Surgical Options for the Treatment of Cervical Spondylitic Myelopathy

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Synopsis

Cervical spondylitic myelopathy is a disorder of the cervical spine stemming from compression of the cervical spinal cord by spondylitic degeneration, often in a congenitally narrowed canal. Surgical options include the anterior approach, either anterior cervical discectomy and fusion or corpectomy and strut grafting, or the posterior approach, either laminectomy or laminoplasty. Techniques, results, and complications are discussed.

Introduction

Brain[9] demonstrated in 1952 that cervical spondylosis, which had previously been known to produce various signs and symptoms of facet joint and cervical root disorders, also was responsible for spinal cord compression and thus myelopathy. The symptoms of cervical spondylitic myelopathy had previously been attributed to various "degenerative diseases of the nervous system".

Cervical spondylosis is a problem usually starting in middle age with progressive degenerative changes in the cervical discs. This degeneration leads to motion abnormalities, loss of disc height, and arthrosis in the uncovertebral and facet joints. Uncovertebral joint arthrosis and disc degeneration with spur formation can cause compression of the spinal cord from the front. Facet arthrosis and ligamentum redundancy can cause compression of the spinal cord from the back (Figure 1).

This circumferential compression due to spondylosis leads to spinal canal narrowing and a static impingement on the spinal cord. In addition, there is a dynamic component of spinal cord compression, as extension of the cervical spine can cause buckling of the ligamentum flavum and flexion can cause disc bulging. Cadaver studies confirm that the area inside the spinal canal is larger in flexion than in extension[75]. Cervical motion and instability can cause pinching of the spinal cord between the anterior chondro-osseus spurs and the posterior ligamentous redundancy and hypertrophied facets[65;66;79].

Cervical spondylitic myelopathy is a constellation of symptoms and physical findings including various patterns of motor and sensory disturbances. The lower extremities are affected first, with spasticity and paresis. The patient often complains of a gait disturbance due to abnormalities in the corticospinal tracts and spinocerebellar tracts. Later the upper extremities become involved with loss of strength and difficulty in fine finger movements[30]. In a review of 37 patients with cervical spondylitic myelopathy, Lunsford noted that 59% had only myelopathy and 41% had a myelopathy with radiculopathy. The initial neurologic dysfunction was a corticospinal tract deficit (58% motor weakness) with reflex abnormalities (87%) including hyperreflexia and other long tract signs. This is sometimes followed by upper extremity abnormalities. Gait and sphincter disturbances developed later[49]. In a large series of 269 surgically treated patients [42], 72% had evidence of hyperreflexia at some level, 88% had loss of discriminatory sensation in the upper extremities, and 34% had loss of lower extremity proprioception. Dysfunction of the bladder was found in 15% and of the bowel in 18%. Sphincter dysfunction was not a prognostic factor for poor recovery.

The pathophysiology of cervical spondylitic myelopathy is multifactorial [6]. A congenitally small spinal canal size is an important predisposing factor. Using the posterior vertebral line to the spinolaminar line as the standard measurement [8], the normal diameter of the spinal canal from C3-C7 has been reported to be 17.6-18.8 mm in normal European subjects and 15-17 mm in normal Japanese men[54] both using a tube distance of 1.4m. Both of these studies suggested that symptomatic patients with spondylosis had congenitally smaller spinal canal size than asymptomatic patients with spondylosis, with 12 mm seeming to be critical for the development of myelopathy. For a tube distance of 72 inches, the average subaxial

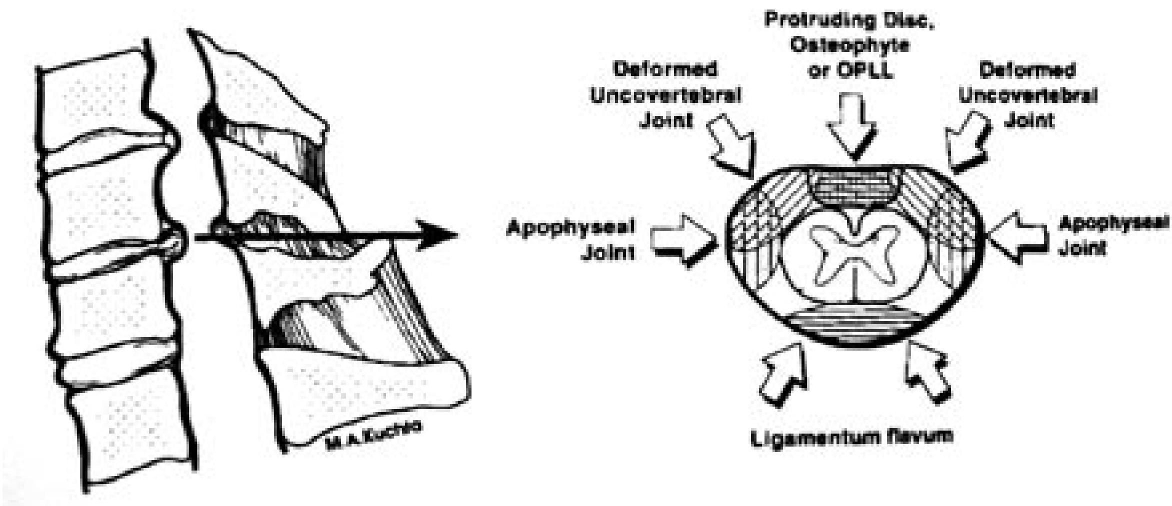


Figure 1:

This demonstrates the pathologic anatomy of cervical spondylitic myelopathy (Reprinted with permission from Law et. al) [48].

cervical canal size is 17mm[19;79]. Cervical spinal cord thickness has been shown to be 9.0-10.0mm +-1.5mm[16;55]. The presence of a congenitally narrow spinal canal can lead to critical narrowing and spinal cord compression with symptoms occurring much earlier in the spondylitic process than in a patient with a normal cervical canal diameter[33;54;60].

The vertebral body ratio method, or Torg-Pavlov ratio, can be used to eliminate the variable of radiographic technique[59](Figure 2). Taking the ratio of spinal canal size (posterior vertebral line to spino-laminar line) divided by body size (anterior vertebral line to posterior vertebral line) gives the vertebral body ratio, with a normal value being 1.0 and <0.82 denoting developmental stenosis. A recent study compared patients with cervical spondylitic myelopathy (28 consecutive patients needing surgery for myelopathy) and normal controls (88 patients with nonsurgical neck pain)[86] using the vertebral body ratio. In the controls, the mean was 0.95 +-0.14, whereas for myelopathic spondylitics it was 0.72 +-0.08 ($p<0.001$). The measurements were made from the mid body, thus eliminating the effect of spondylitic osteophytes. Other studies have also confirmed the important role of congenital stenosis and a narrow cervical canal[19;33].

The natural history of cervical spondylitic myelopathy was studied by Clark and Robinson[12] and was shown to be a progressively deteriorating disorder with 75% of patients deteriorating in a stepwise fashion, 20% of patients deteriorating slowly and steadily, and 5% of patients having the rapid onset of symptoms with a stable plateau of dysfunction. In a study of the conservative treatment of cervical spondylitic myelopathy by Roberts[64], 24 patients were treated with a collar and a trial of bed rest. The collar was worn for 2-18 months, and follow up was from 4 months to 6.5 years. Of the 24 patients, 8 deteriorated in functional status, 9 had no change, and 7 improved. However, 7 patients were unable to be mobilized or were totally bedridden at final follow up whereas only two patients were this dysfunctional on presentation. The risk factors for poor prognosis were suggested to be moderate disability on presentation and long duration of symptoms. However, no natural history study has been able to determine reliable prognostic indicators for progression or resolution.

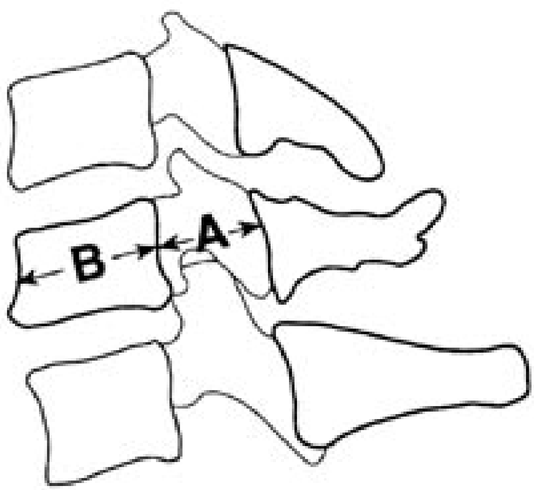


Figure 2:

This drawing demonstrates measurement of the vertebral body ratio method of Torg and Pavlov[59]. The AP canal size (A) is divided by AP body size (B) at the same level. Normally about 1.0, in the original data set significant developmental canal (A) stenosis was a ratio of 0.82 or less. (Reprinted with permission from Law et.aL)[48].

Based on this data, the indications for a surgical approach need to be tailored to the patient's baseline function, symptoms, rate of decline, and medical status. For patients with moderate to severe disability at presentation, it is unlikely that significant spontaneous improvement will occur. In a study that analyzed factors that predict poor neurologic recovery[27], the most important factor was the transverse area at the level of maximal compression (<30 mm^2). Other factors, in order of importance, were age at surgery, pre-operative neurologic function, and number of levels involved. The degree of residual spinal cord deformity after decompression (if <30mm^2) was also important. Myelomalacia on MRI is easy to appreciate and certainly implies some degree of spinal cord trauma, however, the effect on the clinical outcome and approach has yet to be determined. These factors must be kept in mind when considering conservative versus operative treatment.

Anterior Approach for Cervical Spondylotic Myelopathy

Anterior Cervical Discetomy and Fusion

The indications for anterior cervical discectomy and fusion (ACDF) include cervical myelopathy from either soft disc herniation or from spondylitic degeneration that is limited to the disc level. If there is compression behind the body from migrated disc fragments or from ossification of the posterior longitudinal ligament, then another operation should be performed.

A classic description can be found in multiple articles [7;66]. The procedure is usually performed through a short transverse skin incision with the approach medial to the sternocleidomastoid muscle and carotid sheath and lateral to the strap muscles, trachea and esophagus. An anterior discectomy is performed with the whole disc removed with rongeurs and curettes, the endplates are lightly decorticated with a burr, and a tricortical iliac bone graft is placed in a distracted disc space. All compression should be relieved at the time of the operation, including compressive uncinate or posterior vertebral body osteophytes. In addition, free extruded fragments must be removed as well, converting to a hemicorpectomy or corpectomy in order to remove these if needed.

Complications of anterior cervical discectomy and fusion can be grouped into 2 categories. The first is complications of the anterior surgical and decompressive approach, such as airway problems, nerve palsy, soft tissue edema, esophageal injury, and vertebral artery injury. These will be dealt with in detail in the next section on anterior corpectomy and fusion. The second category relates to the risk of non-union for a fusion procedure. As the number of levels increase the chance of a pseudoarthrosis increases in a linear manner[28]. This increasing risk of pseudoarthrosis has been documented as a risk factor for both additional surgery and for poorer outcome[21;28].

The addition of a cervical plate in ACDF decreases the risk of graft extrusion and increases the rigidity of the construct, thus facilitating fusion. In the literature the AO locking plate, properly applied, has been shown to decrease the risk of pseudoarthrosis in 2 and 3 level ACDF[77;78] with minimal risk of hardware related complications. In both of these retrospective papers, the groups were well matched in patient characteristics using multivariate analysis, the only difference being the use of a plate. In single level procedures, there was no statistically significant difference[76]. All of these patients were treated with autogenous iliac crest autograft.

Various series of ACDF for the treatment of myelopathy have shown good results[5;88]. In Zhang's series of 121 cases of cervical spondylitic myelopathy treated by ACDF the follow-up averaged 22 months. Clinical results showed that 90.9% of patients improved, and 72.6% were able to resume "normal" activities. Fusion rates were significantly higher for autograft from the iliac crest versus iliac allograft (85% vs. 50%). Pseudoarthrosis strongly correlated with a poor result. However, they only had three reoperations in the entire group, choosing to reoperate only with neurologic deterioration or worsening pain.

Anterior Cervical Corpectomy and Fusion

The indications for corpectomy and strut grafting in cervical spondylitic myelopathy include the existence of ossification in the posterior longitudinal ligament or other retrovertebral disease, predisposing congenital stenosis, and multilevel spondylosis. An absolute indication is kyphosis, since restoring a relatively straight or lordotic cervical spine is essential in order to provide decompression of the cervical spinal cord. If significant residual kyphosis deforms the spinal cord, multiple anterior or posterior procedures will be of little benefit.

Technique, description

Anterior corpectomy is performed using the same anterolateral approach to the cervical spine as used in ACDF. However, a vertical oblique incision may be needed for exposure if more than a two level corpectomy is needed. Discectomies are first performed at each level in order to visualize the unco-vertebral joints. These serve as landmarks for the lateral limits of the bony resection. Rongeurs are then used to initiate a corpectomy trough, and a high-speed burr is used to thin out the remainder of the posterior vertebral body. Care should be taken to avoid starting the burr until the tip is within the protective subtotal corpectomy trough in order to avoid damage to adjacent soft tissues. The corpectomy is completed with a combination of burr dissection, micro curettes, and fine Kerrison rongeurs.

Complications and Technical Issues

Strut grafting in corpectomy can be undertaken with autograft or allograft bone. Traditionally corpectomy defects up to two levels are managed with autogenous iliac crest [47] and longer constructs managed with autogenous fibula[4]. Both autogenous iliac crest and fibula have good fusion rates. Bernard and Whitecloud in 1992 performed corpectomies in 21 patients, 13 three level, 4 four level, and 2 at two levels using autograft fibula with a 100% fusion rate.

However, iliac crest autograft has donor site complications. In harvesting iliac crest graft, one should stay more than 3cm from the anterior superior iliac spine (ASIS). There is a 10% chance of injury to the lateral femoral cutaneous nerve if the bone is taken within 2-3 cm of the anterior superior iliac spine. In addition, anatomic studies have shown that the ideal thicker bone is more than 3 cm from the ASIS[18]. Finally, if graft is taken within 3 cm of the ASIS, ASIS avulsion or pelvic fracture can occur[40;41]. Other reported complications from obtaining anterior iliac crest autograft include donor site pain (2.8-17%), hernia formation, hematoma, and a 1% chance of infection.

Taking autograft fibula also has complications. The proximal and distal 10cm are avoided to reduce the risks of peroneal nerve damage and ankle instability. In one series[29], 41 patients underwent fibula bone harvesting with a mean follow up of 27 months. Only 58% patients were pain free, with 27% having mild pain, and 15% having severe pain with some loss of muscle strength on the donor side. No gross ankle instability was noted.

The alternative of allograft is attractive due to this significant donor site morbidity. However this comes at the expense of biologic fusion potential. Fernyhough et al [25]compared a consecutive series of 67 autograft fibula grafts to 59 allograft fibula grafts with a comparable distribution between two, three, and four level corpectomies. Using no anterior plates or supplemental posterior fixation, there were 27% non-unions with autograft and 41% non-unions with allograft with a mean follow up of 83 months. They asserted that it takes a fibula up to 24 months to incorporate secondary to its dense cortical nature. The non-union rate increased with the number of corpectomies from 21% with two level corpectomies to 32% for three level corpectomies, and 50% for 4 levels. One technique that may reduce this rate of non-union is to pack the allograft fibula with autogenous cancellous bone obtained during the decompression. There has been no scientific study to confirm this.

Pseudoarthosis rates correlate with a poor outcome[21]and they are associated with residual neck pain and recurrent stenosis. A wide range of pseudoarthrosis rates has been reported from zero to 41%[4;20;21;25;50;74]. Pseudoarthrosis may require surgical revision, either anterior if there is significant graft or plate migration migration or kyphosis, or posteriorly as a stabilizing procedure to allow the anterior pseudoarthrosis to consolidate[24].

Besides non-union, the other major graft related complication of corpectomy and strut grafting is graft dislodgment, which has been reported to be 10-29% for multilevel reconstructions[4;25;32;71;73;83;87]. This can induce catastrophic neurologic injury, airway compromise, or esophageal injury with infection[21]. In one series of patients treated with anterior procedures for myelopathy[21], of 55 corpectomies performed, there were four graft dislodgments requiring revision, and one partial dislodgment requiring the placement of a halo. One of the patients with a dislodgment had an esophageal injury and subsequent infection that resolved with revision, esophageal repair, enteric feeding, and parenteral antibiotics.

Using anterior cervical plating may reduce the incidence of graft extrusion for one and two level corpectomies (Figure 3). However, in a multicenter study [72]of two, three, and four level corpectomies stabilized with a plate, there was a 9% dislodgment rate for two level corpectomies and 50% dislodgment rate for three and four level corpectomies, all within the initial 3 month period. This experience is consistent with biomechanical data that suggests that the longer the corpectomy defect, the more unstable it is[26]. In the same biomechanical model, for three level constructs the use of anterior cervical plating alone actually can unload the graft in flexion and cause extremely high graft pressures in extension, leading to graft pistoning, endplate failure, and graft dislodgement[15].

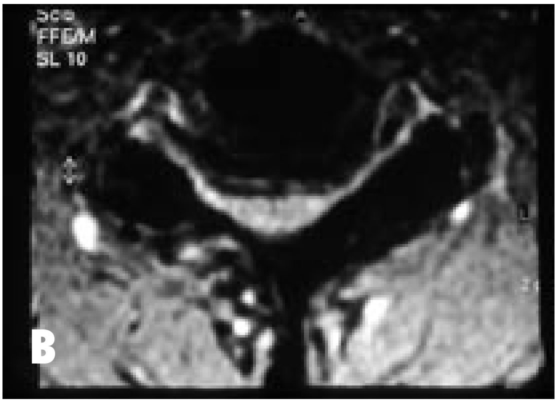


Figure 3:

A 40 year-old medical professional with long standing myeloradiculopathy presented after an episode of trauma which worsened his bilateral hand dysfunction and his gait. MRI (A, B) reveals primarily anterior compression at C4 to C7. The patient underwent a 2 body corpectomy (C, D,) with strut grafting from C4 to C7, and had stabilization with a locking anterior cervical plate. This post-operative MRI (E) at 6 months shows good decompression of the involved levels. A saggital CT (F) scan shows the graft in good position.

Experience with buttress plating alone, a technique that attempts to avoid letting the inferior end of the graft dislodge, has led to a high incidence of pseudoarthrosis and a single death attributed directly to the buttress plate protruding into the airway and obstructing it [63]. One patient in this series whose graft also dislodged but did not displace the plate was circumferencially fused. These problems with long plating and with buttress plating has led many surgeons to abandon anterior fixation alone for three body corpectomy and longer constructs in favor of circumferential fixation.

Illustrating the stability of circumferential fixation McAfee et al[52] reported on a large series of circumferential fusions, 15 of which were multiple level cervical corpectomies. No patient had dislodgment of a graft or plate. This suggests that additional stability can be provided with the addition of posterior fusion and instrumentation. This may also help to reduce graft collapse and reduce residual kyphosis in patients with any degree of osteoporosis. Other authors from this same group observed in other series that posterior fixation seemed to increase stability[87].

Airway compromise is also a significant complication of multilevel corpectomy in patients being treated with anterior surgery. Emery et al [22] reviewed the cases of seven patients operated on for myelopathy who had obstruction of the upper airway immediately after an anterior procedure on the cervical spine for myelopathy and had required reintubation. All had had a multilevel anterior cervical corpectomy for decompression followed by arthrodesis. Early compromise was attributed to edema rather than hematoma. Risk factors common to these patients included moderate or severe myelopathy, multilevel corpectomy, smoking, and one patient had pre-existing asthma. One patient died as a result. The authors recommended vigilance in patients with these characteristics undergoing multilevel corpectomy, as well as prolonged elective intubation until airway edema resolves.

Vertebral artery injury is also a potential complication with its incidence often attributed to technical error [20]. However, this may also be secondary to anatomic variation or tortuosity, with clinical significance of 2.7% in one study[13] though it has been reported to be higher[57]. Injury is more common at C3 and C4 levels, as the vertebral artery is closer to the midline at these two levels. Clinical significance of vertebral artery injury has been reported to vary from catastrophic to none[69]. In a retrospective review of 10 patients with vertebral artery injury[69], the authors found an estimated incidence of 0.5% taking into account all of their anterior cervical procedures as the denominator. All the injuries were during corpectomies. The reasons for injury were threefold: midline deviation, over-wide dissection, or soft pathologic bone. Of the ten patients, three had persistent neurologic deficits. This complication can be avoided by meticulous attention to the pre-operative studies and the anatomic location of the transverse foramen and using that information to vary the surgical approach. Control was either with packing, blind ligation, or direct visualization with ligation or electrocautery.

Adjacent segment degeneration can also lead to symptomatic recurrent radiculopathy or myelopathy. Recent authors [28;36] have found that this occurs at about 3% a year. Symptomatic adjacent segment disease requiring revision surgery is strongly predicted by the preexisting spondylosis at adjacent but asymptomatic levels[28]. Although initial clinical results were good in these patients from the neural decompression, later surgery for adjacent segment disease did adversely affect the end outcome in multivariate analysis.

Other complications of the anterior approach are also more pronounced in corpectomies and strut grafting due to the length, complexity, and increased retraction during these larger procedures. Nerve palsy of the recurrent laryngeal nerve is often a contributing factor to dysphagia and may be a complication of the anterior approach to the cervical spine. Avoidance and treatment of these difficulties include performing a sip test the morning after surgery to assure normal swallowing and checking a lateral x-ray for anterior soft tissue edema. If there is clinically significant soft tissue swelling, this may be reduced with low dose corticosteroids.

Results of Anterior Surgery for Cervical Spondylitic Myelopathy

Emery et al [21] reviewed 108 patients with cervical spondylitic myelopathy treated with anterior cervical discectomy and fusion or corpectomy and strut grafting. 55 patients had a corpectomy, 45 patients had Robinson discectomy, and ten had mixed procedures. As already mentioned, pseudoarthrosis was associated with a poor pain result and was associated with multilevel discectomy (no single level pseudo, 6 of 15 two level, 7 of 16 three level) vs. corpectomy (3 of the 58). Recurrent myelopathy occurred in 3 patients with pseudoarthrosis and 2 patients with adjacent segment disease. 7 patients needed revision surgery for neck pain or radiculopathy (not myelopathy) at an adjacent level. 71 patients had no functional impairment, 15 had mild (no heavy labor or sports) impairment, 8 had moderate impairment (ADL only), 6 had impairment of community walking, 2 were capable of household ambulation only, and 2 were unable to walk. Only one patient had catastrophic worsening. 69% had no neck pain, 18% had mild neck pain, 6% percent had moderate neck pain, and 1% had moderate radicular pain.

Treatment of cervical kyphosis and myelopathy is only adequately addressed with corpectomy and strut grafting. Zdeblick et al [87] reviewed 14 patients with kyphosis and myelopathy, 8 from spondylosis, 5 trauma, and 1 a tumor. 8 patients had had a previous laminectomy as a contributing factor to the kyphosis. In this group, all patients had obtained a solid fusion at final follow-up. Of ten multi-level corpectomies not posteriorly stabilized and treated in a two poster brace, 3 had graft slippage and two of these had a previous laminectomy. Two of these three graft complications needed a reoperation[62]. The mean kyphosis decreased from 45 degrees pre-op to 13 degrees post op. Because of difficulty with post-laminectomy patients, they [87]recommended treating these post laminectomy patients with a halo post-operatively. However a subsequent report from the same group [62] showed that 9 of 18 post-laminectomy patients treated this way continued to have graft related complications, with 5 extrusions or collapses and 4 pseudoarthrsoses despite the halo. This identifies post-laminectomy patients as another group that may benefit from concurrent posterior stabilization[52] in those patients with long corpectomies as previously noted[72].

In summary, anterior corpectomy is a good treatment for cervical spondylitic myelopathy in patients who have multilevel disease of 2-3 levels, especially in those patients with kyphosis. Posterior stabilization should be considered in patients having multi-body corpectomies with a high risk of graft complications including displacement, pseudoarthosis, and collapse. These include patients with osteoporosis, kyphosis, previous laminectomy, or three body corpectomies (Figure 4)

Posterior Approach

Laminectomy

Laminectomy was the original treatment for cervical spondylitic myelopathy when it was first described as a discrete entity[9]. It is the disillusionment with the original results of laminectomy procedures that drove the development of the anterior approach and of laminoplasty. Over the years, however, improvements have been made in laminectomy technique as well. Historical results thus may not be comparable to current results.

Biomechanically, laminectomy has been shown in a cadaver model to significantly increase spinal column flexibility with a tendency to show these changes at the lower level of laminectomy. This may contribute to repetitive spinal cord microtrauma that compromises the neurologic results and may lead to the development of long-term instability[14]. In another cadaver model comparing laminoplasty to laminectomy to intact spines, cervical laminectomy with 25 % or more facetectomy resulted in a significant increase in cervical motion compared with intact specimens in all planes of motion[56]. This biomechanical data has been correlated with a goat animal model of laminoplasty versus laminectomy [3] in which there was a significant increase in forward saggital angulation radiographically in the laminectomy group, but not in the laminoplasty or intact groups. Biomechanical testing of these goat spines showed an increase in instability in the saggital plane in the laminectomy group, but the laminoplasty group was comparable to the intact group. It is clear that the laminae play a role in the stability of the cervical spine, especially at C2 and C7[58].

The incidence of clinically significant kyphosis after laminectomy in children is well established. In one series of multi-level laminectomy for various diagnoses[80], 100% of patients younger than 15 years old developed kyphosis, many requiring revision surgery for stabilization. This high incidence of cervical kyphosis after laminectomy in children has been confirmed by other authors [11]. For adult laminectomy, Gregorius et al[31] evaluated 55 patients operated on for myelopathy who received either an anterior Cloward procedure or a posterior laminectomy. Follow up was 2-20 years with an average of 7 years. They found that the patients who had anterior

Figure 4:

This 75 year-old man developed myeloradiculopathy and severe neck pain. MRI (A) shows anterior compression from C3 to C7 with kyphosis. Post-operative films (B) show the fibular strut graft and anterior cervical plate in good position. At two weeks (C) the patient complained of increased neck pain and a lateral x-ray of the cervical spine shows that the superior screws are pulling out of the body of C3. The patient was taken back to surgery for posterior plates, screws, supplementary cables, and iliac crest bone graft (D). With over 2 year follow up the patient had improvement of his myelopathy, no arm pain, and improved neck pain. The patient would have been better treated with a primary posterior fixation concurrent with his 3 body corpectomy.

procedures tended to improve and the patients who had laminectomy tended to deteriorate over time (p=.035). 31% of the patients who had laminectomy deteriorated in disability status. This late neurologic deterioration attributed to instability and kyphosis in adults has been confirmed in other studies [44;81;84].

Another potential problem with laminectomy is the formation of post-laminectomy membrane[51;82;85]. This is important especially in patients with congenitally short pedicles. These patients may initially have an adequate decompression from the laminectomy as the spinal cord falls back from the anterior spondylitic bars, but the scar that forms directly over the dura can cause re-compression of the spinal cord as it adheres to the lateral masses, matures, and contracts.

The indications for laminectomy include multi-level spondylosis, stenosis, and myelopathy. A requirement for this procedure is lordosis, and most authors agree that post-laminectomy deformity can be avoided by restricting this operation to the lordotic spondylitic cervical spine. An absolute contraindication to laminectomy is the presence of kyphosis.

Surgical technique

In the past, neurologic complications of laminectomy have often been related to surgical technique, such as inserting a Kerrison rongeur or curette into the spinal canal without awareness of spinal canal size. It is now recommended that an en-bloc laminectomy be performed using a high speed burr laterally at the junction of the lamina with the lateral masses at each level[17;53]. Foraminotomies can be performed if associated radiculopathy is present with the

myelopathy. Care is taken to leave as much of the facets intact as possible.

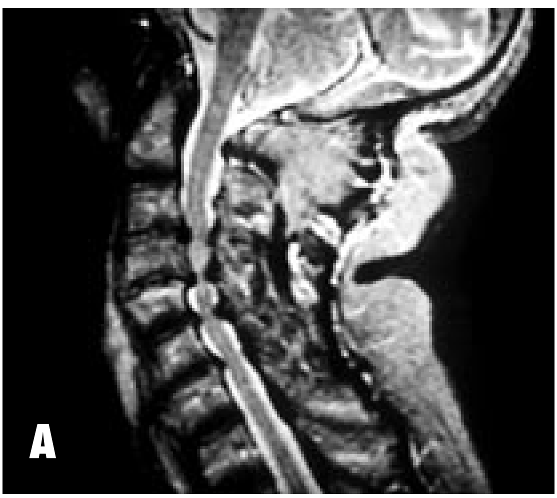
Results of Laminectomy

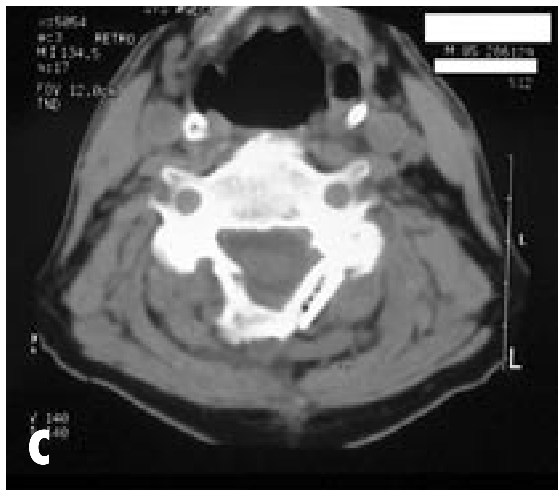
As previously noted, the long-term results in the literature have been historically unsatisfactory. However, there are two recent series that show good results in spines without kyphosis or instability if strict criteria are followed such as avoiding significant facetectomy. In these studies, recovery has been reported to be 70-80%[10;23]. Good results have also been reported in combining laminectomy with posterior fusion, with 76% having improved myelopathy scores[46]. The authors attributed this improvement over historical controls to the avoidance of microtrauma to the spinal cord from cervical instability and avoidance of late cervical deformity[46].

Laminoplasty

Laminoplasty was developed in response to the dissatisfaction with the results of laminectomy in the literature. In the Japanese population, there was a need for an operation to consistently and safely address long segments of compression in the cervical spine due ossification of the posterior longitudinal ligament (OPLL). However, for long constructs there are the previously mentioned graft problems with the anterior approach, including graft dislodgment and pseudoarthosis. With laminectomy, there are the previously discussed problems including the development of kyphosis, instability, post-laminectomy membrane, and late neurologic deterioration.

Laminoplasty (Figure 5) was developed in an attempt to eliminate these problems. The laminae are still available for load bearing[58] and for the attachment





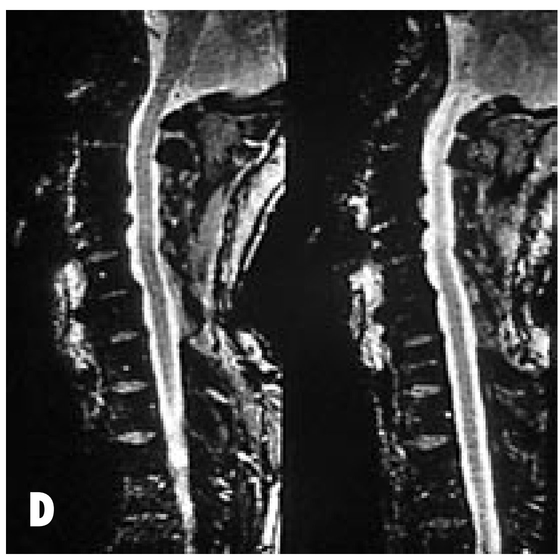
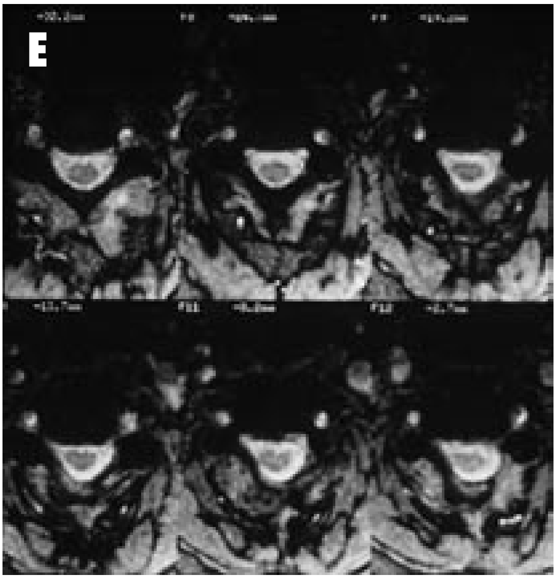


Figure 5:

This 80 year old man presented with a 1 month history of decreased neurologic function, having gone from ambulatory and independent in his ADLs to wheelchair bound and requiring assistance to eat and dress. MRI (A, B) revealed severe multi-level compression of the spinal cord. He was treated with a laminoplasty. 8 week follow up CT scan shows healing of the hinge and the graft (C). MRI at 4 months post-operatively shows(D, E) excellent decompression of the cervical spinal cord. At 8 weeks post-operatively the patient was walking independently and was independent in self-care.



of the paraspinous muscles. In the biomechanical studies with human[56] and animal models[3], a spine treated with laminoplasty is comparable to the intact spine. This may avoid the problems of late deformity, daily microtrauma, and global instability often seen in post-laminectomy patients. The opened but retained laminae may also prevent the development of post-laminectomy membrane[85](Figure 5d, 7e).

Hattori has the initial [45] credit for developing the technically demanding z-shaped laminoplasty in 1971 and later reported in the American literature with minimum 2 year follow up in 1988. Hirabayashi described the more commonly performed open door laminoplasty[38] in which bilateral troughs are cut at the junction of the lamina and lateral mass bilaterally. The trough is completed on one side and the other functions as a hinge to open the laminae and allow decompression. This was originally fixed with sutures. Itoh [43] introduced the concept of the en bloc laminoplasty in which the laminae are propped open with bone graft at every other level to prevent closure of the laminoplasty. Other techniques have been described including spinous process splitting procedures[42;70]. It is important to reattach the nuchal muscles to the C2 spinous process in order to maximize post-operative function[85].

Indications include multilevel cervical stenosis and myelopathy, preferably with stenosis at 3 or more levels. If there is segmental instability this can be addressed with a concurrent lateral mass fusion of the involved levels. Major contraindications include the presence of kyphosis and pre-operative neck pain. Neck pain can be a significant complication of laminoplasty, and in the opinion of the senior author, this can be minimized by treating patients with neck pain with a concomitant posterior lateral mass fusion or by performing an anterior decompression and fusion instead. In order to ensure the best results, patients with significant neck pain should not be treated with a laminoplasty.

Technique

The patient is placed prone using a 3-prong Mayfield headholder. The posterior dissection exposes the involved lamina, usually including C3-C7. The spinous processes are cut so that 1-cm of spinous process remains. Muscular attachments to the T1 spinous process should be preserved in order to prevent postoperative prominence and irritation. If there is any compression at C2C3, undercutting of C2 must be performed concurrently[38]. Care must be taken either to avoid exposing the lamina and spinous process of C2 or, if done, to reattach the nuchal musculature with permanent sutures at the end of the procedure. A laminotomy is then performed at the superior and inferior portions of the laminoplasty. This would usually be at C23 and C7T1. The laminotomy is carried out to the pedicles of T1 inferiorly and out laterally to the lateral masses of C3 superiorly.

The opening laminar cuts are made on the side where the patient's symptoms are worse or where the cord compression is worse. A high-speed burr is used to make a trough at the juncture of the lamina and the lateral mass beginning at C7 on the opening door side. The primary landmark for the spinal canal boundary is the medial aspect of the pedicle of T1, so the cut is made directly above this. A fine 1mm 45-degree micro-Kerrison is used to complete the cut. The Kerrison is always steered as laterally as possible to make certain that the cut remains against the canal wall. The same procedure is then performed sequentially at C6, C5, etc. to C3. At each level the laminar osteotomy is checked to be certain it is complete by lifting up on the lamina with the footplate of the Kerrison and checking mobility. Attention is then turned to the hinge side trough. This also should be performed at the juncture of the lamina and the lateral mass. Starting at C7, the burr is used to create the trough, which is finished when approximately 80% of the thickness of the lamina is resected. The resistance in the hinge must be

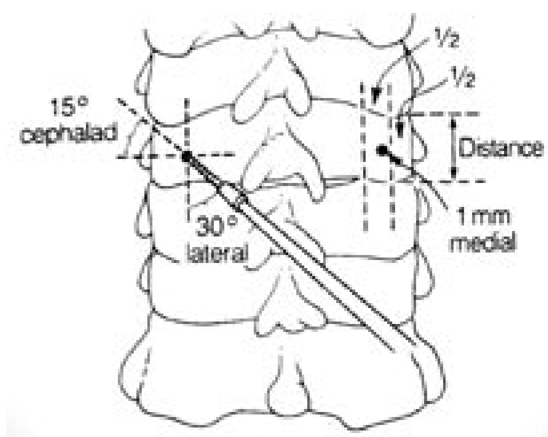


Figure 6:

This demonstrates the technique for lateral mass screws as described by An. (Reprinted with permission from An, et al.)[1].

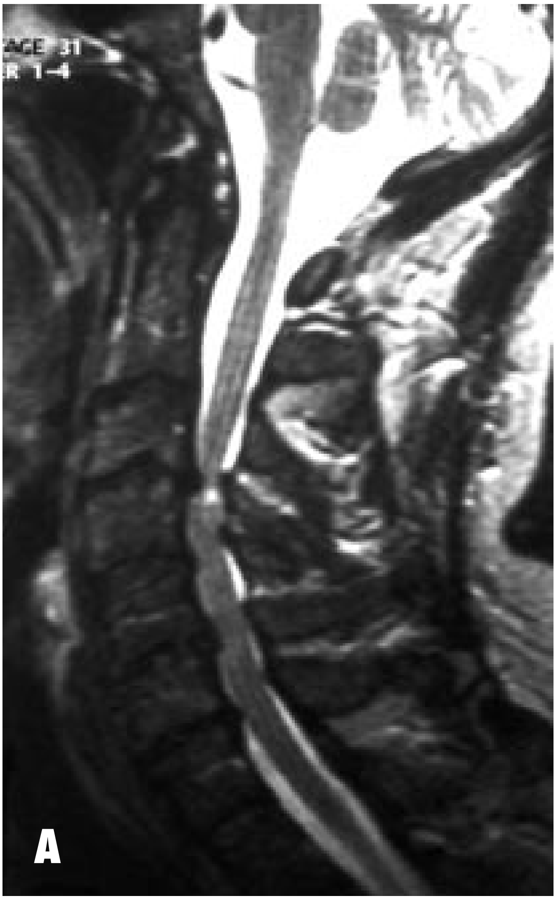


Figure 7:

A medical professional in his late 50's presented with myeloradiculopathy with arm pain and hand dysfunction that was impairing his ability to practice. In addition he had significant neck pain. MRI (A) shows spinal cord compression from C3 to C7. He underwent a (B, C) laminoplasty with concurrent lateral mass plate fusion. A CT scan at 8 weeks (D) shows healing of the hinge side, and early incorporation of the fusion mass and the rib allograft used to prop the door open. MRI at 4 months (E) confirms excellent decompression. Clinically the patient had improved neck pain, improved arm pain, and improved hand function.

checked frequently, as this is a key technical issue in the procedure. The hinge cannot be so thin that it fractures or gives no backspring, as this back spring holds the bone graft firmly in place. This should also be performed at C6, then C5, etc. The laminae are now elevated en bloc such that the opening side is elevated approximately 12 mm. The ligamentum flavum is then removed on this opening side with fine Kerrison rongeurs and Woodson elevators. Foraminotomies can be performed at this time if there is a pre-operative radiculopathy.

At this time the lamina are held open using allograft blocks, a small rib being the ideal graft. 12-14 mm is the appropriate length for the graft, and a trough is cut on each end to allow it to lock into the lateral mass and its corresponding lamina on either side. The grafts are placed at the C3, C5, and C7 levels, taking care to avoid the facet joints with the graft. If the procedure is performed correctly, the residual spring from the lamina should lock the graft into place, obviating the need for fixating sutures. If at any point in the procedure a lamina fractures, if it is at either end of the construct it can be removed and the bone graft placed at the adjacent level. If it is in the middle of the construct, it can be left with its ligamentous attachments, as long as the hinge fracture is not complete. Thus the fractured lamina is not impinging upon spinal canal, and the ligamentous attachments to the other laminae prevent significant displacement.

Patients postoperatively are immobilized in a rigid cervical collar for 8 weeks. At 8 weeks a CT scan is obtained and this will usually reveal healing of the hinge side of the laminoplasty (Figure 5c). The patient is then mobilized and allowed full activities, with therapy to emphasize cervical extension exercises.

Results

Most large series of laminoplasty are from Japan, and document neurologic recovery of 50-80%, regardless of the specific method used[37;38;43;45;70]. This is well maintained with more than 5 year follow up [67;68]. There was no incidence of severe kyphotic deformity in either long-term study.

Complications

One significant complication of laminoplasty is axial symptoms, including shoulder pain and spasm and neck pain. In a recent comparison study of corpectomy and laminoplasty with regards to axial symptoms[39], 27% of all patients had pre-operative axial symptoms. Postoperative axial symptoms were present in 19% (5/26) of the anterior corpectomy patients and 60%(43/72) of the laminoplasty patients. Symptoms of neck and shoulder pain lasting over one year were predicted 75% of the time in this series by severe pre-operative symptoms in these same areas.

Another potential complication is C5 nerve root paresis with deltoid paralysis and biceps weakness. The incidence is reported to be 3–11%[38;45;68]. This generally resolves within 6 months. This complication has been reported for anterior surgery and laminectomy as well, but with less frequency[84]. This is blamed on the large acute posterior shift of the spinal cord at the midpoint of the decompression, thus causing a traction palsy of the C5 nerve root. Foraminotomy and facetectomy has not been shown to decrease the incidence of this complication.[85].

Technical complications such as door closing and loss of decompression are minimized with the use of allograft to prop the door open. Neurologic loss from hematoma was reported to be significantly less comparing one author's sequential series of laminectomy versus laminoplasty (2.4% for laminectomy vs. .3% for laminoplasty)[82;85]. However, this was a sequential series, and the different result may be due to improvement of overall surgical technique over a period of time.

Laminoplasty with lateral mass fusion

Lateral mass plating is a reliable, strong, posterior fixation that has excellent biomechanical properties[61] and a high fusion rate even in unstable trauma situations[2]. This has been tried for laminectomy with mixed results [34;46]. Indications for adding posterior fusion to laminoplasty include global axial pain preoperatively or segmental instability. It is important during the procedure, after decompression, to extend the neck into a functional and slightly lordotic position for fusion and avoiding a chin tuck position. Fusion can be extended as needed to the occiput or to the thoracic pedicles.

Lateral mass screws can be placed according to An's technique [1] which has been show to be safest in avoiding danger to the nerve root, facet, and vertebral artery (Figure 6). The intrinsic biomechanical stability of laminoplasty over laminectomy[3;56] should avoid some of the problems with pseudoarthrosis (5/13) reported with one study [34] but not in another (100%) fusion[46]. There are no current series of laminoplasty with fusion in the literature. However, it can combine the stability and relief of neck pain that fusion provides with the preservation of decompression that laminoplasty provides (Figure 7). ACDF can also be added after laminoplasty for significant, symptomatic anterior compression (Figure 8)

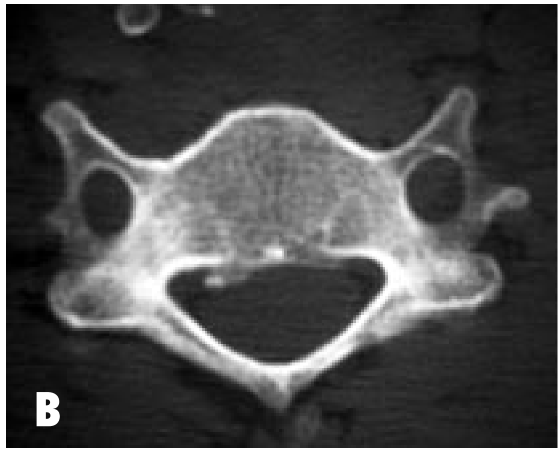


Figure 8:

This gentleman in his mid 50's presented with spasticity and bilateral arm pain. He also had some neck pain. MRI (A) revealed congenital stenosis with a significant disc located at C6C7. Pre-operative CT scan (B) showed a bony spur. He underwent a laminoplasty with a concomitant C6 to C7 ACDF (C,D,E). MRI at 4 months confirms good decompression(F). At his 4 month follow up the patient had no myelopathy and improved neck and arm pain.

Comparative Studies

Gregorius et al[31] examined patients with cervical spondylosis. 55 patients were operated on for myelopathy with follow up of 2-20 years, and averaging 7 years. 26 patients had anterior (Cloward) procedures and 29 had laminectomies. The operation was chosen on the basis of levels involved: one to two levels tended to receive the anterior procedure, three or more levels tended to get a laminectomy. However, the pre-operative groups had similar levels of disability. The patients who had an anterior procedure tended to improve and the patients who had laminectomy tended to deteriorate (p=0.035). Of the 29 laminectomies, 6 (21%) improved, 14 (48%) had no change, and 9(31%) deteriorated in disability status.

A later study compared ACDF, laminectomy, and corpectomy and strut grafting, [81]. Sub-total corpectomy was found to be superior to ACDF in terms of neurologic recovery due the wider decompression possible, according to the authors. For both the group as a whole and the subset of three or move levels involved, corpectomy and strut grafting was found to be superior to laminectomy in final neurologic outcome, mainly due to the 29% rate of late deterioration in laminectomy.

Carol and Ducker [10]examined 206 patients with cervical spondylitic myelopathy, with one year follow up. Patients with one or two levels were treated with anterior Cloward procedures and three or move levels were treated with laminectomy. Facet joints were preserved in these laminectomies. However, the pre-operative groups were not the same. The anterior treated group tended to be younger and have a higher functional status. 73% of the patients receiving anterior procedures improved, versus 68% of patients getting laminectomy. They reported no late deterioration, instability, or kyphosis, but follow up was only one year.

Herkowitz [35] compared anterior fusion vs.

laminectomy vs. laminoplasty for cervical spondylitic radiculopathy (not myelopathy) in a retrospective review. Results were graded on the basis of pain relief, with ACDF having 92% excellent-to-good, laminoplasty 86% excellent-to-good, and laminectomy having 66% excellent-to-good. Both ACDF and laminoplasty were statistically significantly better than laminectomy for pain relief ($p<0.05$).

Yonenobu et. al. compared laminoplasty and anterior corpectomy and strut grafting for cervical myelopathy with minimum two year follow-up[83]. The groups (41 corpectomy, 42 laminoplasty) were comparable. Neurologic recovery was comparable for the two groups. Surgical complications were higher in the anterior corpectomy group, with 10 graft complications (dislodgment, fracture, and non-union). Of these, 4 patients had neurologic deterioration, one esophageal fistula, and one retrolithesis. In the laminoplasty group, only 3 transient paralyses of the 5th nerve root were noted. Due to the incidence of significant graft related complications in the corpectomy group, the authors recommended laminoplasty

In 10-14 year follow up of this same cohort[74], 23 patients had corpectomy and strut grafting(average 2.5 levels), and 24 had laminoplasty. There was no difference in long-term neurologic recovery. The corpectomy group required 6 posterior wirings for non-union (26%). Two neurologic complications occurred in the corpectomy group from graft dislodgment, one myelopathy and one C5 nerve root palsy. There was also one graft fracture. 54% of the corpectomy group had radiographic adjacent degeneration, but only one (4%) needed surgery for recurrent myelopathy. In the laminoplasty group there was a higher rate of axial symptoms (40% vs. 15% in corpectomy, $p<0.05$). There were 4 transient post-op C5 nerve root palsies in the laminoplasty group, all of which resolved.

Thus, neurologic recovery is similar for both groups for both short and long term follow up. Subtotal corpectomy has a higher incidence of graft related complications, and laminoplasty has a higher incidence of axial symptoms.

Conclusion

Cervical spondylotic myelopathy is a disease of the cervical spinal cord resulting form circumferential compression of the degenerative cervical spine, often in a congenitally narrow spinal canal. Surgical recommendations must be based on patient characteristics, symptoms, function, and neuroradiologic findings. Anterior cervical discectomy and fusion is an excellent option for one or two level spondylosis without retrovertebral disease. Anterior corpectomy and strut grafting may provide an improved decompression, and is ideal for patients with kyphosis or neck pain. Laminectomy historically has poor results from late deformity and late neurologic deterioration, but has improved results with good surgical technique. Laminoplasty was developed to address cervical stenosis of three or more segments, and compares favorable with anterior corpectomy and fusion for neurologic recovery. Laminoplasty has a lower complication rate than corpectomy and strut grafting, but has a higher incidence of post-operative axial symptoms.

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