 20-gauge wires are passed under the laminae of the atlas and axis bilaterally. Two posterolateral autologous iliac crest bone grafts are beveled to fit both interlaminar spaces and held in place by the overlying wire (5). Although this construct provides more rotational stability than the Gallie-like technique, the simultaneous passage of two-segment sublaminar wires results in a wider curvature and potentially compresses the cord in a “clothesline” fashion (37). Successful fusion rates of 93% are described (5). The Brooks-Jenkins fusion also requires an intact posterior arch of C1 and has the same contraindications as described for the Gallie method.

Sonntag’s Modified Gallie Fusion

In Sonntag’s Modified Gallie fusion (Fig. 3), a single bicortical bone graft is fit into the interlaminar space between the atlas and the axis and notched to accommodate the spinous processes of the axis. This technique provides increased stability without the disadvantages of the two-level sublaminar wires in the Brooks-Jenkins technique (9). Patients are kept in a halo preoperatively and intraoperatively for optimal anatomic realignment. The C1–C2 interlaminar space is widened with a high-speed drill, the spinous process and laminae of the axis are decorticated, and the inferior aspect of the spinous process is notched to seat the wire. A 4-cm-long iliac crest graft is shaped to fit the interlaminar space, with the concave cortical surface facing the dura. The inferior aspect of the graft is notched to lie over the spinous process of the atlas, and two strands of #24 wire are passed around the posterior arch of the atlas, over the bone graft, and around the notched spinous process of the axis. The wires are tightened to three turns per centimeter. Postoperatively, the patients are recommended to stay in a halo for 3 months, followed by a hard collar for 4 to 6 weeks. A 97% fusion rate is described.

Interlaminar Clamp Technique

The interlaminar clamp technique (Fig. 4) provides similar fusion to that of the Brooks-Jenkins method, but without the disadvantage of sublaminar wires. In the Halifax technique, a double hook and screw construct stabilizes the laminae of C1 and C2 bilaterally and secures bilateral interlaminar bone grafts (37). Initially, this technique was described on a single side only and without the addition of a bone graft with acceptable results, but when used to stabilize the C1–C2 complex, bilateral clamps with bone grafts have proven to be superior (29). Biomechanical experiments have shown this technique to provide excellent anteroposterior stability. However, the rotational movement has been less successful than either the Brooks-Jenkins or the Margerl techniques (24, 41). Because it also requires an intact arch of C1, it has the same contraindications as the methods described previously. Immobilization after surgery only requires a cervical collar, allowing early mobilization.
TECHNIQUES: SCREW FIXATION

Because of the limitations of stabilization of rotation observed with all dorsal wiring techniques, newer techniques of dorsal atlantoaxial fixation have used rigid screw fixation of the atlas and axis. These rigid screw techniques provide significantly higher rates of fusion and allow less rigid postoperative immobilization but are technically more demanding, requiring intraoperative fluoroscopy and/or surgical navigation tools.

Transarticular Screw Technique of Magerl

The Magerl transarticular screw method (Figs. 5 and 6) (36) is more technically demanding than techniques of dorsal wiring, but it has two advantages. First, it does not rely on intact posterior elements and can, therefore, be used in patients in whom the previously described techniques are contraindicated. Secondly, the transarticular screw greatly reduces rotatory movement, increasing the stability and fusion rates of the construct.

Technique

Preoperative planning with plain x-rays and fine-cut computed tomographic scans is essential (59). Traction may be used to restore anatomic alignment, resulting, therefore, in a technically simpler procedure. Preoperative fiberoptic intubation and perioperative somatosensory evoked potentials are advocated by some surgeons (52). The patients are placed in the prone position with their heads fixed in pins or rested on a horseshoe head holder. Final positioning is performed using real-time fluoroscopy to verify alignment of the atlantoaxial complex.

The spinous processes of C1–C3 are exposed, and using subperiosteal dissection, the posterior arch of the atlas is exposed, but only by 10 or 13 mm on each side of the midline to prevent exposure of the vertebral artery. The spinous process and laminae of the axis are similarly exposed, and the dissection is carried laterally to expose the articular processes of C2 and C3. The C2–C3 joint capsule is left intact.

The C1–C2 joint is exposed and the articular cartilage is removed to promote bony fusion. The dissection is extended along the lamina of C2 into the joint space, and the adjacent neurovascular plexus containing the C2 nerve root is carefully retracted caudally. A 20-gauge wire is passed around the posterior arch of the atlas to allow gentle retraction on the atlas and facilitate alignment of the atlantoaxial complex during screw placement. This step is obviously omitted if the posterior arch of C1 is not intact.

The entry point for screw placement is 2 to 3 mm lateral to and 2 to 3 mm above the medial aspect of the C2–C3 facet, respecting the course of the vertebral artery. A 2.5-mm drill bit is directed sagittally, aiming toward the anterior arch of C1, using fluoroscopy. This requires a percutaneous approach from approximately the level of C7. A 3.5-mm tap is used for the entire length of the trajectory to prevent possible anterior dislocation of the atlas during screw insertion. A 3.5-mm fully threaded screw of the appropriate length is then inserted, stopping just short of perforating the anterior cortex of the atlas. The process is repeated on the other side. The laminae of both the atlas and the axis are decorticated, and autologous iliac crest bone grafts are laid over the drilled surfaces to encourage bony fusion. As described before, this technique can then be supplemented by a Gallie-type, Brooks-Jenkins, or Sonntag fusion. Postoperatively, a hard collar is worn at all times for the first 6 weeks, with close clinical and radiographic follow-up.

Stability

Several clinical and cadaveric studies have shown the reliability in the strength and stability of the transarticular screw construct (59). Successful fusion rates have been described as between 86.9 and 100%, and biomechanical cadaveric studies show that the construct is stable not only in flexion and extension, but also in rotation (24, 31, 34, 52). A recent study by Reilly et al. (47) comparing C1–C2 wiring with transarticular screw fixation, documented fusion rates of 71 and 93%, respectively. Fuji et al. (18), however, described a 95.5% rate of adequately positioned screws with a 69.4% rate of the screws perforating the anterior cortex of the anterior arch of the atlas, which, in most cases, was clinically nonsignificant. A review of 75 patients performed by Haid et al. (27) documented a fusion rate of 96%.
Complications

The reported rates of complications for this technique are low. They range between 2 and 14%, depending on the series (24, 31, 34, 52). Farey et al. (14) reported a 4% risk of vertebral artery injury. Dickman and Sonntag (8) have documented a 2% risk of screw malpositioning with no neurological complications. Madawi et al. (34) reported malpositioned screws in 14%, vertebral artery injuries in 8%, hardware failure in 4%, temporary hypoglossal nerve paresis in 2%, and iliac crest donor site infection in 2%.

The risk of vertebral artery injury with this technique has been well documented in the literature. Apfelbaum (3) reported a fatality from bilateral vertebral artery injuries, Coric et al. (6) described an arteriovenous fistula resulting from damage to the artery during screw placement, and Abou Madawi et al. (1) and Madawi et al. (34) reported intraoperative vertebral artery injuries in 8.2% of their patients. The senior author (NMW) of this study performed a retrospective survey of the risk of vertebral artery injury during screw placement from data collected from nearly 2500 placed screws in more than 1300 patients. Including known and suspected cases, the risk of vertebral artery injuries was 4.1% per patient or 2.2% per screw inserted. Only 3.7% of patients with vertebral artery injury incurred neurological injury (60).

The main limitation of the transarticular technique relates to anatomic variations precluding safe screw placement in some patients. A cadaveric study by Abou Madawi et al. (1) and Madawi et al. (34) demonstrated that bilateral screws could not be placed in up to 20% of specimens because of anatomic variations in the location of the foramen transversarium that placed the vertebral artery at risk during screw placement.

C1–C2 Rod-Cantilever Technique

Although the transarticular screw technique of Magerl provides superior fixation than dorsal wiring techniques, it remains a technically challenging procedure. Because of the narrow restrictions on screw trajectory necessary to traverse the C2 pedicle and C1–C2 joint without endangering the vertebral artery, up to 20% of patients cannot have safe placement of bilateral screws (1, 34). In response to these technical limita-

![Figure 7](image) Artist’s rendering of a C1–C2 rod-cantilever fusion; anteroposterior view.

![Figure 8](image) Artist’s rendering of a C1–C2 rod-cantilever fusion; lateral view.
rods are placed in the polyaxial screw heads and secured in position. C1 and C2 are then decorticated posteriorly, and autologous iliac crest cancellous bone is placed over the decorticated surfaces. Postoperatively, the patients wear a soft cervical collar for 2 to 3 weeks.

Results

Harms and Melcher (28) reported satisfactory screw placement and reduction achieved in all 37 patients in their series, with no dural lacerations or vertebral artery injuries. There were no cases of implant failure, and, 1 year after surgery, x-rays demonstrated solid fusion in all cases. Although there were no subsequent data, Harms and Melcher (28) also described the use of their technique for reduction and instrumentation without fusion, with a subsequent removal of instrumentation in a second stage, 3 to 4 months later. According to their data, the patients demonstrated a clinical increase in neck motion as well as restoration of motion of the C1–C2 joint on dynamic magnetic resonance imaging scan examination.

Stokes et al. (52a) reported a successfully applied fusion technique in four patients, with no occurrence of vertebral artery injury, C2 nerve injuries, or spinal cord injuries. Clinical and radiographic evidence of solid fusion at the 4- and 12-month follow-up examinations were documented in all patients.

Although technically simpler than the transarticular screw technique of Magerl, C2 pars screw placement remains technically demanding and requires intraoperative fluoroscopy and/or surgical navigation. Although more widely applicable than transarticular screws, some patients have a narrow C2 pars or medially located foramen transversarium, precluding safe C2 pars screw placement (13). Additionally, the lateral-to-medial trajectory makes screw placement difficult in patients with thick musculature.

Bilateral, Crossing C2 Laminar Screws

Leonard and Wright (33) and Wright (57, 58) described a new technique for rigid screw fixation of the axis and incorporation into atlantoaxial fixation or subaxial cervical constructs (Figs. 9–12). This involves the insertion of polyaxial screws into the laminae of C2 in a bilateral, crossing fashion, which
are then connected to C1 lateral mass screws in a manner similar to the C1–C2 rod-cantilever technique discussed above. Because the C2 screws are not placed near the vertebral artery, this technique allows safer rigid fixation of C2 without fluoroscopy or surgical navigation, although fluoroscopy is still needed for C1 screw fixation. However, unlike the transarticular or rod-cantilever techniques of atlantoaxial fixation, this technique requires intact posterior elements of C2.

**Technique**

Patients are placed in the prone position with the head and cervical spine maintained in the neutral position using the Mayfield head holder (Integra Life Science, Plainsboro, NJ). The posterior arch of C1 is identified to the lateral aspect to visualize the bilateral lateral masses. The spinous process, laminae, and medial lateral masses of C2 are then exposed. The spinous processes, laminae, and lateral masses of the subaxial spine are exposed as needed. C1 lateral mass screws are placed using the Harms technique described above.

The high-speed drill is used to open a small cortical window at the junction of the C2 spinal process and lamina on the right, close to the rostral margin of the C2 lamina. Using a hand drill, the contralateral (left) lamina is carefully drilled to a depth of 30 mm, with the drill visually aligned along the angle of the exposed contralateral laminar surface. The trajectory is kept slightly less than the downslope of the lamina to ensure that any possible cortical breakthrough would occur dorsally through the laminar surface rather than ventrally into the spinal canal. A small ball-probe is used to palpate the length of the hole to verify that no cortical breakthroughs into the spinal canal have occurred. A 4.0 × 30-mm polyaxial screw is carefully inserted along the same trajectory. In the final position, the screw head remains at the junction of the spinous process and lamina on the right, with the length of the screw within the left lamina.

A small cortical window is made at the junction of the spinous process and lamina of C2 on the left, close to the caudal aspect of the lamina. Using the same technique as above, a 4.0 × 30-mm screw is placed into the right lamina, with the screw head remaining on the left side of the spinous process. After screw placement, all exposed laminar surfaces are decorticated with the high-speed drill. The C1 lateral mass screws are connected to the crossing, bilateral C2 laminar screws with posterior rods. Autologous iliac crest bone grafts are wedged under the rods between the lamina of C1 and the spinous posterior rods. Autologous iliac crest bone grafts are used to fill any small cortical windows that may have occurred.

After screw placement, all exposed laminar surfaces are decorticated with the high-speed drill. The C1 lateral mass screws are connected to the crossing, bilateral C2 laminar screws with posterior rods. Autologous iliac crest bone grafts are wedged under the rods between the lamina of C1 and the spinous posterior rods. Autologous iliac crest bone grafts are used to fill any small cortical windows that may have occurred.

In the initial series of 10 patients by the senior author (JAM), no intraoperative or immediate postoperative complications were encountered. All C2 screws were placed satisfactorily, without any technical problems during screw insertion, and no neurological or vascular complications were encountered. All patients demonstrated stability on flexion-extension x-rays obtained at 6 weeks. The first two patients treated with this technique had thin-cut computed tomographic scans with sagittal and coronal reconstructions obtained 6 months after surgery. Both patients had solid arthrodesis with bridging bone from the posterior arch of C1 to the lamina of C2 (57). A larger series of 20 patients with a follow-up period of at least 1 year has recently been reported (58), with 100% fusion rates and no complications.

**Initial biomechanical testing** suggests atlantoaxial stabilization with C2 translaminar screws to be equivalent to transarticular C1–C2 fixation and C1–C2 rod-cantilever techniques. Gorek et al. (22) compared C2 translaminar screw fixation with C1–C2 transarticular fixation and reported equivalent stability. More recently, Lapsiwala et al. (32) concluded that C2 translaminar screws provide adequate stiffness compared with anterior transarticular screws, posterior transarticular screws, and C2 pedicle screws. However, it should be cautioned that this is a newer technique compared with the C1–C2 transarticular technique of Magerl and requires more study before widespread implementation.

**CONCLUSION**

Many techniques of dorsal atlantoaxial fixation have been developed during the past decades, all with strengths and weaknesses. Dorsal wiring techniques are technically simple but have lower rates of successful fusion and require rigid postoperative immobilization. Rigid screw fixation provides higher fusion rates and allows less-rigid postoperative immobilization but is technically more demanding. Transarticular C1–C2 and C2 pedicle fixation require intraoperative fluoroscopy and/or surgical navigation and can place the vertebral artery at risk in some patients. Crossing, bilateral C2 fixation is technically simpler but requires intact C2 posterior elements. These various fixation techniques may provide the surgeon with options to treat atlantoaxial instability with the most appropriate technique depending on patient anatomy, surgical indication, presence of the posterior elements, and surgeon ability.

**REFERENCES**


35. Deletion of proof.
Ventral cervical plates have been employed to provide immediate fixation of the cervical spine since the 1970s (1, 9, 21, 45). Initially used primarily for trauma, their use has increased with time, such that they are now used commonly for reconstruction of the spine after cervical discectomy, corpectomy, or combinations thereof. This increased implementation has occurred despite the absence of convincing data that the plates beneficially affect patient outcome in the vast majority of cases. Given the costs associated with plate use, it is important to question the widespread application of such implants. The purpose of this article is to review the relevant literature pertaining to the use of ventral cervical plates and to provide a balanced discussion of the relative merits of ventral cervical fusion with or without instrumentation.

METHODS

A computerized search of the database of the National Library of Medicine from 1966 to December 2002 was performed using PubMed. The search terms used were: anterior cervical plate and randomized controlled trial (RCT); ventral cervical plate and RCT; cervical plate and RCT; cervical fusion and RCT; anterior cervical plate and outcomes; and ventral cervical plate and outcomes. Individual case reports, case series with fewer than 20 patients, technical notes, non-English language studies, and studies not relevant to the issue of cervical plating were discarded. The reference lists of the relevant articles and several review articles were used to find additional papers for review. Finally, the authors contributed papers known to them that were relevant but did not appear in the literature search or as a secondary reference.

RESULTS

Three randomized studies comparing plated versus non-plated cervical fusions were identified. Several other randomized controlled trials that compared anterior cervical discectomy (ACD) alone with anterior cervical discectomy and fusion (ACDF) were identified. These papers were used primarily as background material. Several historical cohort studies concerning ACDF with and without plating were identified and reviewed. Several large case series that provide useful information concerning cervical corpectomy were identified, and several biomechanical studies and cost-effectiveness studies that provided supportive data were also identified. A total of 143 articles were reviewed. Those providing directly relevant information are cited in the text.

DISCUSSION

Cervical plating may be used to stabilize the spine in a variety of conditions. The discussion section is, therefore, organized by the operative indication.
Trauma

Although no RCTs exist to support the use of ventral instrumentation for stabilization of the spine after trauma, the immediate rigidity provided by cervical plates has been exploited by many authors for the treatment of post-traumatic spinal instability. The application of cervical plates does not restore full rigidity to the spine (13, 41). Rigid cervical plates do, however, seem to perform very well in the setting of trauma. Herrmann (21), Boccanera and Laus (5), Bohler and Gaudernak (6), Bremer and Nguyen (8), and other groups (11, 45) all described small series of ventral plate fixation of the cervical spine for trauma in the 1970s and 1980s. Caspar et al. (9) described excellent results with plate fixation in the setting of fractures and fracture dislocations in a relatively large series of patients in 1989. Since then, multiple authors have reported excellent results using a variety of plates for the treatment of cervical trauma (1, 2, 18, 30, 33, 34, 36, 44). Given the immediate stabilization provided by cervical plating, it would seem that posttraumatic instability would be the ideal indication for ventral cervical plate fixation, and satisfactory results may be obtained in a variety of fracture types. Rigid plate fixation has been successfully applied for the treatment of burst fractures and fracture dislocations of the cervical spine (Figs. 1 and 2). Biomechanical studies of even the most rigid plates demonstrate some dependence on the dorsal elements for the maintenance of stability (41, 42). For this reason, gross instability with incompetence of the dorsal elements and an inability to reduce fractures from a ventral approach remain indications for dorsal or combined approaches (Fig. 3).

Multilevel Cervical Reconstruction

Reconstruction of the ventral cervical spine after multilevel corpectomies is difficult and is associated with significant complication rates. Although Saunders et al. (37) has reported a 5% graft displacement and a 3% pseudarthrosis rate in a consecutive series of 40 patients treated with central corpectomy, other authors have reported graft-related complication rates ranging up to 21% without the concomitant use of instrumentation (4, 7, 20, 27, 50). Riew et al. (35) reported an unacceptably high rate of complications in a series of 14 patients treated with a buttress plate (plate secured at the caudal end of the construct). Details regarding patient selection, operative technique, numbers of levels treated, and postoperative immobilization were not standard across the series, so a direct comparison cannot be made. However, it is clear that graft complications are a recognized hazard associated with cervical corpectomy. Clearly, any technology that decreases graft-related complications would be a welcome addition to the surgeon’s armamentarium.

The application of a ventral plate increases the initial rigidity of the instrumented segment (22, 26, 52). However, there are other biomechanical consequences that are not as obvious. For example, the application of the plate moves the instantaneous axis of rotation of the instrumented segment toward the plate itself (3). Therefore, the interbody graft is loaded in extension and unloaded in flexion, the opposite of what occurs in the noninstrumented spine (Fig. 4). The magnitude of this paradoxical loading is increased through the use of rigid plates. DiAngelo et al. (12) found that the application of

**FIGURE 1.** Ventral plate fixation after a burst fracture. This patient experienced a C5 burst fracture, as well as a subluxation at C4–C5 (A). B, corpectomy, followed by reconstruction with a fibular allograft and rigid plate, resulted in restoration of normal alignment and an excellent clinical outcome.

**FIGURE 2.** Facet subluxation injuries may also be stabilized with ventral cervical plates. This patient had normal results from neurological tests after a motor vehicle accident that resulted in facet subluxation (A). B, reduction was performed using axial traction and a ventral cervical fusion with rigid plate fixation. This technique allows immediate removal of any disc material herniated into the spinal canal. The use of this technique may also reduce the need to sacrifice adjacent motion segments in cases in which damage to the facet precludes single-level dorsal fixation.
a rigid cervical plate increased the global stiffness and decreased the global motion observed in a multilevel corpectomy model. However, flexion of the spine unloaded the graft, and extension caused excessive loading of the graft with only 7.5 degrees of motion. This phenomenon has been described as the “nutcracker” effect (12, 17). The authors thought that this amount of graft loading with extension could contribute to graft pistoning and failure. In a follow-up study, the same group of authors found that application of a translational plate that allowed rostral and caudal motion of the screws resulted in a significant reduction in the paradoxical loading of the graft (16). It is hypothesized, although certainly not proven, that the reduction of this nutcracker effect may improve graft healing and prevent certain graft-related complications.

Although some authors have reported excellent results with rigid plate fixation after multilevel cervical corpectomy (15, 28), others have described significant incidences of plate failure. For example, Vaccaro et al. (43) described a very high technical failure rate in a series of two- and three-level cervical corpectomies reconstructed with an interbody graft and rigid plating system. These authors reported a 50% failure rate in the three-level corpectomy group compared with a 9% failure rate in the two-level corpectomy group. More recently, complication rates that were much lower and fusion rates that were much higher have been reported with the use of rigid plate fixation after cervical corpectomy. For example, Mayr et al. (28) report a fusion rate of 87% and an instrumentation failure rate of 5.4% in a series of more than 250 patients treated at a single institution. Panjabi et al. (31) and Kirkpatrick et al. (26) have each described the typical failure mechanism of long-segment plate fixation as screw loosening and migration, particularly at the caudal end of the construct. The use of translational (axially subsiding) plates may decrease the incidence of this type of failure mode. Similarly, new techniques using segmental decompression and multiple points of fixation (Fig. 5) may prove more reliable for the reconstruction of the spine.

Currently, there are no RCTs or even large matched-cohort studies available to compare plated versus nonplated cervical corpectomy models. The use of plates for the reconstruction of the spine in this situation is based on biomechanical data and on the fact that high complication rates are observed without the use of plates. As new techniques and technology are brought to bear, it is likely that our knowledge base will increase primarily through the publication of prospective series.
The most common application of ventral cervical plates is after ventral cervical discectomy and fusion. Three randomized trials have compared the results of single-level ACDFs with and without plate fixation. Savolainen et al. (38) randomized 91 patients to ACD, ACDF, or ACDF with plate. The vast majority of these patients were followed for 4 years. Overall, there were no statistically significant differences between any of the groups at any point during the follow-up period. There was a tendency for patients in the ACD group to develop kyphosis. However, the authors did not think that this was significant (38). Similarly, Zoega et al. (51) studied 27 patients who were randomized to ACDF with or without plate fixation. They found no significant differences in clinical outcomes, as measured by a visual analog scale. However, they also found a decreased tendency for the development of kyphosis in the ACDF plus plate group. Grob et al. (19) randomized 40 patients to ACDF or ACDF plus plate and found better graft height preservation in the plated group. The plated group did slightly, but not significantly, better than the nonplated group in terms of functional outcome measures.

Several large retrospective series have been published concerning outcomes with or without plate fixation. The results of ACDF are, in general, excellent, with most series reporting good or excellent results in 80 to 95% of patients (23). The addition of a cervical plate has been reported to result in slight improvement in clinical and radiographic outcomes (24, 47). The addition of a plate may improve maintenance of lordosis and decrease graft complications, such as collapse (10, 24, 25, 39, 46, 47). Although uncommon, the development of a cervical kyphosis can result in a debilitating and difficult to treat deformity (Fig. 6). The most readily apparent advantage of the use of a ventral cervical plate, however, is the immediate increase in the rigidity of the fused motion segment (51, 52). This immediate rigidity allows the immediate mobilization of the patient without a cervical orthosis in cases of single- and double-level ACDF for degenerative disease. This benefit is not associated with substantial increased risk of complication, and, as mentioned, graft-related complications seem to occur less often with the use of plates (40).

Taken as a whole, the medical literature does not provide substantial evidence that ventral plate fixation adds to improved clinical outcomes in patients undergoing single-level ACDF.
ACDF. Indeed, three randomized trials concerning the use of such plates failed to demonstrate an improved outcome. These RCTs are not alone in their failure to identify a benefit to a therapy that seems to make sense. For example, there are several RCTs that fail to demonstrate an advantage of ACDF over ACD, despite the known tendency for ACD to result in kyphosis (14, 38, 49). Adding fuel to the fire is an RCT comparing ACDF to physiotherapy that found no differences in functional outcomes 1 year after enrollment (32). Each of the cited RCTs may be criticized for the size of the treatment groups, patient selection criteria used, length of follow-up, and potential insensitivity of the outcome instrument used. Despite this, better data is not available. In this case, the absence of proof is certainly not the proof of absence. There are few surgeons, physiotherapists, rehabilitation physicians, or patients who are not absolutely convinced regarding the efficacy of surgical decompression for the relief of cervical radiculopathy symptoms.

Similarly, there are few surgeons who have treated deformities related to the kyphogenic tendencies of ACD who discount the advantages of a biomechanically sound fusion. It is possible that the failure of these small studies to detect a significant difference between groups is simply related to the limited power of these series in the context of excellent results achieved in the control groups. Successful outcomes for ACDF are routinely reported in the 90% range (see above). For an alternative procedure to be better and for this effect to be discernible with any reliability, we would need to have a fabulous outcome rate, and hundreds (if not thousands) of study patients are needed to achieve statistical power. In short, we may simply be witnessing a ceiling effect.

Despite this paucity of literature-based evidence, the use of ventral plates for single-level ACDF is quite prevalent. Socioeconomic factors are certainly a consideration. The need for postoperative immobilization after ACDF without a plate does delay return of the patient to normal activities. The $700 to $1500 cost of a plate and the few minutes required to place the plate may be inconsequential if one considers the ability of the patient to return to work a month earlier. The use of a plate may actually provide an overall cost savings (29) and certainly improves patient comfort in the first weeks after surgery.

In the case of multiple-level ACDF (defined here as two or more levels), there is evidence suggesting that the use of plates is associated with higher fusion rates, as well as improved patient satisfaction. Katsuura et al. (25) reported a historical cohort series of approximately 70 patients who underwent multilevel ACDF. The plated group had fewer nonunions, had less graft collapse, and had better maintenance of cervical lordosis (25). Similar results (i.e., higher fusion and satisfaction rates with the use of plates) were echoed by Wang et al. (46, 48) in two separate series (two- and three-level ACDF). Zoega et al. (52) noted improved graft height and less angular motion throughout the fused segment in a series of patients undergoing two-level ACDF.

Ultimately, we think that the beneficial clinical effects of single-level ACDF with plate fixation will be demonstrated in an unassailable fashion. The measurable medical benefit may be small because of the excellent results obtained in the nonplated control group. However, the quicker return to activity, the lack of immobilization requirement, and the incrementally higher fusion rates will ultimately result in plated ACDF being recognized as the procedure of choice for the ventral treatment of cervical disc disease. It is the responsibility of surgeons and patient advocates to either generate the required data to support such treatment patterns or to alter treatment patterns to match the reported data.

CONCLUSION

Ventral cervical plate fixation immediately increases the rigidity of the cervical spine. The use of such plates for spinal reconstruction after trauma is supported by basic principles and numerous retrospective and prospective case series. The limitations of the stabilizing effects of plate fixation have been well described. The use of ventral cervical plates for multilevel disease is supported primarily by biomechanical data and retrospective case series. Biomechanical and clinical studies using translational plates will likely influence the choice of implants in the future. In single-level degenerative disease, there is no significant support for plate fixation in the literature. Three RCTs have failed to demonstrate an advantage of plate fixation with regard to ultimate clinical outcome. However, the literature concerning plate fixation is lacking in high-quality studies. It may be extremely difficult to establish the benefit associated with plate use in this scenario because of a ceiling effect. An economic argument may be made to justify the use of ventral cervical plates, and several large case series do support their use. As we continue to strive for faster, better, and safer alternatives to traditional procedures, it must be kept in mind that proof of the innovations and advances through well designed and appropriately powered clinical studies are mandatory.

REFERENCES

D}ecompression and fusion of the cervical spine is a well-accepted treatment for patients with specific intractable symptoms related to degenerative disc disease. Much effort has been spent on improving the rates of successful arthrodesis, given the biomechanically challenging environment within the relatively mobile cervical spine. Rigid internal fixation techniques have improved significantly to enhance the rate of fusion, although the indications for their use are continuously evolving. The instability potentially created by the decompression of neural elements both anteriorly or posteriorly in the cervical spine may be addressed with arthrodesis supplemented by internal fixation. This review summarizes the techniques and indications for rigid internal fixation within the spondylotic cervical spine.

**CONSIDERATIONS FOR RIGID INTERNAL FIXATION WITHIN THE SPONDYLOTIC CERVICAL SPINE**

In general, rigid internal fixation can provide immediate stability to the cervical spine, assist in the correction of deformity, promote bony fusion, and allow for early patient mobilization, with reduced needs for external immobilization (58, 59). When appraising the role of internal fixation within the cervical spine of a patient experiencing the sequelae of intervertebral disc degeneration, it is important to consider the regional anatomy, kinematics, and subsequent biomechanical forces that must be overcome to achieve a solid bony fusion. The pathological changes associated with disc degeneration include disc narrowing and collapse, uncovertebral and facet joint arthrosis, and ligamentum flavum hypertrophy.
These abnormalities can lead to the loss of normal cervical lordosis and sagittal balance and probably contribute to the gradual decrease in cervical range of motion observed with advancing age. Despite this, the fact that the cervical spine is the most mobile region of the axial skeleton, coupled with the loss of normal sagittal plane balance with time, imposes significant kinematic and biomechanical challenges on internal fixation. The high degree of pseudarthrosis and failure of anterior plate fixation in the setting of multilevel corpectomy reconstructions are testaments to these challenges. Contemporary rigid anterior and posterior internal fixation systems for the cervical spine have tremendous stabilizing potential, and the rigidity of the cervical spine after the application of such fixation often exceeds that of the intact spine in biomechanical tests (19, 39, 71). Nevertheless, one must execute an exacting surgical technique in the reconstruction of the anterior column with interbody or strut grafts and reestablish normal sagittal alignment because the failure in either regard cannot be compensated by rigid internal fixation of any form. An understanding of these issues and of the technical aspects of instrumentation application makes rigid internal fixation an extremely valuable tool for surgeons in the management of cervical spondylisis.

**ANTERIOR INTERNAL FIXATION TECHNIQUES**

**General Operative Considerations**

Patients undergoing surgical management of cervical spondylisis require careful medical evaluation before surgery to identify and manage associated comorbid conditions. Neurophysiological monitoring can provide invaluable information regarding cord and root functioning before and during the procedure and, in some instances, can warn the surgeon of impending spinal cord injury and prompt a timely intervention (45). Once reliable baseline somatosensory and motor evoked potentials are acquired after anesthetic induction, the head can be gently and cautiously extended with a soft roll under the shoulders to facilitate the exposure and to restore lordosis of the cervical spine. This head extension must be performed incrementally and with extreme caution (if at all) in patients with severe cervical stenosis and myelopathy. The anesthesiology team in such cases must be forewarned to maintain the patient’s mean arterial pressure at a high-normal level to maximize spinal cord perfusion.

The anterior aspect of the cervical spine is accessed through a standard Smith-Robinson approach using the anatomic planes between the sternocleidomastoid and carotid sheath laterally and the esophagus and trachea medially. The more predictable course of the left recurrent laryngeal nerve influences some surgeons to perform this approach from the patient’s left side, although the importance of laterality in the incidence of iatrogenic recurrent laryngeal nerve injury is somewhat uncertain (9). A right-handed surgeon may find it slightly easier to approach the anterior cervical spine from the right. Either way, the approach is generally straightforward from a technical perspective. In revision cases, if one wishes to avoid the previous incision and approach from the contralateral side, an otolaryngology evaluation to assess the functioning of the vocal cords is important to exclude a previous nerve injury that may be otherwise functionally undetectable.

With exposure of the cervical spine and adequate retraction to protect the surrounding soft tissues (particularly the esophagus and carotid sheath), an anterior disectomy and corpectomy can be performed. Although the technical aspects are familiar to most, a few points warrant mention. In general, complete decompression is most reliably achieved by routinely resecting the posterior longitudinal ligament, although it is recognized that finding the plane between the dura and often-thickened posterior longitudinal ligament can be technically challenging in some cases of cervical myelopathy and impossible in many cases of ossification of the posterior longitudinal ligament. If performing a corpectomy, the bony resection should be wide enough (generally, ≥15 mm) to ensure complete decompression of the spinal cord. It is prudent to take note of the width of the vertebral body and the position of the vertebral arteries on the preoperative axial magnetic resonance imaging scan. The uncovertebral joints above and below serve as useful intraoperative landmarks for the lateral borders of the corpectomy trough. It is of critical importance to note these intraoperative cues while removing the cancellous vertebral body bone with a high-speed burr because lateral deviation can take one inadvertently into the foramen transversarium housing the vertebral artery. A rongeur can be used to perform some of the corpectomy if cancellous bone graft is required. For the subsequent reconstruction, the adjacent endplates should be burred down to the point of punctate bleeding but not further. Protuberant anterior osteophytes are commonly present and should also be resected for an anterior plate to sit flush against the vertebral bodies.

**Options for Anterior Column Reconstruction**

In general, anterior column reconstruction after disectomy and corpectomy is performed with structural autograft, allograft, or a metallic or synthetic spacer. Tricortical iliac crest bone autograft has remained the time-honored “gold standard,” but the limited amount that one can take from the crest and the associated morbidity of its harvest make allograft bone (often from the fibula) an attractive option, particularly for long reconstructions. At present, an increasing number of allograft choices are becoming available, although the long-term efficacy of their use in multilevel reconstructions has not been extensively studied.

**Anterior Cervical Plating Options**

A variety of plate and screw devices have been developed during the past two decades, since the introduction of the original Caspar (Aesculap, San Fransisco, CA) and Orozco (Synthes, Paoli, PA) anterior cervical plates. With the ever-expanding list of anterior fixation systems available on the market, a classification system was proposed by the Cervical Spine Study Group in 2002 to provide a framework for their biome-
Chemical characteristics (39a). The first distinction within this proposed nomenclature differentiates devices that do restrict screw backout from the plate from those that do not. The screws from the Caspar and Orozco systems did not lock into their respective plates, and, thus, were prone to screw backout. Virtually all contemporary plating systems restrict screw backout from the plate, and, thus, distinguish these past systems. For the current systems that restrict screw backout, the systems are either “constrained,” in that the screws rigidly lock to the plate to form a fixed angle device, or “semiconstrained,” in that the screws are allowed to rotate and/or translate with respect to the plate. “Rotationally semiconstrained” systems allow the screw to rotate in the sagittal plane with respect to the plate and are exemplified by the Atlantis plating system (Medtronic Sofamor Danek, Memphis, TN) and the Codman plating system (DepuySpine, Raynham, MA). “Translationally semiconstrained” systems allow the entire screw to translate with respect to the plate and are exemplified by what are typically called “dynamic plates.” Examples of these include the ABC plate (Aesculap, Center Valley, PA) and the DOC Rod anterior cervical system (DepuySpine), the latter of which should not be confused with the DOC Plate plating system (also from DepuySpine), which is a fully constrained system with screws that lock rigidly into the plate. Although the clinical indications for dynamic versus static systems have not yet been clearly established, it is essential for the surgeon to understand the biomechanical considerations of the particular anterior reconstruction being performed and to use the appropriate fixation devices accordingly.

The screws of the Caspar and Orozco systems did not lock into the plate, and in such “unconstrained” systems, bicortical screw purchase was advocated for optimal stability (17, 66). The nonrigid relationship between the screw and plate allowed the screws and the vertebral bodies to move with respect to the plate, leading to problems of screw backout, loosening, and failure (55). Plating systems were then developed that included a mechanism by which to lock the screw rigidly into the plate, thus, adopting the biomechanical advantage of a fixed-angle internal fixation device. Early constrained systems included the Cervical Spine Locking Plate (Synthes), the Orion anterior cervical plate (Medtronic Sofamor Danek), and the Peak polyaxial anterior cervical plate (DePuy-Acromed, Cleveland, OH). Contemporary anterior plate designs, such as that of the Reflex plate (Stryker-Howmedica, Allendale, NJ), allow for the screws to be automatically locked to the plate as they are inserted, with backout being prevented by an expanding and collapsing ring mechanism. Constrained plates with unicortical screws have been shown to provide enhanced stability compared with unconstrained devices with unicortical screws in in vitro biomechanical tests, yet bicortical screw purchase still afforded the greatest stability (38, 72). Although the enhanced stability of bicortical fixation may be particularly advantageous in specific scenarios, such as in multilevel reconstructions, severe osteoporosis, deformity correction, and in situations requiring a “rescue” screw, the potential for a catastrophic iatrogenic spinal cord injury from excessive screw penetration must be carefully weighed and considered. A retrospective analysis of hardware failures revealed a significantly higher incidence of failures with an unconstrained plating system as compared with a fully constrained system (55), and, for the most part, such unconstrained systems are no longer in use.

The excellent stability achieved with constrained anterior plating systems was reflected in the subsequent concern that the devices were, in fact, too rigid and, thus, did not accommodate for settling and the necessary load sharing for graft incorporation. This spawned the development of “semiconstrained” or “dynamic” plating systems that provide for some axial settling and compression of the graft, while still preventing screw backout. In general, this is accomplished by allowing the screws to rotate and/or translate in the sagittal plane with respect to the plate or for the rostral and caudal aspects of the plate to slide vertically with one another. This motion presumably allows the endplates to settle as the graft resorbs or telescopes into the endplates, rather than being “held up” by a rigid fixation device that stress shields the graft (Fig. 1). A biomechanical comparison of two such dynamic plates, the DOC (DePuy-Acromed, Raynham, MA) and the ABC (Aesculap, Tuttinglen, Germany) plates, against the two locked, fully constrained plates (the Cervical Spine Locking Plate and Orion) was performed by Brodke et al. (13) in a corpectomy model. Although both the fully constrained and dynamic plates effectively shared load with a full-length graft, only the dynamic plates allowed for load sharing with a 10% shorter graft that simulated subsidence. In this model of graft subsidence, the ability of the dynamic plates to settle and allow endplate contact with the shorter graft made these constructs significantly stiffer than the fully constrained systems. A number of semiconstrained plating systems are currently available on the market. Common to them is a mechanism to prevent screw backout while allowing for rotational or translational screw motion with respect to the plate. For example, the Reflex anterior cervical plate (Stryker-Howmedica) uses an expanding and collapsing ring mechanism in each screw hole to prevent backout; it is automatically engaged when the screw is inserted through the ring (Fig. 2).

Published reports of the clinical use of dynamic plates are rare. Epstein (29) retrospectively reviewed the results of dynamic plating in 48 patients who underwent anterior column reconstruction after single or multilevel corpectomies. It has been well documented that achieving fusion in such long, multilevel corpectomies is fraught with difficulties (67, 76). Epstein (29), however, reported a 0% failure rate in multilevel corpectomy reconstructions stabilized by dynamic cervical plate fixation, although the presence of posterior internal fixation in these patients—and, hence, circumferential stabilization—likely contributed to the high fusion rate.

Anterior Cervical Plating for Single- and Two-level Discectomy and Fusion

Perhaps one of the most contentious issues related to anterior cervical fixation surrounds the question of whether or not anterior plating is warranted for single- or two-level discectomy and fusion procedures in the setting of cervical spondylosis.
The reported radiographical and clinical outcomes with or without anterior cervical plating have both been extremely satisfactory. The proponents of fusion without plating argue that the application of fixation: 1) adds the cost of an implant to the procedure, 2) increases operating room time, 3) necessitates greater retraction of midline soft tissue structures, 4) increases surgical fees, 5) engenders the potential for hardware failure, and 6) does not ensure a superior clinical outcome to that of uninstrumented fusion (12). Advocates of plate fixation argue that the addition of anterior instrumentation: 1) reduces the rate of graft collapse or extrusion, 2) reduces the risk of pseudarthrosis, 3) more reliably maintains sagittal alignment, 4) reduces the need for external immobilization postoperatively, and 5) ultimately neutralizes the increased cost of the procedure by reducing the incidence of revision surgery (34).

When considering the arguments for and against internal fixation for single- and two-level discectomy and fusion, it should be acknowledged that large-scale prospective randomized studies to address this issue have not yet been published. As the results of fusion with or without fixation both seem to be generally favorable, such a study would likely require an enormous number of patients to achieve sufficient statistical power. For example, a power analysis performed after a retrospective review of 356 patients who underwent one- or two-level fusions with or without plate fixation suggested that approximately 600 patients would be required for a prospective randomized trial using the need for revision surgery within the first 2 years as the primary outcome measure (15). Such a study would obviously be a massive multicenter undertaking. The lack of definitive controlled trials to delineate the relative merits of plating in the context of single- or two-level fusion is unfortunate because comparative studies of instrumented versus noninstrumented fusions in the past have arrived at contradictory conclusions. For example, a prospective semi-randomized comparison in 54 patients revealed no difference in fusion rates and clinical outcome (37), although interbody graft height was better maintained in those patients who had plate fixation. These findings of no significant differences in fusion rates and functional outcome between plated and unplated patients echo those of Connolly et al. (20) and Wang et al. (77) in their reviews of patients treated for single-level disc degeneration. Epstein (28) retrospectively compared single-level corpectomy reconstructions in 35 patients with plating and 48 patients without plating and found no significant difference in reoperation rates for pseudarthrosis or graft extrusion. A prospective randomized trial of 91 patients divided between discectomy alone, discectomy plus a Smith-Robinson fusion, and discectomy plus a Smith-Robinson fusion...
and Caspar plating found no differences in clinical outcome among any of the three groups, leading the authors to conclude that fusion itself was not even necessary (68).

Conversely, the aforementioned retrospective review of more than 350 patients with single- or two-level discectomy and fusion found a much higher rate of pseudarthrosis and need for revision surgery in those patients who did not undergo anterior cervical plating (15, 35). A retrospective comparison of 58 non-instrumented fusions with 36 plated fusions at a single institution demonstrated a 43% incidence of postoperative kyphosis and 10.3% incidence of pseudarthrosis in uninstrumented patients as compared with a 0% incidence of either in plated patients (34). Although Wang et al. (77) did not find that the addition of anterior fixation significantly altered the pseudarthrosis rates for single-level fusions and two-level fusions, the same authors did demonstrate, in a retrospective review, a much higher rate of pseudarthrosis in uninstrumented patients as compared with those undergoing anterior plate instrumentation (78). Finally, in a retrospective comparison of 251 patients treated with anterior cervical plate fixation against a historical control group of 289 patients treated without fixation for single- or two-level fusions, Kaiser et al. (48) found that the instrumented group had a significantly higher rate of fusion and a significantly lower rate of graft-related complications.

The issue of fusion rates notwithstanding, the problem of maintaining sagittal alignment after discectomy and fusion warrants some comment. Even in comparative studies that did not demonstrate the addition of instrumentation to substantially increase fusion rates, a significantly greater degree of graft collapse was observed in those patients fused without anterior plating (20, 37, 77). The ability of plate fixation to maintain the immediate postoperative sagittal alignment after discectomy and fusion has been reported by numerous authors (49, 83). A randomized study of patients undergoing single-level fusions with or without plate fixation demonstrated with radiostereometry that uninstrumented patients had significantly more sagittal rotation and fell into more kyphosis than instrumented patients (85). The significance of this loss of sagittal alignment was demonstrated by Katsuura et al. (50), who reported that a kyphotic alignment of the fusion increased the risk of adjacent segment degeneration. Because symptomatic adjacent segment degeneration is certainly a real concern after cervical discectomy and fusion (42), every effort should be made to minimize its risk. Techniques to reestablish cervical lordosis during reconstruction include distracting the interspace and inserting an interbody graft that is large enough to restore the height of the anterior column, although one should be cautious not to over-distract the posterior facets. In addition, the interbody grafting can be trimmed into a trapezoidal shape that is slightly taller at its anterior border, but one should be aware that it can be difficult to significantly increase cervical lordosis by simply impacting a trapezoidal-shaped graft into place. Alternatively, the lordosis at the motion segment may be more effectively achieved by gently extending the neck after the decompression is complete, before sizing and inserting the graft.

Recognizing that the literature has not provided a definitive answer on this issue of instrumentation for single- or two-level anterior fusions, we advocate anterior cervical plate fixation for many of the reasons mentioned earlier—immediate stability, more reliable maintenance of sagittal alignment, the prevention of graft extrusion and collapse (Fig. 3)—and we think that a higher fusion rate has not yet been demonstrable, given the statistical power of previously published randomized comparisons. With the technical familiarity that most surgeons acquire for anterior cervical plating, we do not think that the additional time required to insert the instrumentation is excessive and is given the potential to reduce the incidence of secondary surgery, well worth the extra operative minutes. Although hardware failure is undeniably a problem unique to instrumented fusions, with contemporary unicortical plating systems that prevent screw backout, the rate of such problems is extremely low.

**Anterior Cervical Plating for Long Anterior Column Reconstructions**

The destabilization of the spine caused by multilevel discectomies or corpectomies imposes significant biomechanical stresses on subsequent anterior column reconstruction, as reflected by an increased rate of pseudarthrosis in multilevel fusions (16). Some uncertainty exists regarding the efficacy of anterior plate fixation alone in the stabilization of such long reconstructions. Such an undertaking requires an exacting surgical technique in the positioning of the plate and screws and meticulous preparation and sizing of the structural bone grafts. Some of the hazards encountered in these cases were reported by Vaccaro et al. (76) in their retrospective multicenter review of early failures in patients undergoing two- or three-level corpectomy reconstructions and fusion with a fully constrained plate. Three (9%) out of 33 patients undergoing two-level corpectomies and six (50%) out of 12 patients with three-level corpectomies experienced plate and graft dislodgement within 3 months of surgery. Failure to lock the screws into the plate and the use of a peg-in-hole type of bone grafting technique were associated with early failure. Similarly, Sasso et al. (67) recently reported a failure rate of 6% (two out of 33 patients) for fully constrained anterior plates in two-level corpectomy reconstructions and a failure rate of 71% (five out of seven patients) for fully constrained anterior plates in three-level corpectomy reconstructions. Bolesla et al. (10) prospectively followed 15 patients with three- or four-level discectomies and fusions and found that, with the application of a fully constrained plate, the fusion rate was only 47% (seven out of 15 patients). This fusion rate is comparable to that observed by Emery et al. (26) in a retrospective review of 16 patients who underwent three-level discectomies and fusions without anterior fixation, of whom 56% (nine out of 16 patients) achieved a solid arthrodesis. A more direct comparison between plating and not plating was performed by Wang et al. (79), who retrospectively reviewed 59 patients who underwent a three-level discectomy and fusion, 40 of whom received anterior fixation. They noted a higher (albeit not statistically significant) rate of pseudarthrosis in those patients who were not plated (37%) compared with those who...
were plated (18%). Nonetheless, the rate of pseudarthrosis in the instrumented fusions was still unacceptably high.

These reports of early fixation failure point to the significant biomechanical forces that must be overcome to achieve fusion after long reconstructions. Important insights into the influence of anterior internal fixation on the loads subjected to a multi-level strut graft were provided by Foley et al. (33) and DiAngelo et al. (21). These authors determined the forces applied to a strut graft spanning a three-level cervical corpectomy in a human cadaveric model with and without anterior plate fixation. Although the application of an anterior plate significantly increased the stiffness of the construct beyond that of the intact specimen, during extension, the tension band effect of the anterior plate subjected the graft to supraphysiological loads that approached the resistive strength of the vertebral endplate-subchondral bone interface. The authors hypothesized that such loads could promote graft pistoning and subsidence, thus, contributing to early fixation failure. It should be noted that fully constrained anterior cervical plates were used in these in vitro biomechanical studies and in the clinical reports of early failure in multilevel corpectomies by Vaccaro et al. (76) and Sasso et al. (67). Such constrained plates have screws rigidly locked to the plate at a fixed angle and, therefore, provide little accommodation for the subsidence that they might actually partially exacerbate during cervical extension. In theory, semiconstrained, “dynamic” anterior cervical plates might impose somewhat different loading patterns on the strut graft and allow for a more controlled subsidence without loosening, but this proposition has not been evaluated in the literature to date.

The numerous clinical reports of high failure rates in multilevel corpectomy or discectomy reconstructions with anterior plating alone have illustrated that, in such long constructs, anterior plating alone may not be biomechanically sufficient to reliably facilitate fusion. This is further supported by the in vitro results from the aforementioned biomechanical studies. Strong consideration must, therefore, be given to supplementing such long anterior fusions with additional posterior instrumentation and/or halo immobilization (65). Circumferential fixation has been found to be quite effective in promoting fusion in multilevel corpectomy reconstructions (27). Exactly how much of an anterior reconstruction requires additional posterior fixation is not well established; however, the literature on failed fusions would suggest that decompressions involving three discectomies or two vertebrectomies begin to warrant consideration for circumferential stabilization. Although the length of reconstruction may be the most significant influence on graft subsidence and the potential for fixation failure (75), other important factors must also be considered, such as preexisting deformity or pseudarthrosis, poor bone quality, nicotine exposure, and other systemic medical conditions. In general, we think that long anterior column reconstructions should be supplemented with circumferential stabilization to maximize immediate construct stability. Although systems that include lateral mass screws or pedicle screws affixed rigidly to rods provide optimal stability to such long reconstructions posteriorly, the optimal anterior plating system remains unestablished at this time. Conceptually, an anterior plating system that reduces the chance of graft extrusion yet allows for some degree of graft loading would be desirable for long reconstructions; however, the “dynamic” behavior of these plates would be affected by the rigidity of the subsequently placed posterior fixation.

**Anterior Cervical Fixation for Pseudarthrosis and for Smokers**

The role of anterior cervical plating in the setting of a preexisting anterior pseudarthrosis and in the patient who smokes...
warrants some discussion. Although the mere presence of a radiographically confirmed pseudarthrosis does not necessarily produce a poor clinical outcome, some patients are symptomatic and require revision surgery (44, 61, 63). Such revision surgery can be performed either anteriorly or posteriorly, or in a combined, circumferential fashion. An anterior revision requires a technically challenging dissection through a partially scarred soft tissue approach, not to mention the need to navigate through a nonhealed fusion bed. As such, many comparative studies in the past have advocated the posterior approach over an anterior decompression and fusion (14, 31). The anterior approach, however, allows for resection of the actual pseudarthrosis, restoration of sagittal alignment, and direct decompression of the neural elements. Zdeblick et al. (84) demonstrated the efficacy of an uninstrumented anterior revision fusion with autogenous bone grafting in 35 patients with cervical pseudarthrosis. Tribus et al. (74) also reported on 16 such patients who were successfully managed with an anterior revision fusion with autograft bone and anterior cervical plating. In general, if an uninstrumented fusion fails and anterior revision surgery is performed, it would seem logical to maximize the immediate stability of the anterior reconstruction with plate fixation.

The deleterious effects of nicotine on bone healing and spinal fusion are well recognized. Hilibrand et al. (43) reported that smokers undergoing uninstrumented multilevel anterior discectomies and fusions with autogenous bone grafts were particularly susceptible to pseudarthrosis and poor clinical outcomes as compared with nonsmokers. These authors advocated performing a corpectomy and strut grafting rather than multilevel discectomies, which, in essence, reduces the number of bone surfaces required to fuse. In contrast to the higher rate of pseudarthrosis in smokers reported by Hilibrand et al. (43), Bose (11) observed equal fusion rates in smokers and nonsmokers undergoing multilevel anterior fusions with the addition of anterior cervical plate fixation (96.7% in smokers, 97.8% in nonsmokers). These results suggest that the extra stability afforded by anterior plate fixation can overcome, to some extent, the deleterious biological effects of nicotine exposure on cervical spinal fusion.

POSTERIOR INTERNAL FIXATION TECHNIQUES

General Operative Considerations

The preoperative evaluation and surgical positioning of patients undergoing posterior cervical fixation for cervical spondylosis are somewhat similar to that described earlier for anterior procedures. After induction of anesthesia, the patient is carefully turned onto the prone position and the head is affixed by a holding device, with neurophysiological monitoring of spinal cord function maintained at all times. The posterior elements are exposed through a midline incision with electrocautery. Caution must be exercised to avoid disruption of the facet capsules or interspinous ligaments of the rostral or caudal levels that are not intended to be included in the fusion. In particular, one must resist the temptation to extensively dissect the muscle-ligamentous attachments off the posterior elements of C2 in an effort to gain slightly better exposure of the lateral masses of C3 because this may lead to localized C2–C3 kyphosis (6).

Posterior Fixation Options and Indications

Options for posterior internal fixation in the cervical spine include wiring techniques between adjacent spinous processes or between the spinous process and adjacent lateral mass, laminar clamps, and screw fixation with rods or plates. Traditional wiring techniques and laminar clamps are, to a large extent, being supplanted by the more rigid fixation provided by screws in the lateral masses and cervical pedicles that do not require intact posterior elements for their application. Lateral mass screws or cervical pedicle screws can be inserted through a plate or affixed rigidly to a rod, similar to pedicle screw systems in the lumbar spine. Contemporary screw-rod systems often have a polyaxial head that allows for screw insertion at varying degrees and, by connecting rigidly to a rod, allow for some degree of compression or distraction.

Although rigid posterior internal fixation strategies were developed initially for the stabilization of posterior element disruption in acute cervical trauma, their application to degenerative and other nontraumatic conditions of the cervical spine has been widely accepted. It has been established that an extensive cervical decompressive laminectomy and facetectomy may lead to the loss of cervical lordosis in the management of cervical myelopathy (60, 70). The loss of cervical lordosis or the development of postlaminectomy kyphosis is best prevented with a fusion stabilization procedure at the index procedure, which can be performed with adjuvant lateral mass fixation (54). When surgically treating cervical kyphosis, posterior internal fixation alone, or in combination with an anterior release and reconstruction, is an effective method of restoring sagittal alignment (3). In summary, it is becoming increasingly evident that rigid posterior instrumentation is an important method of stabilization after long anterior column reconstructions in the setting of cervical spondylosis (Fig. 4) (25, 51, 69, 73).

Lateral Mass Fixation

Using the lateral mass as a posterior fixation point for screws was initially popularized by Roy-Camille et al. (64) for the treatment of traumatic cervical instability, although the instability invoked by anterior or posterior neural element decompression in the setting of cervical spondylosis made its transition into degenerative conditions a logical application. A number of variations in the technique for inserting lateral mass screws within the subaxial cervical spine have been described, differing mainly in the trajectory of the screw and, in theory, differing in the risk of iatrogenic nerve root and vertebral artery injury (59).

With the Roy-Camille technique, the screw entry point is at the center of the lateral mass and is directed 10 degrees laterally, with no rostral-caudal inclination. In the Magerl technique, the screw begins medial and rostral to the center of the lateral mass...
and is directed 25 degrees laterally, with a rostral inclination that is parallel to the facet joints. Similar to the Magerl technique, Anderson et al. (8) described starting the screws 1 mm medial to the center of the lateral mass then directing them laterally 10 degrees with a 30- to 40-degree rostral inclination. An et al. (7) recommended a 30-degree lateral trajectory and 15-degree rostral inclination, starting 1 mm medial to the center of the lateral mass, to exit the lateral mass safely at the juncture between the transverse process and facet. In practice, it may be difficult to intraoperatively reproduce the distinctions between these described techniques that aim the screw in a superolateral direction. The lateral trajectory avoids the transverse foramen where the vertebral artery passes but does put the exiting spinal nerve at some risk. The root does move slightly anteriorly as it passes through its foramen; therefore, a more laterally directed screw has less chance of injuring it, although there is a limit to how far laterally one can aim the screw before breaking out the lateral border of the lateral mass. An anatomic comparison of these techniques by Xu et al. (81) found the trajectory advocated by An et al. (7) to have the lowest rate of nerve root violation.

A number of factors contribute to the fixation strength of lateral mass screws. As one would expect based on the oblique nature of the lateral mass, the superiorly inclined screw trajectory (as per Magerl in Jeanneret et al. [46a], Anderson et al. [8], and An et al. [7]) has a longer path and can, therefore, accept a longer screw than the horizontal trajectory of the Roy-Camille technique (22). A longer lateral mass screw typically has a higher pullout strength (30) and a greater load to failure in flexion (18). Lateral mass screws inserted via the Roy-Camille technique may achieve excellent fixation and stability by engaging the anterior cortex of the inferior facet, as demonstrated by the high pullout strength of transfacet screws that are actually intended to do so (52). Nonetheless, violation of the inferior facet may not be desirable in the clinical setting, particularly at the bottom end of a fixation construct. As would be anticipated, biomechanical testing of bicortical screws demonstrates greater pullout strength than unicortical screws (40), but, in vivo, one must be wary of the potential neurovascular risks associated with the achievement of bicortical fixation. Certainly, in osteoporotic patients, bicortical lateral mass screw fixation may be warranted, although Choueka et al. (18) demonstrated that even with bicortical purchase, pullout strength was still significantly correlated to bone mineral density. Such a correlation, however, was not observed by Heller et al. (40). Despite the considerations of length and bone mineral density, a more recent biomechanical comparison between lateral mass screws inserted using the Roy-Camille and Magerl techniques somewhat surprisingly demonstrated a higher pullout strength for the screws inserted by the Roy-Camille method.

In an effort to delineate the complications associated with lateral mass plating, Heller et al. (41) retrospectively reviewed 654 lateral mass screws in 78 consecutive patients, the majority of whom were undergoing a complex cervical reconstruction. As a function of the numbers of screws, the incidence of nerve root injury was 0.6%; facet breakout, 0.2%; vertebral artery injury, 0%; broken screws, 0.3%; and screw loosening, 1.1%. Graham et al. (36) reviewed 21 consecutive patients with 164 screws and reported no instrumentation failures or vascular injuries, but there was a 6.1% incidence of screw malposition, with an incidence of radiculopathy of 1.8% per screw. Wellman et al. (80) reviewed 43 consecutive patients with 281 lateral mass screws and reported one hardware failure with subsequent instability that required an anterior stabilization; there were no incidences of neurovascular injury.

**Cervical Pedicle Screw Fixation**

Lateral mass fixation in the cervical spine is generally straightforward and produces excellent stability with few neurovascular complications (24, 32, 41). However, at C2 and at C7, the lateral masses are small and screw fixation is, therefore, somewhat limited, resulting in decreased pullout strength (40). In addition, an important consideration is the fact that the vertebral artery at C2 traverses laterally and would, therefore, be endangered by the lateral trajectory of a lateral mass screw. Instrumentation at C2 and C7 has particular biomechanical importance because stable fixation into C2 can serve as an anchor at the bottom of occipitocervical fusions or at the top of long subaxial decompressions.
whereas stable fixation into C7 is helpful in fusions that cross
the cervicothoracic junction (2, 4).

Transpedicular screw fixation within the cervical spine
achieves fixation into both the anterior and posterior columns,
providing superior pullout strength and stability as compared
with lateral mass plates and, for that matter, all other conventional
forms of cervical internal fixation (47, 53). The tradeoff
for such stability is the potential for significant spinal cord,
nerve root, or vascular injury (vertebral artery) with the insertion
of these screws.

In general, the safe cannulization of the cervical pedicles
requires a thorough evaluation of cervical pedicle anatomy and
dimensions on preoperative imaging and visual and tactile con-
firmation in the operating room. For example, Ludwig et al.
(56) reported that, in an in vitro study, cervical pedicles with a
diameter of less than 4.5 mm were at significant risk of a clini-
cally important breach with the insertion of a 3.5 mm screw,
even with the assistance of an image guidance system, illus-
trating that technology is no substitute for careful preoperative
radiographic analysis. Cadaveric evaluations of the C2 pedicle
have suggested that it has a mean width of approximately 8 mm
and a mean height of approximately 9 to 10 mm (46, 47, 62),
with dimensions tending to be significantly smaller in women
than in men (82). The starting point for the C2 pedicle screw
can be identified by exposing the lamina of C2 and using a Penfield
#4 with a small cottonoid to slide up along the medial border of
the pedicle. With direct palpation of the medial wall, the pedi-
cle is then drilled with a 2-mm high-speed burr, which provides
some tactile feedback within the bone and does not require a
great deal of force to advance into the pedicle. Roy-Camille
et al. (64) recommend that the pedicle be drilled approximately
15 degrees medially and 35 degrees superiorly. Howington et al.
(46), in their anatomic and radiographic review of the C2 pedi-
cle, found it to have a medial inclination of 35 degrees and a
superior angulation of 39 degrees (Fig. 4). Ebraheim et al. (23)
have demonstrated that the direct palpation of the C2 pedicle
is a much safer guide for screw insertion than generic trajectory
guidelines. Cadaveric evaluations of the C7 pedicle have
demonstrated that it has a mean width and height of approxi-
mately 7 mm and 7.5 mm, respectively, and a medial orientation
of approximately 25 to 35 degrees (7, 57). We advocate perform-
ing a lamino-foraminotomy at the C6–C7 level to directly pal-
pate the superior, medial, and inferior borders of the C7 pedicle,
which then provides invaluable information for determining
the starting point and trajectory for drilling. Similar to the C2
pedicle, a high-speed burr or power drill is used because a dan-
gerous amount of force is required to manually push an awl into
the pedicle.

With familiarity of the regional anatomy and careful preop-
erative planning, the insertion of pedicle screws in the cervical
spine at the C2 and C7 levels can be performed safely and with
excellent results. Albert et al. (5) retrospectively reviewed
21 patients who underwent C7 pedicle screw instrumentation
as part of a posterior cervical or cervicothoracic fusion con-
struct for a variety of traumatic and nontraumatic conditions.
At 1-year follow-up, excellent stability was achieved with no
hardware failures or neurovascular complications related to
pedicle screw fixation. Abumi and Kaneda (1) reported on
45 patients with nontraumatic disorders who underwent pos-
terior fusion with pedicle screw constructs along the entire cer-
vical spine, not just at C2 and C7. They observed solid fusions
in all 37 of their patients who were available for follow-up,
with no cases of hardware failure, and the maintenance of
alignment in those who required correction of a severe preop-
erative kyphosis. With the exception of one transient radicu-
lopathy that resolved completely with nonoperative manage-
ment, there were no neurovascular complications associated
with placement of any of the 183 screws, although 11 (6.0%)
were determined to have penetrated the pedicles and were
considered to be “at risk.” To more specifically address the effi-
cacy of pedicle screw instrumentation in the correction of cer-
vical deformity, Abumi et al. (3) retrospectively reviewed
30 patients with cervical kyphosis, 17 of whom were treated
with a single posterior procedure and 13 who required an ante-
rior release and reconstruction as well. Kyphosis was signific-
antly reduced in both groups and fusion was achieved in all
patients, with two transient radiculopathies related to screw
insertion.

Because most surgeons are reluctant to insert pedicle screws
into the C3–C6 levels where the lateral masses usually provide
adequate fixation with much less risk, Abumi et al. (2a)
reviewed their complications related to more than 700 pedicle
screws placed in the cervical spines of 180 patients. Only three
patients (1.7% of patients; 0.4% of screws) incurred a neurovas-
cular complication as a result of screw insertion—one vertebral
artery injury and two radiculopathies. Although this might
suggest a fairly benign procedure, one should keep in mind
that these authors probably have the most extensive experi-
ence with this technique in the world. It is recommended that
only those spine surgeons with significant experience instru-
menting the cervical spine should attempt the placement of
cervical pedicle screws, particularly between C3–C6.

Although lateral mass or pedicle screw fixation within the
cervical spine can provide excellent immediate stability, we
still advocate that the lateral masses and facet surfaces be
decorticated and autogenous bone graft be placed to facilitate
the fusion. When a laminectomy is being performed, the bone
from the lamina and spinous process can be stripped of their
soft tissue attachments, morcellized, and used as autogenous
bone graft. Otherwise, we would advocate harvesting posterior
iliac crest autograft because substantially less bone needs to be
harvested when compared with posterior lumbar fusions.

CONCLUSION

Rigid internal fixation within the cervical spine can be safely
used to provide immediate stability and promote bony fusion
in patients undergoing surgical management of cervical
spondylosis. Both anterior and posterior internal fixation
devices are commonly used in a wide spectrum of traumatic
and nontraumatic conditions. An understanding of their indi-
cations, their biomechanical limitations, and the technical
aspects of their application makes rigid internal fixation devices powerful tools in the armamentarium of the spine surgeon managing degenerative and traumatic conditions of the cervical spine.

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**Disclosure**

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Jacopo Berengario da Carpi. ca. 1460–ca. 1530. Isagogae Breues, perlucidae ac uberrimae, in Anatomiam humani corporis a communi Medicorum Academia usitam. Impressum & nouiter reuissum Bononi[ae]: Per Benedictum Hectoris bibliopolam Bononiensem, anno virginei partus 1523 sub die xv. Iulii. (Courtesy of the U.S. National Library of Medicine, National Institutes of Health, Bethesda, Maryland).
Cervical spondylosis is a progressive degenerative process of the cervical spine. Degeneration results in motion abnormalities, loss of disc height, and arthrosis of the uncovertebral and facet joints. Uncovertebral joint arthrosis and disc degeneration can lead to osteophyte formation, resulting in spinal cord and/or nerve root compression. Facet arthrosis and ligamentous redundancy can lead to dorsal compression. Spondylosis leads to circumferential narrowing of the spinal canal and static compression of the spinal cord. Movement of the cervical spine places the spinal cord at risk of injury secondary to dynamic forces, such as buckling of the ligamentum flavum in extension and impingement from a disc-osteophyte in flexion.

A congenitally narrowed spinal canal predisposes the degenerating spine to spondylotic myelopathy. Normal spinal canal diameters, measured radiographically with controlled magnification from the dorsal vertebral body to the spinolaminar line, range from 17.6 to 18.8 mm in healthy subjects. In one study, symptomatic patients were found to have significantly smaller spinal canal diameters (28). Diameters less than 12 mm were found to be associated with an increased risk of developing myelopathy (28).

Patients with cervical spondylotic myelopathy present with motor and sensory disturbances of variable type and intensity. Abnormalities in the corticospinal and spinocerebellar tracts lead to early lower extremity findings of ataxia, spasticity, and paresis. As the disease progresses, upper extremity symptoms develop, with loss of strength and fine motor abilities. Gait and sphincter disturbances may develop as the disease progresses. In a review of 37 patients with cervical spondylosis, Lunsford et al. (26) demonstrated that 59% presented with only myelopathy and 41% presented with both myelopathy and radiculopathy.

The natural history of myelopathy caused by cervical spondylosis is one of progressive neurological deterioration in the majority of patients. Wilkinson (38) demonstrated that conservative therapy using cervical immobilization with an external cervical orthosis resulted in deterioration in neurological function during a 6-year period. The risk factors associated with poor prognosis were disability on presentation and duration of symptoms (18). Clarke and Robinson (9) showed that after a patient became symptomatic, they did not return to baseline. In patients who presented with myelopathic findings, 75% demonstrated a slow progression of disease, with episodes of new symptoms. In one-third of the patients, the clinical course stabilized. Conservative management of these patients provided half of these patients with symptomatic relief of their radicular and gait disturbances. Lees and Turner (25) looked at two cohorts of patients, one group with cervical stenosis with myelopathy and a second group with stenosis without myelopathy. The myelopathic group demonstrated initial progression of disease followed by stability of symptoms. Patients with long-standing disease had progressive neurological deficits. The second
group, who presented without myelopathic symptoms, did not demonstrate onset of symptoms with time. The authors concluded that cervical spondylosis is usually episodic, with an initial onset of symptoms followed by a period of static disease, except in older patients. Contrary to the work of Lees and Turner (25), other authors (34) have shown that the disease process usually follows a steady and progressive neurological decline. Phillips (32) showed that patients treated conservatively with a collar responded differently depending on the length of symptoms. Half of the patients who had symptoms for less than 1 year improved, and 40% of patients who had symptoms for 1 to 2 years showed clinical improvement. None of the patients who experienced symptoms for longer than 2 years showed improvement.

Operative treatment for cervical spondylotic myelopathy is indicated for patients with progressive disease. Surgical decision making regarding the surgical approach is multifactorial. One must take into consideration the location of the lesion, the specific disease pathology, the number of vertebral levels involved, the age at surgery, the preoperative neurological function, and the magnetic resonance imaging (MRI) signal changes consistent with myelomalacia before surgery. These factors help determine which patients are suitable candidates for surgical intervention. An understanding of these factors also aids in the choice of surgical approach. Controversies still exist regarding surgical approaches for treating cervical spondylotic myelopathy.

LOCATION OF DISEASE

The location and extent of disease play a crucial role in determining the appropriate surgical approach for treating cervical stenosis. An isolated ventral disease, in many instances, is most accessible via a direct ventral approach (Fig. 1). Patients presenting with spondylotic myelopathy from ventral pathology may be candidates for simple removal of the offending pathology. Ventral cervical discectomy, with or without fusion, depending on the lordotic curve of the spine, has evolved as a viable treatment option for disease limited to the disc space. Decompression of the soft disc material and bony osteophytes ventrally usually effectively decompresses the spinal canal.

In 108 patients presenting with cervical spondylotic myelopathy, Emery et al. (14) demonstrated significant improvement in premorbid symptoms after ventral decompression and arthrodesis. Of the 82 patients with preoperative gait abnormalities, 71 showed complete or partial improvement in their gait instability. The most significant predictive factor for recovery from myelopathy was the severity of the myelopathy before the operative intervention. The series of 121 cases of cervical spondylotic myelopathy treated with anterior cervical decompression and fusion with a follow-up of 22 months that was presented by Zhang et al. (44) demonstrated that 90.9% of the patients improved clinically, and 72.6% were able to resume normal activities.

In some instances, the pathology may extend over many vertebral levels. The degenerative process may include both the disc space as well as the area behind the vertebral body (Fig. 2). In this situation, single-level or multilevel discectomies may only partially remove the pathological compression. Addressing this type of pathology with a more extensive ventral approach may provide a more suitable decompression. Ventral approaches involving corpectomy and fusion encompass a myriad of disease processes involving a long segment of the ventral spinal canal.

Indications for surgery often include multilevel disc disease, ossification of the posterior longitudinal ligament (OPLL) and disc fragment extrusion behind the vertebral body. Many authors reserve extensive ventral approaches for disease that involves one or two vertebral body levels (5, 11, 13). Okada et al. (30) reported the results of subtotal corpectomy and ventral arthrodesis for the treatment of spondylotic myelopathy. The study showed a high rate of improvement in neurological function, with all but one of 37 patients demonstrating improved walking ability.

Some authors report that disease involving more than
two vertebral body levels may be better addressed by a dorsal approach (23). Cervical spondylolisthesis is a degenerative process involving the entire cervical spine. The area of cervical stenosis may incorporate multiple adjacent cervical levels or different isolated levels. The stenotic pathology is, in many instances, not simply at the disc level. The osteophytic spur may include a significant portion of the vertebral body. The ventral approaches for discectomy are limited to the confines of the disc space and do not, in many instances, address spinal canal narrowing from migrated disc fragments, wide-based dorsal osteophytes, or OPLL, although some surgeons think that pathology extending a significant distance from the disc space can be addressed through this approach. Calcification of the posterior longitudinal ligament usually involves more than one vertebral level and spans across the dorsal aspect of the vertebral body.

The degenerative process includes hypertrophic changes circumferentially—not just ventrally. Enlarged facet joints and thickened ligaments can contribute significantly to the narrowing of the spinal canal diameter throughout the entire cervical spine (Fig. 3). Ventral approaches to multisegmental and dorsal degenerative pathology, in many instances, are either inadequate or involve the complex removal of cervical discs at multiple levels. A dorsal surgical approach allows for a long-segment decompression of the spinal canal. It facilitates the removal of the compressing dorsal elements, hypertrophied facets, and ligaments. Dorsal approaches, including laminectomy with or without fusion and laminoplasty, provide surgical expansion of the spinal canal.

OPLL

Both ventral and dorsal approaches have been advocated for the treatment of OPLL (Fig. 4). To obtain ventral decompression in patients with OPLL, ventral ligaments should be removed (7, 27, 39). Decompression and fusion can be performed if fewer than three levels are involved below C2–C3. However, the potential of surgery-related complications, including cerebrospinal fluid leakage, dislodgement, or pseudarthrosis do exist (7, 16). Some authors have reported inadequate decompression of the ossified ligament with a bony approach (20, 27).

Open-door expansive laminoplasty was developed to address multilevel myelopathy for OPLL (20) Radiographic and biomechanical studies suggest that laminoplasty is superior to laminectomy in maintaining cervical alignment and preventing dorsal deformities (2, 7). Because OPLL tends to progress postoperatively and because neurological improvement is related to the volume of the enlarged spinal canal, it is necessary to expand the sagittal canal sufficiently from one vertebral level above and below the stenotic level (22). When long-term results of laminoplasty are compared with those of ventral decompression for OPLL, both procedures yield good recovery rates, but there are fewer surgery-related complications associated with laminoplasty (27, 39).

BIOMECHANICS

In determining the appropriate surgical approach, the preoperative images are of significant assistance. Some authors think that the loss of lordosis or evidence of kyphosis dictates fusion in the setting of either laminectomy or ventral decompression (Fig. 5). The most appropriate configuration for laminectomy without fusion is lordosis. Most authors agree that postlaminectomy deformity can be avoided by restricting laminectomy to the lordotic cervical spondylotic spine and that laminectomy is contraindicated in the kyphotic spine (14, 15, 23).

Aging is associated with progressive degeneration. Degeneration of the cervical spine results in loss of intervertebral disc space height, as well as subsidence, with a commensurate loss in height of the vertebral bodies. With time, the repetitive application of axial loads creates an increasingly longer bending moment, resulting in the eventual development of a kyphotic deformity (3).

Many authors think that sagittal malalignment may lead to poor postoperative results (8, 35, 42). In some cases, this may be a contraindication for laminectomy or laminoplasty (Fig. 6). However, a subpopulation of carefully selected patients may benefit from laminoplasty. Chiba et al. (8) showed that the longitudinal distance of vertical height of the spine has some degree of correlation with the recovery after laminoplasty in patients with postoperative malalignment. In patients with cervical spondylotic myelopathy, spinal cord redundancy induced by shortening of the cervical spine height caused by multiple levels of disc degeneration may alleviate the compression of the spinal cord, even in the presence of malalignment. OPLL is less likely to be associated with such redun-
dancy of the spinal cord because the ossified ligaments hold the vertical height of the cervical spine and maintain the natural vertical tension in the spinal cord. This results in a greater degree of static compression if the alignment is kyphotic (8).

Sagittal cervical alignment has been shown to affect the postoperative results after dorsal decompression. Kimura et al. (24) reported that kyphotic cervical spines have poorer operative results because the spinal cord is draped over the dorsal aspect of ventral compressing structures. The decompression obtained by laminoplasty can be attributed to two distinct mechanisms: 1) a direct local decompression effect and 2) a total decompression effect obtained by the dorsal shift of the spinal cord away from the ventral compressing elements (17). Baba et al. (1) showed that neurological improvement after a dorsal decompression was associated with migration of the spinal cord dorsally on MRI scans.

Biomechanical studies in a goat animal model of laminoplasty versus laminectomy demonstrated a significant increase in kyphosis radiographically in the laminectomy group but not in the laminoplasty or intact groups. The model showed an increase in sagittal plane instability in the laminectomy group. The lamina seemed to provide sagittal stability, especially at C2 through C7 (31). Preservation of the lamina may provide an anatomic barrier preventing the formation of postoperative scar over the dura mater. Yonenobu et al. (41) showed that an opened, but retained, lamina may prevent the development of a postlaminectomy membrane.

**COMPLICATION PROFILE**

A ventral approach directed at the disc space depends on a stable arthrodesis. The nonunion rate for a noninstrumented Smith-Robinson type fusion using autogenous bone ranges from 3 to 42% (Fig. 7) (5, 6). Studies indicate symptomatic nonunion rates as high as 70% in patients with documented pseudoarthrosis (14, 29). Emery et al. (15) reported on threelevel procedures with ventral plating in 16 patients, noting primary arthrodesis of all three levels in only nine (56%) of the patients. Of the seven patients with pseudoarthrosis, two had severe pain and underwent revision, two had moderate pain, and three had no pain. In their experience, most nonunions were not a result of graft collapse but rather of failure of one of the two graft-body interfaces to ossify. Increasing the number of discectomy levels increases the number of graft-body interfaces.
Some authors prefer to address this problem with corpectomies and strut grafting or by using a dorsal approach to address the long-segment disease. A multilevel corpectomy, similar to single and multilevel discectomies, relies on arthrodesis. Pseudoarthrosis rates correlate with poor outcome (14).

Another serious complication associated with using a strut graft is graft dislodgement (Fig. 8). The incidence of this complication has been reported to be as high as 29% and can lead to catastrophic sequela (4, 14). Graft dislodgement can result in neurological injury, airway compromise, or esophageal injury (4, 14). Emery et al. (14) performed 55 corpectomies for patients presenting cervical myelopathy. Four of these patients developed graft dislodgement requiring revision. One partial dislodgement was treated with a halo. One displaced graft caused an esophageal injury and required surgical repair. The use of ventral cervical plating may reduce the incidence of graft extrusion. However, Vaccaro et al. (36) demonstrated that multilevel corpectomies with ventral instrumentation had a 9% dislodgement rate for two-level corpectomies and a 50% dislodgement rate for three- and four-level corpectomies.

Early surgical treatment strategies for cervical spondylotic myelopathy were dorsal in orientation, using long-segment cervical laminectomy (19). Dorsal decompression via laminectomy was soon observed to be associated with many postoperative complications (33). Cervical laminectomy was observed to significantly increase spinal column flexibility in a cadaver model. The most notable changes were observed at the lower aspect of the laminectomy. This was associated with significant increases in cervical motion, compared with intact specimens, in all planes of motion. The clinical sequela is often an increase in forward angulation (kyphosis) (Fig. 9) (10).

Postlaminectomy kyphotic deformity is a well-known complication in the pediatric population. In one series, 100% of the patients younger than 15 years of age developed a kyphotic deformity after laminectomy (40). Other studies demonstrated late neurological deterioration attributed to instability and kyphosis in adult populations (42). Delayed neurological changes may also result from the formation of postlaminectomy membranes. The scar that forms over the dura mater can cause recompression of the spinal cord dorsally over the site of the laminectomy (41).

Laminoplasty was developed to address the many limitations of laminectomy. In Japan, there was a need for an operation to address long segments of compression caused by OPLL. For long constructs, however, the ventral approaches were associated with the previously mentioned graft problems, including graft dislodgement and pseudoarthrosis. Laminectomy, on the other hand, poses problems with the development of kyphosis, instability, postlaminectomy membrane, and late deterioration. Laminoplasty directly addresses most of these potential complications.

One distinct advantage of laminoplasty over a ventral approach is the documented reduction in postoperative complication rates. In a comparative cohort study of long-segment corpectomy versus laminoplasty for multilevel cervical myelopathy, both surgical options reliably arrested myelopathic progression or led to significant improvement in neurological function. However, the laminoplasty cohort required less pain medication and experienced a significantly lower rate of complications, compared with the corpectomy group (13).

Some authors have reported patients experiencing difficulty with axial pain after dorsal approaches. Hosono et al. (21) detailed findings of neck and shoulder pain after laminoplasty. They found the incidence after laminoplasty to be 60% greater than the control group that underwent subtotal corpectomy. Other studies actually demonstrated an improvement in postoperative pain in patients undergoing laminoplasty (13). Yoshida et al. (43) found that 40% of the laminoplasty patients experienced some axial symptoms. Such pain, however, occurred primarily in patients who had symptoms before surgery. Only one patient out of 137 without preoperative axial symptoms developed de novo postoperative axial neck pain.

Acceleration of adjacent level degeneration is another consideration in determining the surgical approach and technique. Ventral approaches are associated with complications resulting from the necessity for spinal fusion. A ventral decompression and fusion may result in the formation of stresses at the levels adjacent to the fusion mass, resulting in accelerated degeneration of these levels (Fig. 10). Bohlmam et al. (5) noted symptomatic adjacent level degeneration in 11 of 122 patients after ventral decompression and arthrodesis, with 9 of the patients requiring a second procedure to address the additional degenerated level. Dohler et al. (12) reported that instability of the adjacent segments developed in 67% of patients after interbody fusion. In addition, Bohlmam et al. (5) reported that, in 9% of patients, symptoms of radiculopathy developed at
Another vertebral segment after the initial operation. He also reported the development of pseudoarthrosis at the level of the fusion. This is supported by Lunsford (26), who reported a 24% incidence of bone graft complications after ventral spinal fusion. Because of these short-comings, dorsal approaches to spondylosis were developed.

**CONCLUSION**

Despite the various options available, the optimal procedure for the surgical treatment of multilevel cervical spondylosis remains controversial. For patients with a neutral to lordotic cervical alignment, both laminoplasty and corpectomy with fusion are viable alternatives. Wada et al. (37) compared these two procedures for the treatment of multilevel cervical spondylosis. Both procedures demonstrated similar rates of functional recovery. The laminoplasty group was associated with a lower complication rate. This study was limited in that the majority of the patients had disease at only two levels.

Edwards et al. (13) reported the results of corpectomy versus laminoplasty for the treatment of stenosis involving three or more levels. Patients were matched on the basis of similar preoperative prognostic criteria. Functional recovery after laminoplasty in this series tended to be greater than that achieved after corpectomy. The incidence of axial discomfort was identical for patients in the corpectomy and laminoplasty cohorts. However, the severity of pain tended to be greater in the corpectomy group.

Radiographic degeneration of adjacent motion segments occurred with a greater frequency after corpectomy (38%) than after laminoplasty (8%) (13). The incidence of adjacent level disease is well reported after corpectomy. Some authors have reported a 35% incidence of accelerated spondylosis rostral to the uninstrumented motion segment (15, 26, 37). Adjacent level disease is usually not a reported complication after laminoplasty. This may be because of the maintenance of segmental motion.

Edwards et al. (13) reported an incidence of complications significantly lower in the laminoplasty group. Most complications in the corpectomy cohort were related to the surgical approach. Persistent dysphagia or dysphonia was experienced in 31% of the patients. Fusion-related complications were relatively uncommon in the corpectomy group. One patient in the laminoplasty group demonstrated a transient C5 palsy. Both corpectomy and laminoplasty successfully arrested myelopathic progression. Both procedures led to significant neurological improvement and pain reduction in a majority of patients (13).

**REFERENCES**

CERVICAL CORPECTOMY AND STRUT GRAFTING

CERVICAL CORPECTOMY AND strut grafting is a deceptively simple procedure that has been performed for many years for a variety of cervical spine disorders (infection, neoplastic disease, and trauma) but most commonly for cervical spondylosis. The procedure requires attention to detail to ensure adequate decompression of the neural structures and avoiding injury to the soft tissues of the neck and the vertebral artery in the transverse foramina. The following description of the technique is one we have successfully used for cervical corpectomy and strut grafting. We also discuss patient selection criteria, avoidance of common complications, and postoperative management.

KEY WORDS: Cervical spondylosis, Corpectomy, Myelopathy, Ossification of the posterior longitudinal ligament, Surgical technique

Appropriate candidates for single-level cervical vertebrectomy are those patients with signs and symptoms of myelopathy who have evidence on imaging studies of spinal cord compression by osteophytes or soft disc herniation at two adjacent motion segments.

In patients with spinal cord compression at three adjacent motion segments, decompression may be achieved by two-level vertebrectomy or multilevel laminectomy. However, if lateral cervical x-rays and/or reformatted sagittal computed tomographic (CT) scans show straightening of the normal curvature or kyphotic deformity, posterior cervical decompressive surgery is contraindicated for two reasons: progression of kyphotic deformity is likely, and the spinal cord is unlikely to move posteriorly away from the compressive lesion in the presence of kyphosis. In this situation, cervical vertebrectomy will not only result in decompression of the spinal cord but may also achieve restoration of cervical lordosis in patients with straightened or kyphotic spines.

In patients with spondylotic compression at four motion segments, we generally prefer to perform posterior decompressive procedures. However, patients with compressive lesions at four levels and coexisting kyphotic deformity must be treated with a three-level vertebrectomy to achieve adequate decompression. Because graft and plate complications are greatly increased with three-level vertebrectomy, we think that supplemental posterior instrumentation is indicated to prevent plate and graft dislodgement.

OPLL occurs behind the vertebral bodies, at the disc spaces, or in a combination of both as a continuous lesion or with multiple skip areas. Compression may be focal or extensive, involving the entire cervical spine. In general, to achieve sufficient decompression of the spinal cord, at least a one-level vertebrectomy must be performed. The considerations relating to the indications of anterior and posterior operation are similar to those discussed for cervical spondylosis.

IMAGING STUDIES

Magnetic resonance imaging (MRI) is the imaging study of choice for delineating the three-dimensional anatomy of spinal cord compression by spondylosis or OPLL and defining signal change within the spinal cord. We usually supplement MRI scan with sagittally reformatted CT images to further define the bony anatomy, to distinguish soft disc herniations from osteophytes, and to show the alignment of the cervical spine (if lateral plain films are inadequate for this purpose in obese or husky patients). CT myelography has been made irrelevant by MRI scans and is used only in patients with implanted pacemakers or if MRI is otherwise contraindicated.
PATIENT COUNSELING

In experienced hands, the risks of cervical vertebrectomy are low. These include spinal cord and nerve root injury, cerebrospinal fluid fistula, esophageal perforation or dysmotility with dysphagia, and carotid or vertebral artery perforation. The most frequent complication related to the anterior approach to the cervical spine is dysphagia and vocal cord paresis caused by traction or direct injury of the recurrent laryngeal nerve and the superior laryngeal nerve, or soft tissue swelling postoperatively (1, 8, 11, 20). Studies have shown that the risk of temporary voice changes or swallowing difficulty ranges from 11 to 16.5% and permanent voice changes approaches 1 to 2% (1, 8, 11). Special effort should be made to impart to patients the possible changes to voice or swallowing after the surgery, which, depending on one’s occupation, may be debilitating.

INTRAOPERATIVE MANAGEMENT

Intubation and Patient Positioning

Patients with compression of the spinal cord are at increased risk of injury if the neck is manipulated rapidly or placed in excessive extension. For this reason, awake fiberoptic nasal intubation is recommended. For high cervical exposures (e.g., C3 vertebrectomy), nasal intubation is preferred because it allows the mouth to be closed, thus minimizing the mandible’s interference with visualization of the superior aspect of the exposure (2). Anesthesia is induced only after it is noted that the patient is voluntarily able to move all extremities. An arterial line is placed in every patient to monitor blood pressure continuously throughout the procedure, and the blood pressure is maintained in a normotensive range. Electrodes are then routinely placed for somatosensory and motor evoked potential monitoring, although the efficacy of these techniques in improving outcome has never been proven in a prospective randomized study (3, 4, 10, 12, 14, 19, 22). A single dose of prophylactic antibiotics is administered by the anesthesiologist 1 hour before the time of incision.

Care is taken not to rotate the head in either direction, the neck is extended, and the head is placed on a horseshoe headrest. Wide adhesive tape is placed over the inner and outer aspect of the arms and forearms and fixed to the end of the operating table to pull the shoulders caudally and to allow visualization of the lower cervical spine on fluoroscopic images. A footboard is placed to prevent the patient from moving toward the foot of the operating table.

Intraoperative Imaging

We routinely use intraoperative fluoroscopy to ensure accurate placement of anterior cervical plates and screws. If the anesthesia team and equipment are placed several feet above the head of the patient, the fluoroscopic console may be moved rostrally away from the surgical team when it is not in use.

The Incision

External landmarks, such as the thyroid or cricoid cartilage are unreliable guides to the correct localization of the skin incision. We localize the incision using intraoperative fluoroscopy as a guide. Alternatively, several skin staples may be placed on the lateral aspect of the neck at, above, and below the location of the intended skin incision, after which a single lateral x-ray is taken and the site of the intended skin incision is adjusted in relation to the skin staples.

A transverse incision is marked on the skin at the upper one-third of the vertebral body to be resected before the patient is draped. The incision begins at the midline and is carried laterally to the medial border of the sternocleidomastoid muscle. A vertical incision is cosmetically less acceptable than a transverse incision and is unnecessary for a single-level vertebrectomy. If spinal cord compression by osteophytes is in the midline, the side of the incision is irrelevant because recent data indicate that the incidence of recurrent laryngeal injury is similar, regardless of the side of the incision (1, 11). If osteophytes are asymmetrical, an incision contralateral to the osteophytes gives the surgeon better visualization of the osteophytes.

Another important factor that should be considered in determining the side of the incision is a patient’s history of previous neck surgery. If a patient has had any previous neck dissections that may have affected their vocal cord function, we recommend that these patients be evaluated preoperatively with fiberoptic laryngoscopy. If any such injury does exist, the incision and exposure should be on the same side, preferably with the aid of an otolaryngology-trained neck surgeon. In other situations, we obtain soft tissue exposure ourselves.

Soft Tissue Dissection

The platysma muscle lies just under the subcutaneous tissue and varies greatly in thickness. The fibers, which run in a rostral to caudal direction, are spread, and scissors are used to develop a plane between the sternocleidomastoid muscle and the carotid artery laterally and the trachea and esophagus medially. Avoidance of sharp dissection at this point minimizes the chance of injury to the esophagus or the hypopharynx. Hand-held retractors are placed firmly against the anterior aspect of the vertebral bodies, ensuring that the esophagus is out of the field medially and the carotid artery, laterally.

Unless the recurrent laryngeal nerve has otherwise been identified, close attention should be paid at this point to avoid dividing any structure crossing from the carotid sheath medially (11). Especially in the lower cervical spine, the external branch of the recurrent laryngeal nerve runs parallel to the
inferior thyroid vessels, and its injury can be avoided by identifying the nerve directly before dividing the thyroid vessels, if this becomes necessary for exposure, which, in our experience, is usually not the case (1, 11).

**Finding the Midline: Soft Tissue Retraction**

The preverbral fascia is opened sharply, exposing the longus coli muscles. In the absence of large anterior osteophytes, the space between the longus coli muscles is a reliable guide to identifying the midline and may be marked before the longus coli muscles are mobilized. Large osteophytes will displace the longus coli to one side or another and obscure the location of the midline. A preoperative CT scan may be useful to define the relationship of osteophytes to the midline.

There have been reports of injury to the sympathetic chain and subsequent postoperative Horner’s syndrome in patients after anterior cervical decompressive procedures in the lower cervical spine, thought to be secondary to excessive mobilization of the longus coli muscles (9, 20). The superior cervical ganglia and the sympathetic chain at the level of C3 are usually obscured for their entire width by the longus coli muscles. As the muscles descend caudally along the cervical spine, they diverge more from the midline, whereas the position of the sympathetic chain remains relatively static (11, 15). Therefore, as the longus coli muscles are mobilized laterally for exposure of the anterior cervical vertebrae, one can inadvertently cause damage to the sympathetic chain.

Sufficient mobilization of the longus coli muscles is, nonetheless, necessary to obtain sufficient mediolateral exposure to achieve adequate resection of the vertebral body and to ensure that self-retaining retractors remain engaged. Using the bipolar cautery, one can simultaneously cauterize and free the medial aspect of the longus coli muscles from their attachment to the vertebral body that will be resected, as well as half of the length of the adjacent vertebral bodies. Scissors dissection will cause bleeding in the longus coli muscles and is avoided. The use of the monopolar cautery is also avoided because spread of heat and current can result in injury to the recurrent laryngeal nerve or other soft tissue structures (1, 8). A bipolar cautery with blades insulated except at the tips will prevent heat transfer to adjacent structures and result in more efficient hemostasis.

Retraction is achieved using modular retractor blade sets, such as those manufactured by Aesculap (Center Valley, PA) or Medtronic Sofamor Danek (Memphis, TN). Toothed retractor blades are placed beneath the longus coli muscles at the level of the middle of the body to be resected. The ratchet mechanism of both of these retractor systems provides sufficient mechanical advantage to obtain excellent mediolateral retraction of soft tissues. The length of the blades is important; too short of a blade will result in disengagement of the blade as the retractor is opened, and too long a blade will make drilling awkward. The length of the two blades used is usually symmetrical, but a longer or shorter blade medially or laterally can be used to rotate the retractor apparatus and may be helpful to obtain a more unobstructed view of the area to be drilled. Blunt blades are then placed superiorly and inferiorly.

In all cases, regardless of the expected length of the procedure, the anesthesiologist is asked to deflate the cuff on the endotracheal tube after the retractor blades are set. After 20 seconds, the cuff is reinflated to just occlude the space between the trachea and the tube and is left in this position for the remainder of the operation. There is evidence now that this maneuver will decrease the incidence of recurrent laryngeal injury by reducing the pressure against the recurrent laryngeal nerve between the endotracheal tube and retractor blades as the nerve enters the larynx (1).

**Bony Resection**

The anterior longitudinal ligament over the disc spaces above and below the level to be resected is incised, and the most anterior portion of the discs is excised, using curettes and pituitary forceps. The anterior longitudinal ligament is then removed over the vertebral body to be resected and the contiguous portions of the adjacent upper and lower vertebrae. The mediolateral extent of the bone to be resected is marked. Usually, 18 to 20 mm of bone in a mediolateral direction is resected to be certain that all osteophytes are removed (Fig. 1). Postoperative C5 root dysfunction occurs in approximately 5% of patients undergoing decompressive surgery at the C4-C5 level. The reasons for this are not clear, but Saunders (17) noted a marked decrease in the incidence of this complication if he narrowed the width of the bone resection in patients undergoing vertebrectomy at this level. For this reason, at the C4-C5 level, we limit the width of bone resection to 15 to 17 mm.

We use an extra-rough 6-mm diamond burr (Stryker, Kalamazoo, MI) to resect bone because it will not cut or snag soft tissues. It has the additional advantage over cutting burrs of being hemostatic on cancellous bone. After half of the depth of the vertebral body is resected in the anteroposterior plane, the operating microscope is brought into the field. The vertebral artery is most vulnerable to injury at this stage of the surgery because it lies in the middle third of the anteroposterior depth of the vertebral body (6, 7, 15). We recommend noting the location of the two transverse foramina and the distance separating them on the preoperative CT or MRI scans. This practice also allows one to identify any anomalies in the positioning of the vertebral arteries. As a rule of thumb, the vertebral arteries lie...
approximately 27 to 30 mm apart and vary only by approximately 1 to 2 mm cranially to caudally (Table 1).

There is a tendency to resect more bone contralateral to the side where the surgeon stands and skimp on bone resection on the ipsilateral side (Fig. 2). Briefly removing the operating microscope from the field will enable the surgeon to maintain midline orientation and make the bony resection more symmetrical. As bone resection proceeds, the endplates of the adjacent vertebrae are also resected. Bleeding from cancellous bone may be controlled with bits of Gelfoam (Ethicon, Cincinnati, OH) pushed into the bleeding bony interstices. Bone wax should not be used for hemostasis because it does not resorb, and it prevents bony fusion.

The Posterior Longitudinal Ligament (PLL)

When the PLL is reached, the last bits of bone may be resected with fine curettes. The PLL is entered with a nerve hook, with care being taken to lift the ligament away from the dura. A Number 11 knife blade is used to cut down on the ligament over the nerve hook, thus, exposing the dura. The PLL is composed of a thick anterior layer and a filmy posterior layer. If the shiny dura is not seen, the posterior layer may have to be opened separately. Although the dura may be adherent to the ligament in patients with previous surgery or OPLL, the ligament is generally separate from the dura. Apparent “adhesions” may result from failure to open the posterior layer of the PLL, which is normally adherent only to the thick anterior layer. Fine Kerrison rongeurs are used to resect the PLL to the edges of the bone exposure. Resection of the PLL ensures that extruded disc fragments will not be missed and that osteophytes that may be buried in the PLL will be resected.

Epidural veins are most prominent laterally, and venous bleeding in this location will usually signify that resection has been carried sufficiently lateral. Although lateral venous bleeding may be controlled with the bipolar cautery, small bits of thrombin-soaked Gelfoam or FloSeal (Baxter Healthcare Group, Fremont, CA) are equally effective and carry less risk of injury to nerve roots.

Bony Reconstruction

Reconstruction of the vertebrectomy may be performed using a fibula or an iliac crest allograft or an iliac crest autograft. We use an iliac crest allograft because it avoids the morbidity of a second incision. We prefer the iliac crest to the fibular allograft because fusion occurs more rapidly with the mostly cancellous iliac crest compared with the predominantly cortical bone of the fibula. If the endplates are removed, the hard cortical bone of the fibular graft has a tendency to telescope into the cancellous bone of the adjacent vertebral bodies.

The graft is cut 2-mm longer than the rostrocaudal length of the vertebrectomy. The anteroposterior depth of the graft is cut to 13 mm, which will ensure that it is well away from the anterior surface of the dura in all but the smallest adults (Table 2). Distraction on the cervical spine may be exerted by the use of Caspar distracting pins (Aesculap, Center Valley, PA) or by having the anesthesiologist pull on the head in the long axis of the patient’s body. Care should be taken to avoid using a graft that is too long for the length of the vertebrectomy. In our experience, excessive distraction has led to postoperative interscapular back pain, particularly with the use of the Caspar distraction approach.

We then screw a Caspar graft holder (Aesculap, Center Valley, PA) into the graft, and the end of the graft holder is hammered, forcing the graft into the area of vertebrectomy. Use of the graft holder prevents the graft from rotating, ensuring that it fits evenly as it is hammered into place. When the graft is almost flush with the anterior aspect of the adjacent vertebral bodies, the graft holder is removed, and a bone tamp is used to slightly countersink the graft (Fig. 3).

Anterior Instrumentation

The fluoroscopic unit is brought into the field, and an anterior cervical plate is chosen. We now prefer to use the ABC plate manufactured by Aesculap (Center Valley, PA). This is a so-called “translational” plate, which allows for some graft subsidence at the graft-bone interface. The plate may slide in rela-

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**Table 1. Measurements taken from cervical spine computed tomographic scans of the minimum, maximum, and mean distance separating the medial borders of the transverse foramina at each subaxial cervical spinal level in millimeters**

<table>
<thead>
<tr>
<th>Anatomic Structure</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial margin of transverse foramen</td>
<td>Minimum</td>
<td>26.72</td>
<td>23.78</td>
<td>26.75</td>
<td>27.77</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>35.79</td>
<td>28.79</td>
<td>30.26</td>
<td>32.84</td>
</tr>
<tr>
<td>Medial margin of transverse foramen (mm)</td>
<td>Mean</td>
<td>30.46</td>
<td>26.02</td>
<td>28.17</td>
<td>29.78</td>
</tr>
</tbody>
</table>

*Adapted from, Oh SH, Perin NI, Cooper PR: Quantitative three-dimensional anatomy of the subaxial cervical spine: Implications for anterior spinal surgery. Neurosurgery 38:1139–1144, 1996 (15).*

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**FIGURE 2. Postoperative axial CT scan for a patient with inadequate decompression. The surgeon operated from an incision made in the right side of the neck, and the decompression is skewed to the left, which is a typical mistake made when orientation with respect to the midline is lost.**
tion to the screws, but the screws remain fixed in position. This has the effect of maintaining load-sharing and diminishes the chance of screw or plate breakage or screw pullout (21). The plate should be secured in the midline using temporary holding pins and should be short enough so that the ends do not overhang into adjacent disc spaces, which has been shown to be associated with adjacent-level ossification of the anterior longitudinal ligament, a phenomenon with a clinical significance that is not yet defined (16).

Regardless of the system used, fluoroscopic guidance during screw insertion will ensure accurate screw placement, avoiding the graft and adjacent disc spaces. With the translational plating systems, it is important to be cognizant of the eventual graft subsidence in planning the screw placement in the slots of the plate (Fig. 4). With the ABC plating system, placing the rostral and caudal screws at the inferior end of their respective slots allows for maximal graft subsidence and plate movement relative to the screws, whereas placing the screws midway in the rostrocaudal length of the slots would be expected to reduce that subsidence by approximately half. Engangement of the posterior cortex by the screw has been shown to be unnecessary, and screws 14 to 16 mm in length will usually be of sufficient length to accomplish fixation while avoiding penetration of the spinal canal (13, 18).

Closure

A Jackson-Pratt drain is placed in the prevertebral space and brought out through a stab wound placed inferior to the incision. The superficial cervical fascia and platysma muscle are closed in separate layers using interrupted sutures. A subcuticular suture is placed, and the skin is approximated using a dermal bonding solution (Dermabond; Ethicon, Somerville, NJ).

External immobilization is not used for single-level vertebrectomy, but a rigid collar is used for multilevel vertebrectomies for 3 months after surgery.

**POSTOPERATIVE MANAGEMENT**

Dysphagia is more likely to occur in the elderly and patients who undergo extensive mobilization of the esophagus, as it is

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**TABLE 2. Measurements taken from cervical spine computed tomographic scans of the location of the vertebral artery relative to the anteroposterior diameter of the vertebral body at each level of the subaxial cervical spine in millimeters**

<table>
<thead>
<tr>
<th>Anatomic Structure</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior margin of vertebral body to anterior margin of transverse foramen</td>
<td>Mean (mm)</td>
<td>8.66</td>
<td>7.55</td>
<td>7.29</td>
<td>7.31</td>
</tr>
<tr>
<td>Posterior margin of vertebral body to posterior margin of transverse foramen</td>
<td>Mean (mm)</td>
<td>2.17</td>
<td>2.76</td>
<td>2.75</td>
<td>3.42</td>
</tr>
</tbody>
</table>

*Adapted from, Oh SH, Perin NI, Cooper PR: Quantitative three-dimensional anatomy of the subaxial cervical spine: Implications for anterior spinal surgery. Neurosurgery 38:1139–1144, 1996 (15).*
necessary for multilevel vertebrectomy, particularly in the upper cervical spine. We, therefore, have our patients initiate oral intake only under direct observation by a member of the neurosurgical staff to avoid the risk of aspiration. When necessary, swallowing studies are ordered to appropriately document any observed difficulty negotiating food or liquids, and the patient’s diet is adjusted accordingly.

The drain is typically removed the morning after surgery, and the patient is discharged to home with instructions to resume normal activities, while avoiding vigorous athletic activities that might result in graft or plate dislodgement. The patient is seen 2 weeks postoperatively to evaluate neurological function, at which time, lateral plain x-rays are taken to assess the graft and plate position. Further follow-up is performed at intervals of 1 to 2 months until fusion has occurred.

We do not use perioperative steroids unless there has been rapid deterioration of neurological function preoperatively or if the spinal cord has been compromised during surgery. The use of nonsteroidal anti-inflammatory agents in the postoperative period has been reported to decrease the incidence of successful fusion in the lumbar spine (5). Although data is lacking to show that the same is true for the cervical spine, we nevertheless ask patients not to use nonsteroidal anti-inflammatory agents for 3 months after surgery.

On the basis of the existing literature, between 73 and 100% of patients have an improvement of symptoms and neurological function after anterior cervical decompression, corpectomy, and fusion for multilevel cervical spondylosis (18).

REFERENCES

MULTIPLE LEVEL DISCECTOMY AND FUSION

THE VENTROLATERAL APPROACH for surgical decompression of the cervical spine is widely used and well known to most spinal surgeons. Because compression of the spinal cord and nerve roots usually occurs ventral to the spinal cord, and the spinal cord does not tolerate traction, this approach allows safe and direct decompression of most compressive pathology. This article reviews the indications, diagnostic evaluation, and technique for multiple level discectomy and fusion. It further addresses the advantages and disadvantages of this technique compared with alternate surgical procedures.

KEY WORDS: Cervical spondylosis, Cervical vertebrae, Myelopathy, Radiculopathy, Spinal fusion

The ventrolateral approaches for discectomy and fusion described by Smith and Robinson (23) and Cloward (6) have now been routinely used for over four decades. Compression of the cord and nerve roots predominantly occurs ventral to the spinal cord in cervical spondylosis (9). Because the spinal cord does not tolerate lateral traction from a dorsal approach well, the ventrolateral approach allows safe and direct decompression of ventral pathology. Multiple level discectomy and fusion allows ventral decompression, maintenance of disc height, correction of hypermobility, restoration of cervical lordosis, and arresting or resorption of spur formation with fusion (14, 15, 17, 24, 25).

Degenerative cervical disc disease most commonly affects the C5 to C6, C6 to C7, and C4 to C5 disc spaces in order of frequency. It can affect single or multiple levels. Central disc herniations may symptomatically compress the spinal cord without affecting the exiting nerve roots, which can lead to cervical spondylotic myelopathy (CSM). Lateral herniations may compress the exiting nerve roots in the intervertebral foramen without affecting the spinal cord, leading to cervical radiculopathy. The herniation may compress both the spinal cord and exiting nerve root leading to a cervical spondylotic myeloradiculopathy.

CSM and cervical spondylotic myeloradiculopathy often occur in patients with a congenitally narrowed canal where the canal is further compromised by herniated disc material, osteophyte growth, or ligamentous hypertrophy (2). The normal anteroposterior diameter varies in normal individuals, ranging from 16 to 18 mm between C3 to C7, with the spinal cord diameter ranging from 8.5 to 11.5 mm (4). Symptomatic CSM has been associated with narrowing of the anteroposterior diameter of the canal below 10 to 12 mm (1, 31). The effects of compression of the spinal cord may be worsened by abnormal movements of the vertebrae, leading to repeated compression of the spinal cord. The pathophysiology of CSM is controversial. Although the initial hypothesis was ischemia of the spinal cord caused by compression of the anterior spinal artery (13), many other authors have advocated occlusion of intramedullary arteries as the cause of ischemia. In CSM, computed tomography (CT) and magnetic resonance imaging (MRI) demonstrate ventral compression of the spinal cord in more than 75% of patients (9). Anterior cervical discectomy and fusion has become a common technique used in the surgical treatment of cervical radiculopathy or cervical myelopathy associated with cervical spondylosis (7, 8, 18, 22, 23).

INDICATIONS

Indications for multilevel decompression and fusion vary by disease process. For cervical radiculopathy, indications for surgery include progressive neurological deficit, static neurological deficit with radicular pain, and persistent, or recurrent arm pain that is not responsive to conservative therapy (11). Neurological deficits and radicular symptoms should correspond to lesions identified on diagnostic studies. For very lateral soft disc herniations into the neural foramen without...
significant osteophyte formation, other procedures such as dorsal foraminotomy or ventral microforaminotomy may be considered. Multiple level discectomy and fusion should be considered for nerve root compression at multiple levels with significant axial neck pain or significant narrowing of the neural foramen by osteophyte formation.

For cervical myelopathy or myeloradiculopathy, indications for multilevel decompression and fusion are based on the progression of clinical symptoms of cervical myelopathy and on the radiological detection of multisegment spondylosis with ventral compression. The clinical diagnosis of cervical myelopathy requires clinical symptoms of myelopathy, radiographic evidence of mechanical compression, and exclusion of nonmechanical causes of long tract alteration such as multiple sclerosis and amyotrophic lateral sclerosis. Indications for surgical treatment of CSM include progressive impairment of function without sustained remission and failure to demonstrate improvement in myelopathy after cervical immobilization (3). Some studies have pointed to the smallest transverse area (27, 32) or duration of symptoms (10, 19, 32) as the best predictors of outcome, whereas Chiles et al. (5) have cited cord atrophy, intrinsic hand muscle wasting, lower preoperative functional grade, compression at multiple levels, and bony osteophyte compression as negative predictors of outcome.

Age, severity of disease, number of levels operated, and preoperative grade are not predictive of outcome. The only factor related to postoperative outcome is duration of preoperative symptoms.

**DIAGNOSTIC EVALUATION**

For cervical radiculopathy, cervical myelopathy, or cervical myeloradiculopathy, MRI of the cervical spine is the initial diagnostic imaging technique of choice for gathering information required for surgical intervention. In cases where a patient is unable to obtain an MRI (i.e., pacemaker, metal artifact from cervical instrumentation, or claustrophobia) or where the MRI does not clearly delineate the pathology, a water-soluble myelogram followed by CT is performed. CT has improved sensitivity over MRI for delineating between osteophyte formation and soft disc herniation. If instability or segmental motion is suspected, then radiographs of the cervical spine with flexion and extension views are indicated. White et al. (30) have shown in cadaveric studies that horizontal movements between vertebral bodies greater than 3.5 mm seen on lateral radiographs or forward angulation greater than 11 degrees of one vertebral body with respect to another indicate relative instability. Electromyography and nerve conduction studies may help to provide objective evidence of nerve root compression. These studies can also help to differentiate among plexus, peripheral nerve, and muscle disorders, which can mimic cervical radiculopathy.

**TECHNIQUE**

The operation is performed in the supine position under general anesthesia with the extremities padded and protected. The neck is moderately hyperextended with the head placed in a headrest. A roll can be placed under the shoulders to obtain greater extension. If the patient has severe canal stenosis on imaging studies or a Lhermitte’s sign on physical examination, the surgeon should consider limiting the amount of extension of the neck until the compressive pathology has been surgically removed. Extension can be increased with 1 inch tape passed around the chin and attached to either side of the operating table. Alternatively, the patient may be placed in cervical traction. Use of wrist restraints or 2 inch tape placed at the shoulders can be used to provide downward traction of the shoulders for improved intraoperative radiographic imaging. The operation may be performed under loupe magnification or with the assistance of an operative microscope.

The incision may be centered using anatomic landmarks or preoperative localizing radiograph with a metal object taped to the side of the neck. The anatomic landmarks include the hyoid bone (C3), the thyroid cartilage (C4), and the cricoid (C6); these landmarks can be highly variable between patients. The incision is centered at the midpoint of the construct that is considered. For example, if disectomies at C4 to C5, C5 to C6, and C6 to C7 are planned, then the incision is centered on the C5 to C6 level. An extended horizontal incision with extensive dissection above the platysma may be used for exposure; the authors prefer an oblique exposure along the ventral border of the sternocleidomastoid muscle for greater than two-level discectomy. With the latter incision, it is easier to extend the exposure superiorly and inferiorly, and tissue retraction is minimized. Dissection is performed down to the platysma, which is incised parallel to the ventral border of the sternocleidomastoid muscle. An avascular plane of dissection is developed down to the vertebral bodies between the trachea and esophagus medially and the carotid sheath laterally. A spinal needle is then placed into a disc space, and lateral radiograph or fluoroscopy is used to verify the level. The avascular plane should be extended superiorly and inferiorly to reach all vertebral levels to be fused and to minimize traction of the soft tissues.

The prevertebral fascia and the medial aspects of the longus coli muscles are cauterized and reflected laterally from the lower half of the uppermost vertebrae being fused to the upper half of the lowermost vertebrae being fused. Dissection is carried out laterally until the uncinate processes are exposed on each side. Self-retaining retractors are then placed beneath the medial edges of the reflected longus coli muscles. Osteophytes extending ventral to the front of the vertebral bodies and into the disc space are removed by drilling or rongeurs. Removing these osteophytes initially allows better visualization of the disc space during discectomy and provides a flatter ventral vertebral body surface for later instrumentation.

The disc and cartilaginous endplates are then removed with curettes and rongeurs. After removing the ventral half of the disc, vertebral body spreaders or Caspar posts are used to increase the disc space height by 30 to 50%. The remainder of the disc, the posterior annulus, and osteophytic
ridges are then removed, and foraminotomies are performed. If possible, the authors prefer to leave the posterior longitudinal ligament (PLL) intact. If there is concern for herniated disc behind the PLL, then a small window in the PLL can be made and a nerve hook used to explore for extruded disc. It is not always possible or preferable to preserve the PLL; such cases would include large disc herniations that cannot be removed through a window in the PLL and segmental ossification of the PLL.

Restoration of cervical lordosis can be performed by increasing the ventral column height, decreasing the dorsal column height, or a combination of the two. The intact PLL acts as a fulcrum when an interbody graft is placed, and distraction of the ventral column results in compression of the dorsal column; this allows some restoration of the normal cervical lordosis (Fig. 1). For multiple discectomies, autograft interbody grafts have a lower incidence of pseudoarthrosis than allograft. After placement of the grafts, a cervical plate is placed with screws at the most inferior part of the cranial vertebral body and the most superior part of the caudal vertebral body to be fused. This helps to prevent the screws or plate affecting adjacent levels as the construct subsides. Intermediate screws are placed at each level, and the spine is “brought to the implant,” restoring some cervical lordosis as well (Fig. 2).

ADVANTAGES OF MULTIPLE LEVEL DISCECTOMY AND FUSION

The choice of surgical procedure for treatment of cervical spondylosis is dictated by several factors including location of pathology (ventral, dorsal, or circumferential), extent of pathology (limited to interspace or extensive behind the vertebral body), medical condition of the patient, presence of instability, presence of kyphotic deformity, and familiarity of the surgeon with the procedure techniques. Controversies exist regarding the optimal surgical approach for treatment of CSM. The procedure should be chosen to decompress the affected spinal cord or nerve roots, maintain or restore stability of the spine, and correct or prevent kyphotic deformity. The procedure must be tailored to the individual patient’s pathology and medical condition as well as the surgeon’s comfort with a given procedure.

There are several advantages to multiple level discectomy and fusion over alternate surgical procedures. Ventral discectomy and fusion is very familiar to most spinal surgeons because single level discectomy and fusion is one of the more common spinal procedures performed in the United States. The main advantage of this surgical approach is that it allows the surgeon to remove the ventral compressive pathology and restore cervical lordosis.

Versus Corpectomy

Cervical corpectomy and fusion is a viable technique for removal of ventral compressive pathology and stabilization of the cervical spine. Similar to multiple level discectomy and fusion, it allows direct ventral decompression of the exiting nerve roots. It also offers the distinct advantage over multiple level discectomy of decompression behind the midportion of the vertebral body.

The difference in fusion rates between corpectomy and multiple level discectomies is altered by use of ventral cervical instrumentation. Hilibrand et al. (12) and Nirala et al. (16) showed in retrospective studies that corpectomy without instrumentation has much higher fusion rates than multiple interbody grafting without instrumentation, although corpectomy has a higher level of graft displacement or extrusion. Single level corpectomy and two level discectomy with ventral instrumentation have comparable fusion rates and complication rates (29, 33). Comparison of three level discectomy with two level corpectomy also shows similar rates of fusion. Samartzis et al. (20) showed a 94.7% fusion rate with three
level discectomy and fusion with plating, whereas Sasso et al. (21) reported a 94% fusion rate, and Vaccaro et al. (26) reported a 91% fusion rate with two level corpectomies.

At three or greater levels of corpectomy with ventral instrumentation, failure rates rise. Sasso et al. (21) reported a 70% failure rate with a three level corpectomy and ventral plating. Vaccaro et al. (26) had similar findings, with a 50% failure rate at three levels. Graft displacement after corpectomy is proportional to graft length and is increased as vertebral bodies are pulled toward the lordotic ventral plate. This is seen on postoperative lateral radiographs.

Another difference is the translational stability which a construct with intermediate points of fixation provides. Although there are many more interfaces between the vertebral bodies and the interbody grafts, multiple level discectomy and fusion provides more points of fixation to hold the construct rigidly in place for longer constructs. With corpectomy and strut graft fusion, there are only two interfaces between the vertebral bodies and the graft occurring at the remaining rostral and caudal vertebral bodies. There is more translational movement, however, at these interfaces because the construct only allows for two points of fixation (Fig. 4). This may be the mechanism for the increasing complication rates and lower fusion rates seen in longer corpectomy constructs in studies by Sasso et al. (21), Vaccaro et al. (26), and Wang et al. (28).

**Versus Dorsal Procedures**

For cervical radiculopathy caused by compression at multiple levels, it is important to assess both the sagittal balance of the cervical spine and the location of the offending pathology. If cervical lordosis is present in the neutral position, and the compressive pathology is primarily foraminal, then multiple dorsal foraminotomies are a reasonable approach. Dorsal foraminotomies have the advantage of maintaining the mobility of the spine at each segment. If the ventral compression extends into the spinal canal, then ventral decompression cannot be safely performed from a dorsal approach. Dorsal foraminotomy cannot correct kyphosis and may predispose the spine to progressive kyphosis, especially if straightening of the spine or cervical kyphosis is present before the operation.

For cervical myelopathy caused by compression at multiple levels, it is again important to assess sagittal balance and location of the offending pathology. If the compression is caused by large disc herniations or osteophytic bars, then a dorsal decompression will still result in cord compression, especially in the setting of a straightened or kyphotic spine. Dorsal laminectomies and laminoplasties produce best results when the compression is primarily dorsal (i.e., congenital stenosis) or circumferential where the ventral compression is relatively...
Cervical kyphosis is difficult to correct from a dorsal approach. In the natural aging process, the cervical discs desicate, resulting in a collapse of the ventral column and straightening of the spine. Correction of kyphosis requires increasing the height of the ventral column, decreasing the height of the dorsal column, or a combination of both. Multiple level discectomy and fusion has the advantage of being able to increase the height of the ventral column and can be used to decrease the height of the dorsal column if the PLL is left intact to act as a fulcrum. This is especially useful in a “fixed” kyphotic deformity where cervical lordosis cannot be obtained with extension of the cervical spine. In cases where kyphosis is present in the neutral position, but lordosis can be achieved with extension of the spine, then ventral or dorsal fusion can be used to restore cervical lordosis. Dorsal surgery does not have the complications of dysphagia and vocal cord paresis, which can be seen in ventral surgical procedures of the cervical spine.

CONCLUSION

Cervical discectomy and fusion is a common procedure performed in spinal surgery, and the technique is very familiar to most spine surgeons. Ventral compressive pathology is present in 75% of CSM by CT and MRI. Multiple level discectomy and fusion is optimal for addressing ventral compressive pathology that is at or near the disc spaces. It increases the height of the ventral column and can be used to translate the intervening bodies forward, which helps restore lordosis to the cervical spine.

It provides a rigid construct, with multiple points of fixation imparting translational stability to the construct. Limitations of multiple level discectomy and fusion include inability to address dorsal pathology, difficulty in decompressing behind the vertebral body, and increasing rates of pseudoarthrosis with increasing number of levels fused.

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CERVICAL LAMINECTOMY: TECHNIQUE

SPINAL CANAL DECOMPRESSION via cervical laminectomy with or without foraminal decompression is a mainstay of treatment of cervical spondylotic myelopathy and myeloradiculopathy. The goal of this surgery is to expand the cervical canal dorsally by removing the spinous processes, laminae, ligamentum flavum, and bony hypertrophy that are contributing to the canal stenosis. In selecting this particular approach to decompression, the surgeon must take into account the spinal geometry and the primary pathology of the patient: an “effective” cervical kyphosis is a contraindication to a dorsal approach, and spinal canal compromise secondary to ventral compression is best addressed through a ventral or a combined ventral and dorsal approach. This technique is technically facile and versatile in application. Complications with this procedure are relatively rare, with postoperative spinal instability being the primary concern. With proper patient selection and attention to surgical technique, laminectomy is a safe and effective approach to the management of cervical myelopathy in selected patients.

KEY WORDS: Cervical spondylosis, Cervical spondylotic myelopathy, Cervical vertebrae, Laminectomy


S
ince the first successful cervical laminectomy was performed by Sir Victor Horsley (39), dorsal decompression of the cervical spine has become a standard approach to treatment of cervical spondylotic myelopathy (CSM) secondary to congenital or acquired spinal canal stenosis. Such a dorsal approach can be performed with relative ease and safety and provides free access to the spinal canal, the foramina, the lateral disc space, and the intradural contents.

The modern paradigm for managing CSM uses both ventral and dorsal approaches, with ventral procedures being more common overall (16, 33). The ventral procedures consist primarily of discectomy, with or without vertebrectomy, followed by fusion. The ventral approach provides the advantage of direct access to and removal of the ventral compressive osteophytes and disc extrusions that commonly occur in cervical spondylosis but it does not provide adequate access to address dorsal compression, is more technically demanding when addressing multilevel disease, and carries the risk of accelerated juxtaposition degeneration. In contrast, the dorsal approach provides the advantages of technical ease in decompressing multilevel disease and maintenance of segmental mobility (10) but does not provide adequate access to address ventral compression, does not address abnormalities of alignment, and is associated with the development of progressive spinal instability and deformity (6, 17, 38). Both approaches can provide satisfactory results (5, 11, 14, 18, 26, 31, 32, 37), but, as with all surgical planning, patient selection and selection of approach through consideration of pathology are key determinants of successful surgical intervention. Those patients with primarily ventral pathology are best served through a ventral approach, and those with primarily dorsal compression and/or congenital canal stenosis are best served through a dorsal approach. In this regard, cervical laminectomy has remained a valuable tool in the management of CSM.

PREOPERATIVE CONSIDERATIONS

The symptoms and syndromes of CSM can be closely mimicked by a number of other neurological disorders, including amyotrophic lateral sclerosis, multiple sclerosis, and syringomyelia, and diagnostic evaluations must keep this differential in mind (7, 14). Patient history, detailed neurological examination, and radiographic imaging are the primary basis of diagnosis in CSM. Cervical magnetic resonance imaging scanning is currently the imaging modality of choice, although computed tomography scanning with or without myelography remains useful for better delineation of bony anatomy. Plain films with dynamic views are valuable adjuncts in the evaluation of spinal geometry and segmental instability.

Once the diagnosis of CSM is confirmed, management choices include conservative and surgical approaches. In patients with mild, static disease or who are poor surgical candidates, a trial of conservative management with rigid collar immobilization, physical therapy, and epidural steroid injections may be appropriate, with improvement observed in up to one-third of patients (1, 30, 37). Unfortunately, it is unclear which patients will respond to conservative management, and there exists some controversy regarding the natural history of the disease (23). In patients with moderate-to-severe myelopathy or with progressive myelopathy, surgical management is appropriate.
Decompressive cervical laminectomy has its greatest usefulness in the management of patients with single or multilevel canal compromise secondary to congenital spinal stenosis (anteroposterior diameter ≤10 mm) (13), with or without superimposed spondylosis, and is also used effectively in the treatment of ligamentum flavum hypertrophy or ossification and other causes of dorsal compression. Laminectomy can also be effective in the treatment of ossification of the posterior longitudinal ligament (22). The versatility of this technique lies in its extensile nature, allowing extensive multiple segment decompression, if necessary. Decompression can be carried across the cervicothoracic junction with this technique, although this is typically coupled with a concomitant fusion because of the increased stresses observed at this junction. The dorsal exposure provided by this technique also allows appropriate access to perform foraminotomies in those patients who have radicular symptoms related to nerve root compression in the foramina.

In addition to considering the location and type of pathology, the decision-making process for surgical management of CSM must also involve careful evaluation of the patient’s cervical spinal geometry and stability. Laminectomy is most effective in those patients with maintained “effective” cervical lordosis or relative “straightened” configuration (Fig. 1). Results of laminectomy in those patients with “effective” cervical kyphosis are significantly worse, with the “sagittal bowstring” effect likely contributing to poorer outcomes (2, 3, 14, 29). A preexisting kyphotic deformity of the cervical spine also places the patient at risk for progression of deformity after laminectomy, which can also contribute to poor outcome. Therefore, kyphotic configuration of the cervical spine should be a contraindication to the dorsal approach, and the surgeon should consider a ventral or a combined ventral and dorsal approach to treatment in these cases. In cases in which significant segmental instability of the cervical spine is identified preoperatively, the surgeon may wish to consider a ventral approach or supplementing a dorsal decompression with fusion to avoid further progression of instability postoperatively.

**SURGICAL TECHNIQUE**

Patients with a diagnosis of CSM are at particular risk for further spinal cord injury secondary to increased cord compression and/or cord ischemia during the induction of general anesthesia. Before induction, the surgeon should communicate to the anesthesiologist the need to avoid the extremes of neck motion during intubation. In certain cases of critical canal stenosis, awake fiberoptic intubation with neurological examination may be necessary. Mean arterial pressure should be closely monitored during induction, and care should be taken to avoid hypotension (mean arterial pressure < 70 mmHg) because compression of the anterior spinal artery can also be a causal factor regarding CSM (34). Appropriate prophylactic antibiotic therapy is also administered at this time.

During the positioning of the patient, the patient’s head and neck should be manually supported by the surgeon and maintained in a neutral position. A three-pin headholder is affixed to the patient’s head, and the patient is positioned prone on the operating room table with the trunk supported by padded chest rolls or a four-poster frame. Laminectomy frames and padded headrests can also be used. If a headrest is used, care must be taken to avoid undue pressure on the eyes because increased intraocular pressure can contribute to ischemic optic neuropathy and visual loss (28). The bony prominences are padded, the legs are flexed at the knees, the arms tucked and secured at the patient’s sides, and the patient is secured to the table using appropriate straps. The head is then fixed into a neutral or slightly flexed military position using the appropriate table adaptor, and the table is placed into the reverse Trendelenburg position to reduce venous congestion and provide adequate surgeon access. Alternatively, the sitting position can also be used for this procedure. The purported advantages of the sitting position include improved venous drainage, more facile hemostasis, a reduction of blood in the field by gravity drainage, and improved ventilation. It is particularly useful in those patients who are morbidly obese or who have severe respiratory compromise. Disadvantages include surgeon fatigue and venous air embolus. If the sitting position is used, proper anesthetic precautions should be undertaken; precordial Doppler and end tidal CO₂ monitoring should be used to help detect air emboli, and the patient should be kept well hydrated. In these cases, a central venous line with the tip in the right atrium is both useful in monitoring of central venous pressure and in potential treatment of an air embolus sequestered in the right atrium. The surgeon must also pay particular attention to maintaining hemostasis and waxing bone edges when this position is used. With proper anesthetic and surgical precautions, the sitting position can be used safely (25, 43). Somatosensory evoked potential moni-
Laminotomies at the laminar-facet groove just medial to the facet complexes. The free-floating lamina and spinous processes are then resected to complete the laminectomy (from Benzel EC, Norviel MF: Biomechanics of Spine Stabilization, AANS Publications, 2001, pp 94–95 [3]).

A high-speed drill is used to create bilateral laminotomies at the laminar-facet groove just medial to the facet complexes. The free-floating lamina and spinous processes are then resected to complete the laminectomy (from Benzel EC, Norviel MF: Biomechanics of Spine Stabilization, AANS Publications, 2001, pp 94–95 [3]).

After positioning, the suboccipital region is shaved, a midline skin incision is drawn, and the region is sterilily prepared and draped. Long-acting local anesthetic with epinephrine is infiltrated into the skin, and the skin incision is opened. Monopolar electrocautery is used to continue the dissection in the midline. The ligamentum nuchae is divided and dissection continued to split the splenius capitus fascia. The plane between the semi-spinalis capitis musculature is then entered. Taking a moment to identify the midline plane avoids unnecessary blood loss or intramuscular dissection. A subperiosteal dissection is then performed to mobilize the remaining paraspinal musculature and expose the spinous processes and laminae of the appropriate cervical levels, usually C3–C7. The large bifid spinous process of C2 is usually easily identifiable, and care should be taken to avoid unnecessary dissection of the muscular attachments to C2 because these contribute to upper cervical stability (12, 15). An intraoperative localization film can be used to verify the appropriate levels. Exposure of the laminae is taken out to the medial aspect of the facet complexes, and care must be taken to avoid injury to the facet capsules. Angled self-retaining retractors maintain the exposure.

A high-speed drill with a cutting bit is then used to perform bilateral trough laminotomies at the affected levels at the laminar-facet groove just medial to the facet complex (Fig. 2). After completion of the laminotomies, the spinous processes and lamina of the treated levels are free floating. The intraspinous ligament between the most rostral treated segment and the adjacent superior level is divided with the monopolar rongeur and resected with a Leksell rongeur; this procedure is repeated for the most caudal area of the treated segment and its adjacent inferior level. The most rostral and caudal spinous processes are then grasped using Kocher or penetrating towel clamps, and gentle dorsal traction is applied to lift the lamina and associated ligamentum flavum off of the underlying dura mater. The ligamentum flavum is then divided using an angled Kerrison punch, and the laminae are lifted en bloc off the underlying dura. Angled Kerrison punches are then used to remove residual lamina to complete the laminectomy to the lateral edge of the thecal sac and also to undercut the C2 lamina for further decompression, if necessary. Bipolar electrocautery and oxidized cellulose soaked in thrombin are used for hemostasis in the epidural space, and bone edges are waxed as necessary. Use of this technique allows decompression without placing the footplate of a punch or rongeur into an already narrowed spinal canal, minimizing the risk for further spinal cord compromise. In cases of severe spinal canal stenosis, introduction of an instrument or footplate into the spinal canal may exacerbate the cord compression and should be minimized or completely avoided by using a high-speed burr, exclusively, for the decompression.

Alternatively, the laminectomy can be performed in a piece-meal fashion. The spinous processes are resected and a partial laminectomy performed with a Leksell rongeur. The remaining lamina can then be thinned using a high-speed drill and the laminectomy completed with angled punches. Care must be taken to minimize the profile of the punch footplate against the dura during the laminectomy.

In patients with significant foraminal stenosis on imaging studies and correlative symptoms of myeloradiculopathy, concomitant foraminotomy at one or multiple levels can be performed using angled Kerrison punches or a high-speed Burr. In situations of advanced stenosis, the use of a drill, exclusively, may be advisable to minimize further compression of the nerve root within the foramen by introduction of an instrument. The foramina are located at the junction of the facets and can be palpated using a small blunt probe or nerve hook. Resection of up to 50% of the facet complex typically allows for adequate foraminal decompression and typically does not produce significant spinal instability (36, 44).

Concomitant intradural exploration and dentoate ligament section have been suggested by some surgeons to treat the “coronal bowstring” effect that can be present in CSM secondary to ventral spondylosis (4, 35). However, this procedure does not seem to improve the overall outcome of decompressive laminectomy, and ventral decompression is now more commonly considered for management of the “bowstring” effect (3).

Dural lacerations are managed with primary closure using fine nonabsorbable sutures. In extensive dural lacerations, use of myofascial autograft, dural substitutes, and fibrin sealant may be necessary for a watertight closure. The Valsalva maneuver can help to verify adequate closure.

After satisfactory hemostasis is attained, the wound and skin are then closed in layers according to the surgeon’s preference. A drain can be used if hemostasis seems suboptimal.
**COMPLICATIONS**

Laminectomy is associated with the common postoperative risks of infection, compressive epidural hematoma, cerebrospinal fluid fistula, deep venous thrombosis, pulmonary embolus, and cardiopulmonary failure that are observed with other spine surgeries. Complications more specific to cervical laminectomy include perioperative neurological injury, progressive postoperative deformity, and delayed neurological deterioration.

A varied rate for postoperative neurological complications are recorded in the literature, with a rate of greater than 10% observed in some studies (8, 37, 41). However, in the largest study of complications after cervical laminectomy, a low risk for neurological complication was observed with only 1.8% of 1862 cases developing neurological deterioration postoperatively (16). Of the neurological complications in this study, the majority were related to further injury of the spinal cord with progressive myelopathy, while a minority were related to new or progressive radiculopathy. In contrast to this observation, one study reported a 12.9% rate of postoperative radiculopathy after cervical laminectomy for CSM, although the majority of these deficits resolved completely within 6 months postoperatively (8).

Postoperative deformity after extensive cervical decompressive laminectomy is a significant concern and can be a contributing factor to delayed deterioration and poor outcome (2, 29, 38, 42). The reported rates for postoperative development of progressive deformity range from 21 to 42% (17, 20, 21, 27) and seem to be significantly higher for children (6, 24, 40). Preexisting "straightening," or hypermobility, of the cervical spine seems to increase the risk of deformity progression postoperatively. There are conflicting reports in these case series regarding whether or not progressive postoperative deformity has any bearing on clinical outcome, and the majority of adult patients developing deformity did not require further surgery. Children seem to be a special case, however, and are more apt to require surgical correction of progressive deformity (24, 27). In the case of children requiring dorsal decompression, strong consideration should be given to supplementing the decompression with a concomitant fusion or performing a laminoplasty procedure. Because of the significant risk of developing postoperative deformity, patients, particularly juveniles, who have undergone extensive decompressive laminectomy should be closely monitored with serial plain films. In patients who develop symptomatic deformity postoperatively, anterior and/or posterior surgery for deformity correction and fusion should be considered.

Patients who do not demonstrate appropriate postoperative recovery or those who develop delayed neurological deterioration and recurrent symptoms of CSM should be reevaluated with plain films and magnetic resonance imaging or computed tomography myelography to verify appropriate neural element decompression. Potential causes for delayed deterioration include progression of spondylotic changes and recurrent stenosis, development of a constrictive laminectomy mem-

brane, and development of progressive spinal deformity. Again, further surgery using ventral and/or dorsal techniques as dictated by the offending pathology and spinal geometry should be considered.

**OUTCOMES**

After decompressive laminectomy for CSM, 56 to 85% of patients demonstrate neurological improvement (5, 9, 14, 18, 29, 31, 32). There are no unequivocal predictors of outcome; although some authors have suggested maintenance of lordosis (14, 29) and shorter duration of symptoms (<2 yr) (5) as predictors of positive outcome, others have suggested kyphotic deformity (29), advanced age (>70 yr) (22, 29), severity of myelopathy (5, 14, 32), and longer duration of symptoms (>3 yr) (9) as predictors of negative outcome. Although there have been reports of durable treatment efficacy (5, 22, 29), there does seem to be a significant incidence of delayed functional deterioration (9) that may require further surgical intervention in selected patients.

**CONCLUSION**

Cervical laminectomy is a versatile and technically facile approach to the management of CSM and myeloradiculopathy and can be applied with relative safety and reasonable efficacy. However, as with any surgical treatment, close attention must be paid to patient selection; cervical spinal geometry and the location of the offending pathology must be strongly considered in the application of this technique to maximize good outcomes. Close postoperative monitoring of symptoms is also of particular importance because there is clearly a significant risk of progressive spinal deformity and delayed functional deterioration with this technique. Concomitant posterior spinal fusion with this technique may prove to be an effective preventative measure to the development of progressive deformity and may promote better long-term outcomes (19).

**REFERENCES**


OPEN-DOOR EXPANSILE CERVICAL LAMINOPLASTY

OPEN-DOOR EXPANSILE laminoplasty is a practical surgical technique for the treatment of cervical myelopathy secondary to cervical spinal stenosis. Laminoplasty procedures were first described in the late 1970s and have undergone numerous modifications. The current article reviews the indications, techniques, and outcome data for cervical laminoplasty. Complications of laminoplasty and comparison to laminectomy outcomes are also discussed.

KEY WORDS: Cervical spondylosis, Laminoplasty, Myelopathy, Surgical technique

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MANAGEMENT OF CERVICAL SPONDYLOTIC MYELOPATHY

Conservative management of cervical spondyotic myelopathy (CSM) is largely empiric. No well-designed clinical studies systematically evaluating the efficacy of common treatment modalities exist. The mainstay of conservative therapy is immobilization, together with anti-inflammatory medications, in an attempt to address modifiable sources of static and dynamic cord compression. Theoretically, immobilization of the grossly or microscopically unstable spine may facilitate resorption of degenerative osteophytes, in addition to preventing ongoing dynamic compression. Although conflicting evidence exists, the majority of available evidence suggests that CSM is largely a surgical disease in the presence of symptoms and signs, appropriate radiographic evidence, and supportive studies.

Once surgical intervention is decided on, the principal decision regarding surgical management is whether a ventral or dorsal approach should be used. A ventral decompressive procedure and fusion is the most appropriate surgical procedure in the presence of ventral compressive factors limited to one or two vertebral body levels. This procedure most directly addresses the pathology and facilitates fusion with the use of bone graft, with or without the addition of instrumentation. Good-to-excellent clinical results have been achieved in as many as 92% of patients undergoing this procedure (8). However, concerns regarding fusion rates, hardware failure, and graft materials carry significant clinical implications in the setting of multilevel ventral decompressions. The risk of adjacent level disease may be as high as 25% in studies that have looked at the long-term results of anterior fusion surgery (10).

Sir Victor Horsley was the first neurosurgeon credited for decompressing the cervical spine of a patient with progressive CSM using a dorsal approach (42). Until the description of ventral approaches, management of CSM traditionally consisted of a decompressive laminectomy. Although this procedure effectively enlarges the functional spinal canal area, thus allowing the spinal cord to move away from compressive elements and expand, it does so at the expense of the dorsal stabilizing structures. Depending on the preoperative spinal alignment, the levels of decompression, and the period of time passed since surgery, development of spinal instability and gradual kyphotic deformity may be observed. Given these concerns and the considerable population experiencing multilevel compressive pathology necessitating dorsal decompression, Asian surgeons developed the laminoplasty procedure in the late 1970s (32, 48), with numerous modifications since that time (4, 11, 22, 23, 30, 45). This procedure, by leaving the dorsal stabilizing structures in situ, is thought to mitigate the development of kyphosis and, with subsequent bone fusion, to stabilize the cervical spine and have improved outcome. Although evidence exists to both support and refute these claims, it is now acknowledged that patients with significant preoperative kyphotic alignment are unlikely to do well with either procedure and are best managed with a ventral surgery.
Cervical laminoplasty is usually recommended in patients who have multilevel cervical spondylosis and stenosis typically extending over three to four levels. Patients generally have a normal cervical lordosis and/or a relatively straight cervical spine. A dorsal decompressive procedure is avoided in the presence of significant kyphosis. The majority of our patients are recommended to undergo decompression from an open-door cervical laminoplasty from C3 to C7, with partial laminectomies of C2 and T1 and fusion with rib allograft at C3, C5, and C7, supplemented by vertebral autograft. The decompression extends somewhat rostral and caudal to the maximum levels of compression, so that the spinal cord does not migrate back and become entrapped or kinked at the rostral or caudal levels (lamina) of the decompression.

For the initial part of the procedure, the patient is placed in the supine position with the neck minimally extended, and endotracheal intubation is performed. Awake fiberoptic intubation may be preferred in patients with severe spinal cord compression because of the increased risk for spinal cord injury after neck extension. This will reduce the risk of neck hyperextension and permit the surgeon to repeat the neurological exam after placement of the endotracheal tube. In select cases, one may prefer to also turn the patient in the prone position when the patient is awake, because this presents yet another instance in which inadvertent movements of the neck may occur and result in neurological deterioration. Neurophysiological monitoring options include somatosensory evoked potentials, motor evoked potentials, and electromyograms. The value of the routine use of such monitoring is often questioned because it has been difficult to demonstrate that the information provided can actually change what the surgeon does during the surgery that will make it safer. However, some retrospective studies have demonstrated the positive predictive value of such tests in determining outcome (3, 4). The stimulating and recording electrodes are placed and secured, and baseline recordings are obtained before turning the patient. A number of options exist for holding the head during surgery in the prone position. We use the Mayfield three-pin headrest, which allows the surgeon to easily control the degree of flexion and extension of the cervical spine as well as reducing the possibility of pressure on the patient’s eyes. The patient is then transferred onto the operating table in the prone position, with the head secured in a slightly flexed position. Tape can be applied to the superior and dorsolateral aspects of both shoulders and secured to the caudal region of the operating table to assist with intraoperative radiographic visualization of the lower cervical levels, as required. After the operative field is prepped and draped, the midline is infiltrated with commercially available 1% lidocaine with epinephrine to minimize skin bleeding. A midline incision is performed, and either monopolar or bipolar electrocautery is used to control soft tissue bleeding. The midline fascia is then incised with monopolar electrocautery, and subperiosteal dissection is used to reflect the soft tissue structures off the spinous processes, lamina, and mesial portions of the facets bilaterally, taking care to preserve the facet capsules.

Soft tissue dissection and retraction of the extensor cervical muscle groups and exposure of the cervical lamina and mesial facets are obtained from the caudal portion of C2 to the rostral limit of T1. The caudal one-third of the C2 lamina and the rostral one-third of the T1 lamina are removed using a combination of a high-speed air drill and a 2-mm Kerrison punch to visualize the underlying dura at this level. We also remove the spinous processes of C3 to C7 inclusively with a Horsley and morselize the bone for subsequent autografting. The next segment of the procedure involves performing osteotomies of cervical lamina three to seven, inclusively. In so doing, one creates an “open” side and a “hinged” side of the above lamina (Fig. 1).

In general, the side with the greatest compression and/or the most clinically symptomatic is the open side. If one is planning to perform foraminotomies in addition to the laminoplasty, the open side is best placed on the side of the intended foraminotomies. A high-speed air drill with a small bit is used to create troughs at the level of the lamina-facet junction from C3 to C7. Drilling proceeds through the outer and inner cortical margins of the lamina on the side to be opened. On the hinge side, drilling proceeds through the outer cortical margin and cancellous bone; however, the inner cortex is not violated. After the drilling is complete, bone allografts are prepared for purposes of stabilizing canal expansion. We prefer to use rib allografts for this purpose. Again using the drill, three separate grafts are cut, each approximately 8 to 16 mm in length. Grooves are then made transversely along the cut surfaces of the rib grafts, approximating the thickness of the cut laminae. After the grafts have been prepared, attention is turned to “opening the door.” Initially, a 2-mm Kerrison punch is used to remove ligamentum flavum along the length of the open door. Subsequently, two
small curettes are introduced into the open gap produced by drilling the laminae and advanced just deep to the outer cortex. By pulling the curettes upwards, the laminar facet gap on the open side is slowly enlarged and, thus, results in a green-stick “fracture” along the previously created trough on the hinged side. Minimal advances are made before moving to other laminae, in an effort to open all of the involved laminae as a functional unit. Lifting the lamina as one unit is important in preserving the intraspinous ligaments and mid-line ligamentum flavum, so as to maintain the integrity of the dorsal stabilizing structures. The goal is to expand the anteroposterior diameter of the canal by approximately 4 mm. Great care must be taken to achieve this goal without violating or fracturing the inner cortex of the hinge side. Once this is accomplished, the rib allografts are placed in the gap that has been created at the C3, C5, and C7 levels, with the cut edges of the lamina resting in the cut groove of the rib (Fig. 2). If performed properly, the grafts should fit snugly in the gap, there should be a slight closing force securing the graft position, and the inner cortex of the hinge side should be intact (Fig. 3). The open side should have enough tension to hold the grafts in place. We have rarely seen the complication of rib allograft sinkage into the spinal canal, despite the absence of instrumentation using this method. We then place the morselized spinous process autograft over the decorticated bone surfaces of the facet and lamina on the hinged side to provide some stiffness to the construct. Longterm follow up has shown that there is fusion between the allograft and the lamina medially and the facet joint laterally. In our experience, there is intersegmental fusion of the rib allografts at each cervical level at which they are placed on the basis of follow-up radiographic studies—particularly axial computed tomographic scans (Fig. 3). Placement of vertebral autograft harvested from the spinous processes may augment this fusion process, and may accelerate the fusion process, which can occur across the facet joint after laminoplasty (37). In our laminoplasty technique, the tension band is maintained—particularly between C3 and C7, where the ligamentum flavum and the interspinous ligament are maintained—allowing for further stability to the spine and avoiding excessive movement. The tension band also helps maintain the curvature by maintaining the dorsal stabilizing elements, compared with laminectomy. With the green-stick fracture, the tension band remains intact. Often, the tension band does not provide a rigid fusion, and this may be advantageous because the remaining mobility of the spine may be sufficient to avoid stress at the adjacent levels.

Should the patient experience radiculopathy as well as myelopathy, one can add one or several foraminotomies to the laminoplasty procedure. Typically, the foraminotomy is initiated once the lamina has been elevated and the ligamentum flavum excised. The mesial one-third to one-half of the facet over the exiting nerve root is drilled with a high-speed drill. The opening can be widened with 1- or 2-mm angled Kerrison punches.

Should rigid stabilization be required, the addition of facet cables with or without a rib allograft can be inserted. Lateral mass screws attached to a plate or a rod can also be applied (29). It is sometimes difficult to position the rib allografts to hold open the lamina after additional hardware is placed, but it can be done. Other variations of the approach include the use of the spinous process autograft instead of the rib allograft to hold open the lamina (1, 28). Some surgeons prefer to stabilize the rib allograft with miniplates or CG clips (CG Surgical Ltd., St Clair, New Zealand) to the adjacent lamina and facet on the open side (7, 28, 38) or with sutures (30). The lamina can be split in the midline with a T-handled Gigli-like saw and the allograft spacers positioned between the green-stick fractured hemi-lamina (5). In the Kurokawa-type of laminoplasty, the spinous processes are split in the midline and troughs are drilled bilaterally at the lamina-facet junction. The spinous processes are then split in the midline (23). An autograft spacer may be used to keep the split spinous processes open (44).

Postoperatively, patients are maintained in a Miami J-collar for 12 weeks. Plain x-rays with flexion and extension views are obtained immediately after surgery and at 12 weeks. Activity is limited to light regular tasks during the 12 weeks.

In our experience, an open-door expansile cervical laminoplasty (without additional stabilization procedures) takes approximately 90 minutes to complete, with an average blood loss of 200 ml. The complication rate is low, particularly when compared with decompressive operations that attempt to achieve the same number of levels of decompression and sta-
bilitation tackled from the front (25). It is ideally suited for the elderly myelopathic, osteoporotic patient with multiple levels of stenosis and little or minimal neck pain. In the young patient, particularly if there is significant axial neck pain, a ventral procedure may be better suited. In patients with acute traumatic central cord syndrome without evidence of radiographic instability, an expandable laminoplasty again is a surgical option (46).

OUTCOMES

Overall, recovery rates of approximately 50% are consistently reported after laminoplasty (9, 12, 22, 27, 36, 38), although improvement is seen in as many as 75% of patients (24). With respect to spondylotic radiculopathy, a retrospective study found that outcomes were best after ventral decompression (92%), and only slightly worse (86%) after laminoplasty (8). Laminectomy was associated with the poorest outcome (66%).

CONCLUSION

Although management decisions must take into account a number of factors and are highly individualized, the following represents some general guidelines and our interpretation of critical literature.

Dorsal decompression is typically indicated if multisegment pathology needs to be addressed and if predominantly dorsal pathology exists. Additionally, in the case of ossification of the posterior longitudinal ligament, significant adhesion between the posterior longitudinal ligament and the underlying dura results in additional risk of dural laceration if approached ventrally. Laminectomy has traditionally been used for decompression and continues to be the procedure of choice for many clinicians in North America (47). Decompression does occur but at the expense of the dorsal stabilizing structures. Loss of cervical lordosis or development of kyphosis are seen in as many as 43% of patients (11, 31). However, clinically significant malalignment and instability are less common (13, 16, 33, 45). The crucial implication of ensuing kyphosis is its potential role in subsequent clinical deterioration because kyphotic alignment of the spinal cord results in secondary cord compression and is associated with poorer outcome (18). Although this risk may be relatively insignificant in a patient who is otherwise debilitated and has a limited life expectancy, it is a very significant risk in a younger patient requiring earlier treatment because of underlying congenital canal stenosis.

Clinically, studies have shown that improvement directly correlates with the degree of canal expansion. However, excessive expansion, as well as irregular canal area (20), may be associated with additional problems. It seems that optimal canal expansion approximates 4 to 5 mm in the sagittal anteroposterior diameter (11), correlating with an approximately 50% increase in canal area (2, 38) and facilitating a 3-mm dorsal shift of the spinal cord (40). However, decreased lordosis correlates with decreased volume expansion after laminoplasty, as well as decreased dorsal migration of the cord (2). Although improvement certainly occurs with less substantial enlargement, more-aggressive enlargement is not advisable. Retrospective studies indicate that increased canal diameters (beyond the above) are associated with an increased incidence of postoperative complications, specifically C5–C6 paresis. Presumably, this is a result of traction on the nerve roots because the C5 level frequently represents the apex of the lordotic curve and exhibits the most significant migration. Although numerous studies suggest that this is a transient phenomenon in most cases, it is obviously distressing for the patient and may take as long as 6 years to recover sufficiently (36). Far more critical than canal expansion is subsequent cord expansion, with studies showing a direct correlation between Japanese Orthopedic Association scores and spinal cord area (30).

Both clinically and radiographically, limited range of motion (ROM) is frequently observed after laminoplasty. Studies suggest that approximately 50% of range of motion (ROM) is lost after laminoplasty, particularly extension (5, 11, 14, 17, 21, 37). This correlates well with radiographic evidence of spontaneous bony fusion (37, 39). It has been proposed that this is actually beneficial, in that it ameliorates ongoing mechanical stress or injury without being rigid and inducing stress and degeneration of adjacent levels. Although numerous studies have shown no correlation between limited ROM and recovery rates or outcome, this may represent a biomechanical etiology for the postoperative axial pain, which is problematic. However, it is important to remember that the majority of literature pertains to patients undergoing decompression for ossification of the posterior longitudinal ligament, which itself is associated with increased rigidity and, thus, may overestimate the restricted ROM attributable to the laminoplasty procedure.

Restenosis or persistent compression can occur if the lamina is insufficiently elevated or the lamina is dislodged forward (27). The allograft should be of adequate size to increase the canal diameter. Different techniques have been used to keep the canal open by suturing the elevated lamina to the facet or to the overlying muscle.

In summary, although the laminoplasty procedure was designed to address some of the concerns of multilevel decompressive laminectomy, it is not without its own complications. Historically, sinkage of the open door was a concern, but, with the addition of stabilizing structures, this is now rare. However, axial neck pain, shoulder girdle/C5–C6 weakness, and decreased ROM continue to be particularly problematic (Table 1). Additionally, although numerous studies suggest that

<table>
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<th>TABLE 1. Complications related to laminoplasty</th>
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<tr>
<td>Neck pain</td>
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<td>Decreased range of motion</td>
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<td>C5 nerve root palsy</td>
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<td>Sinkage of graft into the canal</td>
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mal-T1 alignment and instability are more common after laminectomy (14, 26), both may develop after laminoplasty, occasionally at rates comparable to those seen with laminectomy (13, 41). Overall, recovery rates of approximately 50% are consistently reported after laminoplasty, with axial pain and malalignment having little impact on ultimate outcome and Japanese Orthopedic Association scores (6, 9, 27, 35), unless associated with a decreased cervical curve index of greater than 10 (20, 36). Outcomes are comparable to (13, 30), if not better than (8), those associated with laminectomy. Laminoplasty may, however, be preferable in patients with poor bone quality, as well as younger patients with multilevel compression in the setting of lordotic alignment because these patients are at risk to develop delayed malalignment or instability (Table 2).

REFERENCE


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Cervical spondylosis is one of the most common entities encountered by the practicing spine surgeon (1, 3, 5). The term is commonly used to describe degenerative changes of the intervertebral disc, with consequent degenerative changes of the uncovertebral joints, ligamentum flavum, and facet complex. In many cases, symptoms are absent or mild and can be managed nonoperatively. In other cases, hypertrophy of these structures and osteophyte formation can lead to neural impingement. Depending on the location of the pathology, neural impingement can result in the development of neck pain, radiculopathy, myelopathy, and/or a combination myeloradiculopathy. Persistent radiculopathy unresponsive to nonsurgical management (nonsteroidal anti-inflammatory drugs, oral/epidural steroids, or physical therapy) and myelopathy are the usual indications for surgical intervention. Surgical approaches are often tailored to the type of pathology. Patients with isolated radiculopathy can be treated with either a ventral or dorsal decompression of the affected nerve root via a foraminotomy. Cervical spondylotic myelopathy has traditionally been treated either with an anterior cervical discectomy/pectomy or laminectomy. As with any surgical treatment, the surgical outcome is highly dependent on selecting the appropriate treatment for the appropriate patient (6, 7, 10, 14, 19).

Dorsal surgical approaches for the management of cervical spondylosis are well established and are among the oldest spinal procedures known (9, 15, 16). However, in recent years, much effort has been made to modify these approaches (4, 13). The goal has been to achieve the same surgical result with less injury to the surrounding tissues; less tissue injury has been correlated with less postoperative pain and better outcomes (2, 8). Additionally, preservation of motion may prevent the development of pathology at adjacent spinal segments. The terms minimally invasive or minimal-access spinal surgery have been coined to describe these techniques. Although these techniques are the product of years of clinical research and technological advances, they have their basis in well-established treatments (6, 7, 10, 11, 14, 19). Herein, we describe modification of the dorsal laminoforaminotomy technique for nerve root and central canal decompression.

MINIMALLY INVASIVE SURGERY FOR THE MANAGEMENT OF CERVICAL SPONDYLOSIS

DORSAL SURGICAL PROCEDURES have a well-established role in the treatment of both radiculopathy and myelopathy caused by cervical spondylosis. Laminectomy and laminoplasty procedures can both lead to postoperative kyphosis because of the removal of the dorsal supporting structures of the neck. Minimally invasive or minimal-access spinal surgery procedures of the dorsal cervical spine are evolving techniques with the goal of decompressing the neural structures with minimal disruption of the dorsal supporting structures. We think that this will lead to less postoperative pain and a decreased incidence of postdecompression kyphotic deformity. Patient selection, techniques, and results are discussed for both minimally invasive cervical laminoforaminotomy and stenosis decompression.

KEY WORDS: Cervical spondylosis, Endoscopy, Microsurgery, Minimally invasive, Myelopathy, Neck pain, Radiculopathy

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ness of the upper extremities. Patients should have failed a course of conservative therapy before considering surgery, in the absence of significant motor weakness. In patients with acute radiculopathy, it may prove difficult to determine the distribution of the patient’s symptoms. Many patients have evidence of multilevel neural foraminal stenosis, and imaging studies alone may not prove useful in establishing the pathological level. Establishment of a dermatomal distribution is of critical importance in preoperative planning. In the absence of significant motor weakness (which can be used as a localizing sign), it is helpful to provide pain control through the use of nonsteroidal anti-inflammatory drugs, narcotic pain relievers, muscle relaxants, or steroid tapers. If it remains difficult to establish the radicular pattern of the patient’s symptoms, diagnostic nerve root injections with combined local anesthetic and steroid may prove helpful. Patients with a unilateral monoradiculopathy are the best candidates for surgical decompression; however, imaging findings at adjacent levels with concordant nerve root injections and/or symptoms may be considered an indication for multilevel decompression. Preoperative imaging studies should include, at a minimum, static and dynamic plain films of the cervical spine as well as a good quality magnetic resonance imaging (MRI) scan of the cervical spine. Evidence of instability should lead to consideration of a fusion procedure. A computed tomography (CT) myelogram may be substituted for the MRI scan or obtained as a follow-up study in cases in which an MRI scan is not helpful. Although CT myelography does not aid in the diagnosis of spinal cord injury, it is quite useful in the work-up of cervical spondylosis with respect to central and foraminal stenosis. Patients with diffuse spondylotic changes on imaging studies and no clear radicular symptoms are poor candidates for laminoforaminotomy and should be referred for nonsurgical management.

Minimally invasive laminoforaminotomy is performed with the patient under general anesthesia, and, as such, patients must be suitable for a general anesthetic. However, the minimal blood loss, the short length of the procedure, and the option of performing the procedure in the sitting position may make the procedure a viable option for patients who would not otherwise tolerate an open, prone procedure. Patients with a known patent foramen ovale, or a previous history of embolic stroke, cerebrovascular, and/or cardiovascular disease may not be suitable for surgery in the sitting position. Routine screening for a patent foramen ovale is generally not indicated. The risk of a symptomatic venous air embolism is low (11, 12).

**Surgical Technique**

The technique for the minimally invasive microendoscopic laminoforaminotomy using a tubular retractor system has been described in detail elsewhere (Fig. 1) (8). We think that the 30-degree angle of the endoscope allows for better visualization of the operative field than conventional microscopy, particularly in patients with thick necks, in whom a longer tube is required. A longer working tube makes it difficult to angle the operating microscope. If central canal decompression is also planned, an endoscope is mandatory because it is impossible to angle the operating microscope appropriately. With the microendoscopic technique, the sitting position is favored because this promotes drainage of blood and irrigation from the wound, which would otherwise obscure the endoscopic image. The procedure can be adapted for use with the operating microscope and the prone position. Intraoperative electromyographic and somatosensory evoked potential monitoring are used throughout the procedure, particularly during placement of the tubular retractor system. As such, the anesthetic technique should be discussed preoperatively; use of a short-acting paralytic on induction and an anesthesia technique that does not interfere with neuromonitoring are critical.

The patient is placed under general anesthesia. We advocate the use of an intraoperative precordial Doppler probe and, if possible, a brachial central venous pressure line. Because the risk of a symptomatic venous air embolism is low and the risk associated with placement of a central venous catheter may outweigh its benefit, use of a central venous catheter is not recommended. The patient is placed in Mayfield pins. Baseline electromyographic and somatosensory evoked potential data are collected. The patient is slowly brought into the sitting position and connected to the Mayfield pins. C-arm fluoroscopy is brought in from above or below, and a true lateral image is obtained. Fluoroscopy is crucial in gauging the extent of decompression; therefore, adequacy of imaging should be established before final preparation and draping. The video monitor and endoscope should be positioned to the side of the patient past the operative plane for comfort during the procedure (Fig. 2). After preparation and draping, fluoroscopy and a guide pin are used to mark a point 1.5-cm off midline,
directly overlying the desired disc space. A stab incision is made in the skin, and the guide pin is docked on the superior facet at the desired level, using fluoroscopic guidance. The junction of the inferior and superior facet should be avoided to minimize the risk of violating the canal or neural foramen. The guide pin should be kept orthogonal to the skin; the instruments can be directed medially after the endoscope has been inserted. If the guide pin is introduced too far laterally, it can be slowly directed medially until the facet is contacted. A second stab incision can be made if the first incision was inadequate. The stab incision is then widened to approximately 2 cm, and the underlying fascia is divided with scissors, with care taken not to divide the underlying muscle. It is recommended that the dorsal cervical fascia be divided sharply, rather than forcing the dilators through the fascia, risking injury to the underlying spine and spinal cord. Currently, the only available tubular retractor system is the MetRx system. The first tissue dilator is passed over the guide pin, using fluoroscopic guidance, and the guide pin is removed. Further dilators are then passed in sequence, until the required working aperture is achieved and the working channel slides into place (Fig. 3). The endoscope is then attached to the working channel. A suction tip is used to confirm the bony landmarks. Starting superiorly and laterally, the superior lamina, facet complex, and interlaminar space are then freed of residual soft tissue. An angled curette is used to define the junction of the superior lamina and facet. A high-speed burr may be used to thin the medial aspect of the superior facet, and Kerrison punches may be used to perform a foraminotomy. The drill can also be used to thin the lip on the inferior facet. If the disc space is to be explored, the superior 2 to 3 mm of the inferior pedicle should be drilled away. The nerve root should be readily visualized; the remainder of its course should be gently explored with a blunt nerve hook to determine the adequacy of the decompression (Fig. 4). In the case of disc herniation, the nerve root appears swollen, 40 mg of methylprednisolone can be applied to a piece of gelatin foam and left in situ after hemostasis has been obtained and the wound has been irrigated. Significant bleeding can be encountered from the epidural venous plexus. Judicious use of electrocautery and hemostatic agents are usually enough to control this bleeding. Finally, the working channel should be withdrawn slowly, with the endoscope attached, allowing for visualization of muscular bleeders that were previously tamponaded by the retractor. The wound is closed in layers, and the skin is dressed with cyanoacrylate.

Two adjacent levels can be decompressed through a single incision by centering the initial incision on the facet halfway between the neural foramina. Three adjacent levels may be decompressed by making a slightly longer incision and translating the retractor caudally or rostrally, as needed. A bilateral decompression can be performed through a single midline incision: the subcutaneous tissues are divided bluntly with a finger, superficial to the fascia; the skin and subcutaneous tissues are then mobilized 1.5-cm laterally in the desired direction. Care is taken to close the fascia ipsilaterally before proceeding to the contralateral side.
Patient Selection

Presenting symptoms include signs of cervical myelopathy, including, but not limited to, bilateral upper extremity dysesthesias, difficulty with fine motor movements of the upper extremities, upper extremity weakness, and hyperreflexia. In advanced cases, spasticity of the upper and lower extremities and gait difficulties may also be present. Bowel and bladder dysfunction are uncommon. Symptoms may also be combined with those of cervical radiculopathy, producing a combined cervical myeloradiculopathy. Imaging studies should include, at a minimum, static and dynamic views of the cervical spine and a high-quality MRI scan. CT myelography often proves useful. Contraindications are similar to those for the traditional cervical laminectomy. Patients with significant mobile or fixed kyphotic deformities may be best treated with a ventral or combined ventral and dorsal approach. Patients with loss of the normal cervical lordosis and mild kyphosis may be treated endoscopically in the presence of concomitant posterior compression. Although these patients may be at risk for the development of progressive kyphosis with the traditional open cervical laminectomy, it is our hypothesis that, with the MEDS approach, we are able to preserve the midline dorsal cervical tension band, contralateral muscular attachments, and contralateral facet complex, thereby, minimizing this risk. Patients with posterior compression of the cord secondary to buckling of the ligamentum flavum are ideal candidates for this procedure. Noncontiguous and contiguous multilevel decompressions have been performed, the longest being three adjacent levels.

Surgical Technique

Positioning and anesthesia concerns are identical to those for a dorsal cervical microendoscopic foraminotomy. Because of the need to visualize across the spinal canal, the microendoscopic technique, as opposed to the operating microscope, is required. Single level and multilevel decompressions can be performed with the standard fixed aperture tubular retractors. For two-level decompressions, the tube can be angled rostrally or caudally, as needed. The incision should be centered on a point between the two interspaces. For a three-level or greater decompression, a longer incision (e.g., 3 cm for a three-level decompression) can be used; the tube is translated rostrally or caudally as needed, and then angled. Using a longer incision provides better visualization and decreases the amount of soft tissue resection required. For multilevel decompressions, an expandable working channel, such as the X-tube (Medtronic-Sofamor Danek) may also be used. In general, it is easiest to begin with the most caudal level first, minimizing the amount of blood running into the field. After the soft tissues have been cleared off the level of interest and the level has been confirmed with fluoroscopy, the lateral edge of the lamina is defined. To minimize the risk of injury to the underlying spinal cord, a high-speed burr is used to drill away the lateral aspect of the lamina. It is usually necessary to angle the working channel rostrally to resect the remainder of the spinous process. Fluoroscopy can be used to confirm the rostrocaudal extent of the decompression. The ligamentum flavum is initially left intact to protect the underlying dura.
mater. However, to adequately visualize the contralateral aspect of the spinal canal, the ligamentum flavum is resected with the aid of curettes and Kerrison punches. Care should be taken to avoid retraction on the thecal sac; the undersurface of the contralateral lamina should be drilled away to provide better visualization. A hooded drill bit is under development to prevent injury to the dura mater during this portion of the procedure. Decompression is complete when a nerve hook can be passed along the lateral aspect of the dura mater contralaterally. Once a single level has been decompressed, further levels can be decompressed with a high-speed burr or a Kerrison punch (Fig. 5). Care should be taken to obtain meticulous hemostasis. Bony bleeding should be waxed as soon as possible to reduce the risk of venous air embolism. Particular attention should be given to muscular bleeders during removal of the working channel and endoscope. Significant bleeding previously tamponaded by the retractor can be encountered. The wound is closed in layers and dressed with cyanoacrylate.

**Postoperative Care**

Patients undergoing microendoscopic foraminotomy are usually observed for several hours after the procedure and discharged to home the same day. Elderly patients or patients undergoing the procedure late in the day have been kept in the hospital overnight. Postoperative medications include a 2-week supply of oral narcotics, baclofen, and a stool softener. Unless contraindicated, patients are also given a single dose of intravenously administered ketorolac at the conclusion of the procedure. Follow-up visits are at 7 to 10 days and 6 weeks after surgery. Occasionally, a flare-up of the patient’s presenting radiculopathy is encountered, presumably from perioperative swelling of the affected nerve root. In our experience, these have been self-limited and can be treated with a 5-day methylprednisolone taper. Patients undergoing the cervical MEDS procedure have been kept overnight and discharged the following morning. Postoperative care is identical to the foraminotomy procedure, except that the use of ketorolac is delayed until the morning after surgery, given the small risk of a postoperative epidural hematoxia secondary to drug-induced platelet dysfunction.

**RESULTS**

Our experience with microendoscopic foraminotomy has been previously published (8). This technique has been established as a safe, effective alternative to the open technique. The cervical MEDS procedure is currently under development. Results of our cadaveric studies are in preparation for publication. Currently, four patients have undergone the procedure, for a total of seven levels decompressed (Table 1). All patients reported resolution of their symptoms (myeloradiculopathy in all cases) by the 6-week follow-up. Postoperative imaging revealed adequate decompression at six of the eight levels decompressed. Further decompression would have been possible in the remaining two cases, but, intraoperatively, the canal seemed to be adequately decompressed. In one case, a superficial wound infection was treated with a combination course of intravenous and oral antibiotics. Progressive postoperative kyphosis was encountered in none of the patients. We think that preservation of the midline dorsal tension band and contralateral muscular attachments will decrease the prevalence of postdecompression kyphosis compared with the open technique. Longer follow-up periods and a larger sample size will be required to confirm this.
CONCLUSION

The concept of minimally invasive/minimal access spinal surgery is ideal for the management of cervical spondylosis. The extensive muscle dissection required for the traditional dorsal approaches leads to significant postoperative pain and the potential for postoperative deformity. By minimizing the extent of muscular dissection and by preserving the contralateral soft tissues, the approaches described in this report may lead to shortened hospital stays, decreased narcotic use, and better outcomes. As familiarity with the use of tubular retractors increases, other modifications of traditional open procedures will be developed. Endoscopic cervical stenosis decompression is a technically demanding procedure, however, and as the surgeon’s comfort with the use of tubular retractors increases, so does safety. A minimally invasive technique for cervical laminoplasty is currently under development, and the placement of unilateral lateral mass screws using tubular retractors has also been described (17, 18). Rather than being novel techniques, these developments represent refinement of established techniques. As such, they can be readily added to the surgical repertoire. As comfort with the use of tubular retractors and endoscopic techniques increases, the development of more complex techniques will continue, potentially including the use of this system for the resection of intradural lesions.

REFERENCES

Most capable clinicians, when faced with a complex decision involving multiple variables, can make strategic error(s) during the decision making process. Errors are classified in two broad types herein: 1) errors of consideration, and 2) errors of prioritization. These errors are not necessarily errors in the traditional sense, but, in many cases, may be imperfections that become manifest during the decision making process.

Errors of consideration consist of the suboptimal consideration of one or more variables during the decision making process. They can be divided into three subtypes: 1) errors of omission, 2) errors of logic, and 3) errors of obscurity. Errors of omission and of logic both involve familiar variables that are evident to the clinician, whereas errors of obscurity are associated with variables that are not evident to the clinician.

Finally, errors of prioritization are the result of the consideration of variables in a suboptimal order during the decision making process. The types and definitions of decision making errors are described in (Tables 1 and 2).

Most of the errors of consideration and errors of prioritization, which are commonly and innocently made, have no ill-effect. When these errors are made, the variables that compose the clinical problem or clinical dilemma at hand (except in situations involving errors of obscurity) were, simply stated, inappropriately or inaccurately processed. Errors of obscurity are usually unavoidable. Some information may simply remain unknown, whereas other information may be known. Therefore, these types of errors are, in general, excluded from the discussion herein.

Most complex spine operations are comprised of more than one component (procedure) that should be appropriately prioritized. Components of an operation should be categorized by priority into the primary, secondary, and tertiary components.

The primary component is the most important component of the operation. In turn, it dictates the need for and type of procedure that comprises the secondary component. Usually, but not always, spinal decompression is the primary component of a complex operation. Either neural elements must be decompressed or the threat of neural element compression by the pathological process must be alleviated. This may destabilize the spine to a greater extent than would have otherwise occurred, thus, altering the choice of the secondary component of the procedure (the stabilization component). This, in turn, should dictate the tertiary component (e.g., the fusion portion of the operation).

Such a prioritization process helps ensure that neural element decompression, as well as spinal stability, is achieved. It also solidifies, in the surgeon’s mind, the relative importance of each component of the operation, and promotes rational decision making.

**EXAMPLES OF DECISION MAKING ERRORS**

It is, perhaps, instructional to consider examples of each of the aforementioned decision
Errors of Consideration

Errors of Omission

Errors of logic occur because the clinician fails to strictly apply the principles of logic to the clinical problem at hand. However, one person’s logic is not necessarily that of the next person. A clinical algorithm may be chosen on the basis of bias, clinical experience, etc. The logic used is also based on these variables and understandings. This process (algorithm), however, may be illogical to others. It is, therefore, emphasized that logic is relative.

Errors of Obscurity

To not consider a variable that is unknown to the clinician is understandable and acceptable. It is impossible to consider an unfamiliar variable (Table 1). Therefore, no further discussion on this topic is necessary, except for the need for an appropriate emphasis placed on knowledge-base acquisition. This can minimize the number of unfamiliar variables.

Errors of Prioritization

To consider all variables, but to apply them in an order that is considered illogical or inappropriate, is not uncommon. A clinician may determine all of the relevant clinical variables affecting a pathological process; however, if these variables are not considered in an orderly manner, a suboptimal result may ensue. For example, to consider spinal deformity correction before considering neural decompression may result in an increased neurological deficit.

PROBLEM-BASED DECISION MAKING

The major variables that substantively affect the decision making process should be considered to be components of the overall problem or dilemma. Dividing the overall problem into its component parts assists the clinician in solving even the most complex of problems.

Problem-based decision making is herein defined as a decision making strategy that involves: 1) the separation of complex problems or dilemmas into their component parts, 2) the prioritization of the component parts, and 3) the orderly solution of each portion of the overall problem posed by each of the component parts to methodically solve the overall problem. Problem-based decision making can make a seemingly impossible problem solvable, or it can make the apparently obscure, visible.

The importance of the establishment of a diagnosis cannot be underestimated; yet, this clinical goal is not often achieved. It is not necessarily always prudent to establish a diagnosis at all costs. For example, the diagnosis of the primary site of a metastatic spine tumor is frequently not made before the death of the patient. It may be practical to not pursue the diagnosis of the primary tumor because it is clinically irrelevant. It is, however, important, and in most cases vital, to establish the diagnosis of a pathological spine lesion. Is it a tumor, an infection, or the result of trauma? Management strategies vary significantly. Although the primary diagnosis is not necessarily relevant, the determination of the pathology type most certainly is. Therefore, it must be established with confidence in the majority of cases.

Confidence, however, is relative. For example, in a patient with metastatic cancer, the absolute confirmation of the historical diagnosis of the primary lesion may not be relevant. The clinician may often confidently assume that the lesion is a metastatic tumor. On the other hand, a patient without an established diagnosis of metastatic cancer with a similar spine lesion may not engender the same degree of confidence regarding the etiology of the lesion. The clinician may appropriately take the posture that the diagnosis of a metastatic lesion in the latter patient cannot be assumed, particularly if pathology that may be amenable to curative therapy may be present. Therefore, an aggressive approach to the diagnosis of the spine lesion may indeed be appropriate.

Conversely, the patient with a cervical spondylotic myelopathy (CSM) presents a unique dilemma to the clinician regarding diagnosis (myelopathy). With CSM, it is important, but often

### Table 1. Errors influencing clinical decision making

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<td>Nonfamiliar variables:</td>
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### Table 2. Definitions of error types

- **Errors of consideration**: the suboptimal consideration of one or more variables during the decision making process
- **Errors of omission**: the failure of consideration of one or more familiar variables during the decision making process
- **Errors of logic**: the inappropriate consideration of one or more familiar variables during the decision making process
- **Errors of obscurity**: the failure of consideration of one or more nonfamiliar variables during the decision making process
- **Errors of prioritization**: the consideration of variables in a suboptimal order during the decision making process
difficult, to establish the extent of the pathology. Is the spine stable? If not, how unstable is it? Is spinal cord compression present? If so, is it clinically relevant? Is the compression ventral, dorsal, or both? These questions are important and do indeed encompass and embody the diagnosis, not in its most pure sense but in the context related to management strategy determination. Therefore, it is important to address these questions with regard to the management strategies that are derived from the establishment of the diagnosis.

**CERVICAL Spondylosis**

CSM is a pathological process that is well suited to the problem-based decision making process. The complex problem it presents can be separated into at least three component diagnostic parts: 1) improvement or preservation of neurological function; 2) correction or prevention of deformity; and 3) maintenance of spinal stability. It is this author’s opinion that the prioritization of these three component diagnostic parts, from a decision making point of view, should be in the order presented above; i.e., of primary concern is neurological function, of secondary concern is deformity correction and prevention, and of tertiary concern is the maintenance of stability. Henceforth, a patient with CSM, in whom a kyphotic deformity is present (Fig. 1A), has 1) a neurological deficit, 2) a deformity (kyphosis), and 3) a potential instability that is related to the treatment of the kyphosis and the maintenance of deformity correction. Therefore, a ventral decompression may be in order (component diagnostic part Number 1). This requires a ventral decompression because the predominant compression vector is ventral.

This, in turn, mandates a deformity correction procedure to optimize decompression (component diagnostic part Number 2). Such a procedure also prevents further deformity and related neurological injury, as well as providing a stabilizing construct that not only maintains the deformity correction but also prevents further instability (component diagnostic part Number 3). Thus, a complex problem was divided into its component parts, which were then prioritized and managed serially (Fig. 1B).

**Relevant Diagnosis**

It is important to correlate the diagnosis with the patient’s symptoms. For example, the presence of spondylolisthesis (e.g., fixed subluxation) may not be relevant regarding the patient with cervical spondylosis without myelopathy. In this case, the patient may be best managed nonoperatively (e.g., via muscle relaxants and exercises). Therefore, spondylolisthesis, in this case, is not a clinically relevant diagnosis. In addition, diagnostic considerations may change as a result of surgery. For example, surgery (spinal decompression) may cause iatrogenic instability. If the probability of instability is high after a decompression operation, a simultaneous prophylactic stabilization procedure may be indicated. In this case, the relevant diagnosis is, in part, changed as a result of surgery (from spinal compression to spinal compression plus instability).

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**FIGURE 1.** A patient with cervical spondylotic myelopathy with kyphotic deformity post laminectomy. The patient underwent a ventral approach with multilevel anterior cervical disectomy and fusion instrumentation from C3 to T1 with correction of kyphosis.

**A COMPARISON WITH EVIDENCE-BASED DECISION MAKING**

The problem-based decision making process is difficult to conceptualize. It, therefore, is often not used; yet its routine use in clinical medicine may improve the efficacy of the complex problem-solving process. Although problem-based decision making is based on the foundations of evidence and logic, it should not be confused with evidence-based decision making. Evidence-based decision making is the output or results of evidence-based medicine. Sackett (1) defines evidence-based medicine as “the conscientious, explicit, and judicious use of the current best evidence in making decisions regarding the care of individual patients.” One of the problems with evidence-based methodologies is that statistical manipulation can be used to portray clinical variables, problems, and solutions in a deceptive manner. In the clinical arena, data is often insufficient to make relevant decisions that are based on objective and statistically significant data alone. Furthermore, the failure or success of a clinical regimen using evidence-based methodology may be based on “large population” assessments that do not effectively consider all subpopulations. Errors of interpretation (a variant of the error of logic subtype; Table 1), therefore, are commonplace if evidence-based methodologies are used alone.

Finally, reporting bias can create a situation in which the available evidence seems to suggest the benefit (or lack thereof) of a treatment modality. The available evidence may be skewed by the absence of reports suggesting the opposite result (e.g., a lack of benefit), although they may exist. Negative findings are infrequently reported in the literature. This selection bias cannot be ignored when interpreting the available evidence. Hence, the strict use of evidence-based methodologies exposes the clinician to the propensity to make errors of logic. Finally,
evidence-based decisions are often based on a misinterpretation of the significance of the available evidence. This evidence is often insufficient and/or too confusing to be of objective clinical use. This can be compensated for by liberally using a common sense approach to the careful assessment of facts (the evidence). Problem-based decision making embraces and embodies this common sense approach. It is, therefore, a logic-based, not an evidence-based approach. It is emphasized that both are necessary components of the clinical decision making process. One provides the foundation of knowledge (evidence-based decision making). The other provides the rational thought required to fill the gaps in our knowledge (problem-based decision making). Sackett (1, p 1086) acknowledges this. He states, “Good doctors use both individual clinical expertise and the best available external evidence, and neither alone is enough. Without clinical expertise, practice risks becoming tyrannized by evidence, because even excellent external evidence may be inapplicable to or inappropriate for an individual patient. Without current best evidence, practice risks rapidly becoming out of date, to the detriment of patients.”

**REFERENCE**