Anterior Surgical Treatment of Cervical Spondylotic Myelopathy

Review Article

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Abstract *Background:* Cervical spondylotic myelopathy (CSM) is a common indication for cervical spine surgery. Surgical options include anterior, posterior, or combined procedures each with specific advantages and disadvantages. *Questions/Purposes:* This article will provide a description of the various anterior alternatives and discuss the available evidence used in guiding the surgical decision making process with the aim of answering the following questions: (1) What anatomical/disease related factors favor anterior over posterior surgeries? (2) What are the common anterior procedures and how safe and effective are they? (3) What are the most effective options for multilevel CSM? (4) Is there a role for motion preservation? An additional objective is to discuss technical advances that have improved success rates for anterior procedures. *Methods:* The PubMed database was searched. Keywords were CSM and anterior surgery. Three hundred eighty two articles were found one hundred three were reviewed. Articles describing anterior cervical techniques were selected along with studies describing the various anterior techniques or comparisons of anterior to posterior techniques. *Results:* Anterior decompression and fusion procedures are more effective than posterior procedures for patients with primarily ventrally located compression especially in the presence of cervical kyphosis. ACDF, ACCF, and hybrid combinations are safe and effective treatment options for multilevel CSM. Anterior procedures may be more cost effective and result in significantly improved

postoperative quality of life and health-related quality of life measures compared to posterior procedures. *Conclusion:* Anterior cervical decompression techniques are safe and effective in the treatment of CSM. Anterior surgeries may be preferable to posterior approaches, when considering health-related quality of life measures and cost effectiveness.

Keywords cervical spondylotic myelopathy · anterior cervical fusion techniques · anterior surgery

Introduction

Cervical spondylotic myelopathy (CSM) represents one of the most common causes of progressive spinal cord dysfunction in the adult population and is one of the most common indications for cervical spine surgery in the USA. It is well established that surgical decompression of the cervical spinal cord is an effective treatment option for CSM that, at a minimum, halts the progression of symptoms and can also promote functional recovery. CSM may be treated with anterior, posterior, or combined procedures each with specific advantages and disadvantages. In spite of more than 40 years of evaluation of various techniques, the evidence comparing these procedures is limited and there remains debate as to the optimal surgical approach for treating CSM.

Methods

The PubMed database was searched. Keywords were CSM and anterior surgery. Three hundred eighty two articles were found, one hundred three were reviewed. Articles describing anterior cervical techniques were selected along with studies describing the various anterior techniques or comparisons of anterior to posterior techniques.

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Results

Anterior Surgery Techniques

Anterior Cervical Discectomy and Fusion

In the 1950s, the first reports of ventral approaches to cervical disc pathology appeared. The two most common methods for anterior cervical discectomy and fusion (ACDF) were described by Robinson and Smith in 1955 and by Cloward in 1958. Robinson and Smith described an operation for removal of cervical disc material and fusion across the disc space through the placement of a rectangular iliac crest bone graft. With the Cloward technique, the discectomy was performed using a cylindrical dowel and fusion was achieved with placement of a threaded cage. Although numerous modifications have been developed since the 1950s, the great majority of spine surgeons currently use either the Cloward or the Smith-Robinson technique.

ACDF allows for the removal of disc material and posterior osteophytes compressing the spinal cord or nerve roots at or immediately adjacent to the level of the disc space [26]. Following a thorough discectomy, the disc space is distracted and height restored through placement of a structural interbody graft. Placement of a structural interbody graft allows for indirect decompression of the foramen and canal and can serve to maintain or restore cervical lordosis through placement of lordotic interbody spacers.

For limited disease with primarily disc level compression single level, ACDF has become the treatment of choice. Single-level ACDF is associated with high fusion rates and good clinical outcomes, particularly when used in conjunction with anterior plating [29, 11, 15] (Fig. 1).

Anterior Cervical Corpectomy and Fusion

Cervical corpectomy and fusion (ACCF) involves creation of an anterior midline longitudinal trough in the vertebral body down to the PLL, removing the adjacent discs, and

decompressing the neural elements through this trough. Anterior cervical corpectomy and fusion (ACCF) is ideally suited in cases where the compressive pathology is not confined to the disc space region, and extends behind the vertebral body [56, 29, 34].

The key anatomical landmark to be identified during the decompression is the lateral cortical wall of the vertebral body, which is at the junction of the transverse process and the vertebral body. Identification of this landmark facilitates the creation of a symmetrical central trough while avoiding an injury to the vertebral artery. It has been shown that adequate decompression may be safely achieved at C3 and C6 levels, by not extending from the midline more than 15 and 19 mm, respectively, which ensures a safety margin of 5 mm to the medial border of the foramen transversarium [16, 43, 56]. Reconstruction following corpectomy involves placement of a strut graft, typically structural iliac autograft, fibula allograft, or a cage construct packed with autograft. Anterior plating is recommended following anterior cervical corpectomy, especially when multilevel corpectomies are preformed due to the high incidence of early instrumentation failure [56, 69].

ACCF has been demonstrated to be clinically effective for single-level or two-level disease [21, 41]. Potential advantages of corpectomy-based approaches include more complete decompression, especially with significant stenosis directly behind the vertebral body, fewer bone-graft interfaces, and potentially greater surface area for fusion to occur. In a 2-level ACDF, there are four bone-graft interfaces, compared with only two for a corpectomy. The theoretical risk of pseudarthrosis is therefore generally less with corpectomy than with multilevel ACDF. In a metaanalysis, by Fraser et al. [15], the fusion rate for ACDF with plating was 97.1% for 1 level, 94.6% for 2 level, and 82.5% for 3 level procedures. The authors reported that for 2 level disease, there was no significant difference between ACDF and ACCF; however, for 3 level disease, the ACCF was associated with higher fusion rates than ACDF [15]. These findings were supported by Song et al. [61] who reported higher

Fig. 1. Illustrative case. A 38-year-old man with progressive neck pain, myelopathy, and C7 radiculopathy. **a** Sagittal T2-weighted magnetic resonance imaging scan (MRI) demonstrating multilevel cervical disc degeneration and spinal cord compression at C4–5, C5–6, and C6–7 with intramedullary T2-weighted signal changes at C6–7 interspace. **b** Lateral radiograph showing diffuse arthrosis and loss of cervical lordosis. **c** Postoperative radiograph following 3-level ACDF (C4–C7) with anterior plating demonstrating restoration of lordosis.

fusion rates with ACCF (93.3%) than multilevel ACDF (88.0%) and comparable, significant improvement in visual analog scale (VAS), Japanese Orthopaedic Score (JOA) scores, and cervical lordosis in both groups [61]. More recent studies with the routine use of anterior plating suggest the fusion- and graft-related complication rates associated with single-level corpectomy and 2-level discectomy and fusion are comparable [37, 54]. Fusion rates are also similar for 3-level discectomy and fusion with plating (94.7%) and 2-level corpectomy (91–94%) [3, 15].

A particular area of concern in patients undergoing multilevel corpectomy is early construct failure. Early construct failure rate dramatically increases with constructs of three or more levels [43, 56]. Long-strut grafts without points of intermediate fixation create significant stresses at the ends of long corpectomy constructs. Addition of an anterior plate results in a change in the loading pattern of the strut. Stand-alone strut graft is loaded in flexion and unloaded in extension; the addition of a plate completely reverses the loading pattern, which is the likely mechanism underlying the relatively high complication rates and lower fusion rates seen in series utilizing multilevel corpectomy [68, 24, 42]. Vaccaro et al. treated 45 CSM patients with either 2-level or 3-level corpectomies and anterior plating without supplemental posterior instrumentation. The investigators reported a 9% dislodgment rate in the 2-level corpectomy group and a 50% dislodgment rate in the 3-level corpectomy group and graft

migration occurring in more than 80% of the 3-level instrumented corpectomy group despite the use of a halo [68]. Sasso et al. [49] reported a 71% early catastrophic dislodgement of the graft-plate in their instrumented 3-level corpectomy group. In order to provide additional stability, many surgeons recommend supplemental posterior instrumentation for corpectomies involving three or more vertebral bodies [49, 24, 68]. In the absence of posterior instrumentation, the large lever arm created in an anterior-only construct can lead to instability and graft dislodgement, even when an external fixator is used. The combination of anterior-posterior instrumentation has been shown to be an effective means of limiting motion with long constructs and decreasing graft migration and dislodgment. Accosta et al. [1] reported that multilevel instrumented corpectomy with posterior fixation offered a biomechanically stable fixation which could limit cage subsidence and loss of sagittal balance postoperatively (Fig. 2).

Surgical Options for Multilevel Disease: ACDF vs ACCF

The optimal surgical approach for patients with multilevel CSM remains a controversial subject. The mainstays of treatment for multilevel CSM include multilevel corpectomies and discectomies as well as hybrid combinations of these techniques. There has been much debate in the literature regarding which approach yields the best outcomes in patients with multilevel CSM, and no single superior technique has been described. In treating multilevel CSM, the decision to employ either a corpectomy- or a discectomy-based approach and tradeoffs to be considered include adequacy of decompression, postoperative stability, ability to restore cervical lordosis, fusion rates, and ease of surgery.

From a biomechanical standpoint, techniques involving multilevel discectomy have distinct advantages over corpectomy-based procedures. The large moment arm created by a long corpectomy construct leads to significant stresses at the bone-graft and bone-screw interfaces at the ends of the construct [24, 42, 59]. These stresses can lead to rotational instability, pistoning or toggling of the graft, and its eventual dislodgment. The rotational and translational stability increases with a construct with multiple intermediate points of fixation. Although there are many interfaces between vertebral bodies and interbody grafts, multilevel ACDF provide more fixation points to hold the construct rigidly in place which serves to increase immediate stability. By comparison, corpectomy strut grafts provide only two interfaces between the vertebral bodies and the graft with two points of fixation at the remaining rostral and caudal vertebral bodies which results in increased translational movement at these interfaces [56, 32, 20]. Many authors advocate the addition of posterior instrumentation for multilevel corpectomy (three or greater) in order to increase construct rigidity and lessen the incidence of early hardware failure [34, 49, 68]. In multilevel ACDF, the multiple segmental fixation points leads to a much more stable construct in the immediate postoperative period, which, in the absence of the correction of a significant kyphotic deformity,

Fig. 2. Anterior cervical reconstruction techniques for multilevel CSM. Lateral cervical spine radiographs demonstrating anterior reconstruction techniques for multilevel CSM. **a** 4-level anterior cervical discectomy and fusion (ACDF). **b** 2-level anterior corpectomy and fusion (ACCF). **c** Hybrid ACDF-ACCF construct. **d** Hybrid cervical disc replacement (CDR)-ACDF construct.

obviates the requirement for supplemental posterior instrumentation. Reducing the need for circumferential procedures is a significant advantage of ACDF over ACCF as these procedures have a high degree of associated morbidity. Several series report complication rates in the range of 31 to 56% for 3 level corpectomies with posterior instrumentation [8, 68, 62].

Multilevel discectomy allows for superior restoration of cervical lordosis than corpectomy-based approaches [54]. Following disc space decompression, placement of interbody grafts with lordotic anterior plates and segmental instrumentation allows the intervening vertebral bodies to be translated toward the lordotic ventral plane which allows for the recreation of a gradual lordotic curve over multiple segments [61]. With corpectomy techniques, the ability to restore normal cervical lordosis is limited. Performing an ACCF tends to straighten the spine across the area of decompression. Removal of a large bony trough through the vertebral bodies precludes the use of segmental fixation and often requires placement of long-strut grafts to reconstruct the anterior column following the decompression [54, 56]. In a retrospective comparative series, Song et al. [61] demonstrated superior restoration and preservation of cervical lordosis using multilevel ACDF compared to ACCF. In the ACDF group, the average angle of lordosis improved from $2.47 \pm 5.56^\circ$ to $10.21 \pm 3.41^\circ$ compared to the ACCF group $1.04 \pm 11.6^\circ$ to $6.07 \pm 5.9^\circ$ 3 months postoperatively. Similar results were reported by Lin et al. [30], who reported segmental lordosis correction of 9.79 ± 3.4 to 17.75 ± 2.6 using multilevel ACDF compared to 9.54 ± 3.0 to 14.49 ± 2.5 using multilevel ACCF.

One particular area of concern when performing multilevel ACDF is the ability to achieve solid fusion across multiple fusion surfaces. Prior to recent advances in anterior plating systems and grafting materials, multilevel ACDF was associated with a significantly higher non-union rate than ACCF, especially when treating multilevel disease [16, 43, 30]. Historically, fusion rates following non-instrumented multilevel ACDF (3 level or greater) were unacceptably low [34, 62, 71]. Early studies suggested that corpectomy without instrumentation was associated with much higher fusion rate than multilevel interbody grafting without instrumentation [68, 11]. More recent studies with the routine use of anterior plating suggest the fusion- and graft-related complication rates associated with single level corpectomy and 2-level discectomy and fusion are comparable [37, 54]. Fusion rates are also similar for 3-level discectomy and fusion with plating (94.7%) and 2-level corpectomy (91–94%) [3, 15]. In patients with >3 level pathology without significant retrovertebral pathology, 4-level ACDF with plating can be associated with high fusion rate (92.6%), relatively low complication rate (15%), and obviates the need for supplemental posterior instrumentation [8].

Multilevel compression involving four disc levels can be treated with a 4 level ACDF or 3 level corpectomy [20, 8]. In cases where the pathology is limited to the disc space, a multilevel discectomy is often the best approach. In patients with 4 level disease with significant retrovertebral compression or fixed deformity, a corpectomy may be required. A

stand-alone 3 level corpectomy is a biomechanically inferior construct and most would advocate supplemental posterior instrumentation. The skip corpectomy is an alternative technique for multilevel CSM which involves two, single-level corpectomies separated by an intact intervening vertebra [9, 44]. In general, the skip corpectomy is indicated for compressions extending from C3–4 to C6–7 and involves corpectomy at C4 and C6 with preservation of the C5 vertebral body for segmental fixation. The skip corpectomy technique has four healing surfaces which are four fewer than the eight surfaces associated with an equivalent multilevel ACDF and by having an intermediate point of fixation, avoids the use of a long-strut graft. Ashkenazi et al. found that skip corpectomy was associated with 100% fusion rate, and a low rate (4%) of mechanical failure [2, 3]. Similarly, Dalbayrak et al. [9] reported high fusion rates (100%) and low graft hardware-related complication rate (3.4%) following skip corpectomy. The biomechanical characteristics of different hybrid discectomy and corpectomy models have been investigated by Singh et al. [59] who reported increased segmental rigidity and decreased likelihood of plate dislodgement in association with the skip corpectomy technique [59]. Other biomechanical studies suggest skip corpectomy was associated with better translational stability than a standard three-level corpectomy [42].

The partial corpectomy is an alternative anterior technique designed to address some of the limitations of both multilevel ACDF and corpectomy for use in patients with cervical disc degenerative disease affecting two or more adjacent levels. The technique described by Groff et al. involves discectomies at the affected levels followed by removal of the anterior portion of the intervening vertebrae with approximately one third to one half of the posterior portion of the body left behind [19]. Reconstruction involves strut graft placement in the resulting trough followed by anterior plating. In their retrospective series of 144 patients, Groff et al. demonstrated a high fusion rate (95.8%) with 2.1% pseudarthrosis rate and no cases of early graft failure. The authors believe the high fusion rate is attributable to enhanced stability, compared to complete corpectomy, as well as additional fusion surface area from the residual vertebral body [19]. Partial corpectomy combines the safety of ACDF with high fusion rates independent of the number of levels decompressed and obviates the need for posterior stabilization.

Another alternative to a 3 level corpectomy is a hybrid anterior reconstruction technique introduced by Singh et al. which combines a one level corpectomy with a one level discectomy [59]. Biomechanical and clinical studies have demonstrated less bleeding, superior restoration of segmental lordosis, better segmental stability, and higher fusion rates with the hybrid decompression and fusion (HDF) technique than the two-level corpectomy [59]. Ashkenazi et al. [3] published a series of 25 patients with an average follow-up period of 29 months, in which the hybrid technique was used to treat multilevel CSM. These authors found no evidence of late onset instrumentation-related failure and bony fusion in 96% of the patients. In a recent retrospective comparative review of three reconstructive techniques for

multilevel CSM, Liu et al. suggested that HDF is preferable to multilevel corpectomy when treating multilevel CSM in instances where multilevel ACDF is not possible [32].

Cervical Disc Replacement

The incidence of adjacent segment degeneration following anterior cervical fusion has been reported to be approximately 2.9% per year [22]. Motion preservation technology has gained popularity because it is intended to reduce abnormal stresses transferred to adjacent levels, thus theoretically reducing the chance of developing adjacent segment degeneration. Whether adjacent level degeneration is the result of the fusion, or simply a part of the natural course of the disease process is not entirely clear [39, 43, 46]. Procedures that decompress the spinal cord while either limiting the fusion or maintaining segmental motion by placing disc arthroplasty devices have been hypothesized to decrease the incidence of adjacent level disease [45, 53]. Sekhon et al. have published reports of patients with myelopathy being treated with single-level and multilevel cervical disc arthroplasty [53, 52]. They concluded that cervical arthroplasty may be a reasonable alternative to fusion for limited CSM. In the largest study to date comparing motion preservation versus fusion for cervical myelopathy, Riew et al. [45] combined the data from two prospective randomized trials that examined ACDF and cervical arthroplasty. At 2-year follow-up, both groups had significant improvement in both neck disability index (NDI) and short form (36) health survey (SF-36) scores. The investigators concluded that for limited disease, disc arthroplasty performed as well as a single-level fusion for neurologic function, satisfaction, and neck pain. No conclusions were reached regarding adjacent level degeneration in this short-term follow-up study [45].

More recently, hybrid arthroplasty-discectomy procedures, in which a cervical disc replacement is performed adjacent to an ACDF, have been reported to be superior to 2-level ACDF in several clinical measures including NDI, postoperative neck pain, and range of motion recovery [55]. Despite encouraging initial results, there remains a concern that motion preservation at the myelopathic segment may allow continued microtrauma to the spinal cord and the future role that motion preservation will play in the myelopathic patient remains to be determined.

Technical Points

Interbody Grafting

Graft options for ACDF and ACCF include iliac crest autograft, allograft wedges, or struts or use of an interbody fusion device (allograft vs. interbody cage). Each graft alternative has unique advantages and disadvantages. Ideally, a graft or interbody cage should allow for 2 to 4 mm distraction beyond the preoperative disc height to allow for indirect foraminal decompression, restoration of disc space height, and to decrease folding of the ligamentum flavum dorsally. Autogenous iliac crest bone graft is considered the gold standard against which all other graft options are

measured. Iliac crest bone graft (ICBG) allows for quicker biological incorporation and is less expensive; however, there is additional donor site morbidity including chronic pain in 10–39% and other donor site complications in 10–49% [4, 57]. Early studies using autograft for ACDF were nearly uniformly successful with fusion rates approaching 100%. In a series of reports, Gore and Sepic described fusion rates of 97–100% [18]. Concerns for donor site morbidity led to use of fibular allograft as a substitute; however, problems with graft subsidence and pseudarthrosis were a concern. With the addition of anterior cervical plates, Samartis et al. described equivalent fusion rates between allograft and autograft in procedures involving up to three levels [48]. In that report, they suggested that preparation of the endplates after a through discectomy, recessing the graft 2 mm from the anterior margin of the vertebral body, and the use of segmental screw fixation were more important than the type of graft used. Autograft harvested from the iliac crest and allograft bone from either the cadaveric iliac crest or fibula or titanium cages with or without the use of autologous graft or substitute have been used successfully for 1 or 2-level ACDFs. Alternatives to autograft, allograft, or titanium cages include polyetheretherketone (PEEK) cages and carbon fiber cages. In 2006, Ryu et al. published a prospective randomized study comparing allograft and carbon fiber cages, demonstrating equivalence between the two graft options for anterior cervical fusion [47]. More recently, Uribe et al. showed good clinical outcomes and high fusion rates using titanium mesh cages (Harms Cage) filled with autograft for multilevel ACDF 97% and ACCF 93% with low pseudarthrosis rates and suggested that when combined with an anterior cervical plate, allow for equivalent clinical outcomes, fusion rates without donor site morbidity associated with ICBG [67].

Anterior Plating

Use of an anterior cervical plate with ACDF and ACCF has resulted in a significantly higher fusion rates compared to non-instrumented anterior fusions [72, 73, 70]. Other benefits of plating include improved initial stability, decreased need for bracing, and reduction in complications from graft dislocation, end-plate fracture, and kyphotic collapse. The original anterior cervical plate designs provided rigid fixation between segments, acting as a tension band in extension and as a buttress plate in flexion [58]. These plate types are commonly referred to as constrained devices. Rigid fixation devices are load bearing and may eliminate the mechanical loads on the bone graft, which are thought to be important for fusion. These static designs may also prevent any settling from occurring, thus leaving a gap between the bone graft and the end plate. To overcome these disadvantages, dynamic anterior cervical plates have been introduced that allow for graft loading by axial settling. In biomechanical cadaveric cervical corpectomy studies comparing dynamic and static plates, Brodke et al. [7] showed that more load sharing occurred in dynamic cervical plates, because these plate designs allowed for axial settling to make up for graft resorption during the postoperative period. Fogel et al. [14]

reported that static plates had significantly higher graft loads in extension and significant loss of graft load in flexion, whereas the dynamic plate maintained a graft load throughout the ROM even when graft contact was imperfect. The design of the plate does not affect the outcomes in single-level fusions but statistics indicate that multiple-level fusions may have better clinical outcomes when a dynamic plate design is used [63].

Different techniques for placement of anterior cervical plates during anterior cervical fusion can have implications on the development of adjacent level degeneration. Koller et al. [28] reported that progression of adjacent segment disease after instrumented ACDF was linked to a plate to adjacent disc distance of less than 3 mm. Park et al. [40, 39] recommended that anterior cervical plates be placed at least 5 mm away from the adjacent disc spaces to decrease the likelihood of adjacent level ossification. DuBois et al. [10] suggested that placing instrumentation at least 3 mm from the adjacent level disc would decrease the potential for adjacent level changes. Recent advances including low profile, integrated interbody cages have been developed in order to obviate the need for anterior plating with the goal of reducing plate-related morbidity. A number of biomechanical studies have shown that an anchored cage design with integrated screws afforded biomechanical stability comparable to that of the standard interbody cage with anterior plate [5]. Though long term studies are limited, several integrated low profile designs have been shown to have decreased rates of dysphagia compared to standard anterior plating systems [23]. Several recent devices have come to market that share the properties of being a low profile interbody spacer that allows for fixation to the adjacent vertebral bodies without a formal anterior cervical plate. The Prevail cervical interbody device (Medtronic) is an interbody device with rostral and caudal midline flanges that allow for a screw interface with the ventral corner of the adjacent vertebral body. The Zero-P device (Synthes) has similar properties but does not require preparation of the anterior surface of the vertebral body. This “anchored spacer” consists of a PEEK interbody cage with a ventral titanium housing that allows for anchoring screws to be placed diagonally into the adjacent vertebral bodies. Scholz et al. [51, 50] recently examined the biomechanical properties of this stand-alone cervical interbody device. This device demonstrated decreased range of motion compared to interbody cage alone (no fixation) and no significant difference when compared to the addition of a locking or dynamic anterior cervical plate.

Discussion

Comparison of Clinical Outcomes Anterior Fusion Techniques

For single-level, disease-instrumented ACDF has become the gold standard due to relative ease of performance, and excellent outcomes. In properly selected patients (those with limited disease isolated to the disc space and without evidence of instability or significant neck pain), cervical arthroplasty has been shown to be equivalent to ACDF in

clinical efficacy, though may leave concern for ongoing dynamic compression at adjacent segments or in the presence of kyphosis. In patients with multilevel disease where a one level procedure will not be adequate to achieve decompression, the surgeon has to decide whether to perform ACDF, a corpectomy, or a hybrid procedure. The clinical outcomes of patients undergoing anterior decompression and fusion procedures for 3 level CSM was compared by Liu et al. [32]. The authors compared JOA scores, NDI scores, and clinical outcomes according to the Odom criteria of 180 patients who underwent either ACDF, ACCF, or hybrid decompression and fusion (HDF). The JOA scores significantly increased from 10.8 ± 1.8 to 14.1 ± 1.6 in the ACDF group ($p < 0.05$), from 10.6 ± 1.4 to 14.5 ± 1.8 in the ACCF ($p < 0.05$), and from 11.2 ± 1.9 to 13.8 ± 1.9 in the HDF group ($p < 0.05$), respectively. The corresponding NDI scores significantly decreased from 35.1 ± 2.9 to 13.6 ± 2.8 in the ACDF group ($p < 0.05$), from 35.3 ± 3.0 to 14.0 ± 2.9 in the ACCF group ($p < 0.05$), and from 34.7 ± 2.6 to 14.2 ± 3.1 in the HDF group ($p < 0.05$), respectively. According to the Odom criteria, the percentage of patients with excellent and good clinical outcomes was 84.1% in the ACDF group, 79.5% in the ACCF group, and 83.3% in the HDF group, respectively. Although significant pain relief and functional activity improvement had been achieved in the three groups at final follow-up, there was no significant difference in the JOA scores, NDI scores, and the excellent and good rates of clinical outcomes among the three groups. A recent systematic review by Shamji et al. [54] also demonstrated significant improvements in JOA scores, NDI scores, and VAS scores in patients undergoing anterior decompression and fusion surgical procedures, but these authors found that when the pathoanatomy permits, multiple ACDF was favored compared with ACCF and HDF for NDI and VAS scores, with equivalence being observed for JOA scores [54]. They found that there was conflicting evidence for the superiority of ACCF or HDF with regard to clinical outcomes, and while neither of the two was superior, they recommended that HDF procedures be performed over multiple ACCF when retrovertebral disease is significant [54].

Sagittal balance and improvements in sagittal alignment have also been compared between the three anterior reconstructive techniques. Liu et al. [32] reported that ACDF, ACCF, and HDF were associated with improvements in cervical and segmental lordosis. There was no statistical difference in the restoration of cervical lordosis between the ACDF and HDF groups, but the improvements of cervical and segmental lordosis in the ACCF group were significantly less than either the ACDF or HDF group ($p < 0.05$). Lin et al. [30] evaluated the change in sagittal alignment after ACDF and ACCF in patients with multilevel CSM, and reported statistically significant improvement in postoperative scores after ACDF. These results were supported by Shamji et al. in a systematic review paper that concluded that all reviewed studies demonstrated greater change in sagittal alignment after ACDF than ACCF, with the difference in score changes being statistically significant in 80% of them [54]. The benefits of sagittal correction and improved cervical spine biomechanics have important

implications for reducing adjacent segment disease, which has been reported to be 17% following ACCF [30].

Anatomic Considerations

Regardless of the approach, the overall goal of surgical intervention in patients with CSM is to alleviate spinal cord compression, restore spinal cord morphology, and to correct and maintain both regional cervical alignment and global sagittal balance [43, 56, 29]. There are several surgical options that have been used to treat patients with cervical spondylotic myelopathy and considerable controversy over which surgical approach provides the best outcomes with the least associated morbidity. Surgical options for CSM are divided into anterior, posterior, or combination anterior and posterior approaches. In general, the choice between anterior and posterior approaches is based on patient-specific anatomic factors including: (1) the primary location of compressive pathology (ventral versus dorsal), (2) the regional sagittal alignment, (3) the extent of disease involvement, (4) the presence of preoperative neck pain, and (5) the presence of congenital stenosis [29, 27, 56, 36].

Location of Compressive Pathology

The anatomic location of the primary compressive pathology is an important consideration when planning a surgical intervention. In general, anterior cervical approach is preferred if the compressive pathology is primarily ventral, primarily localized to an interspace or interspaces, and/or is associated with cervical instability, spondylolisthesis, or a kyphotic deformity [43]. Primarily ventral pathology causing cord compression particularly if it is focal rather than contiguous over multiple levels is best treated by an anterior approach. In patients with primarily disc space pathology, anterior cervical discectomy will allow for adequate decompression; however, in patients with significant retrovertebral compression, an extruded migrated disc fragment, or ossification of the posterior longitudinal ligament (OPLL), corpectomy may be necessary [43]. In a series of patients with CSM due to OPLL, Iwasaki et al. [25] described two shapes of anterior compressive pathoanatomy: (a) hill-shaped lesions and (b) broad-based or flat lesions. In their study, Iwasaki et al. found that hill-shaped lesions responded better to ventral decompression techniques whereas flat or generalized stenosis patients did as well or better with dorsal procedures such as laminoplasty [74, 21, 25].

Extent of Disease Involvement

In general for patients with one to three level disease, most surgeons prefer an anterior procedure, either single or multilevel ACDF, ACCF, or a hybrid construct. Patients with four or greater levels of involvement have traditionally been managed with posterior decompression procedures or combination anterior and posterior surgeries. Historically, management of four level disease from an anterior approach required long segment corpectomy with strut grafting. Early construct failures were commonplace and many advocated additional posterior stabilization [68, 36, 49]. More recently,

advances in grafting and instrumentation techniques have allowed for multilevel ACDF (including 4 or 5 level) or hybrid ACDF-ACCF constructs which have demonstrated distinct advantages over long segment ACCF and may negate the need for posterior supplementation in the absence of a kyphotic deformity [38, 30, 31, 33].

Sagittal Alignment

Progressive cervical spondylosis may result in the development of regional or segmental kyphotic cervical spine deformities in patients with CSM. The development of a cervical kyphotic deformity is the result of progressive subluxation of the apophyseal joints due to degenerative changes in the facets and discs. The presence of a kyphotic region causes the spinal cord to shift anteriorly within the spinal canal which in the presence of anterior compressive pathology increases the mechanical stresses on the spinal cord [43]. During cervical spine flexion, the presence of a kyphotic segment may result in neuronal injury through both stretch-related mechanisms and through repetitive compression against anterior compressive lesions [64].

When planning a surgical intervention for patients with CSM, the presence of segmental kyphosis as well as the global cervical sagittal alignment must be taken into consideration as they have been shown to have direct impact on patient outcomes. A number of clinical studies have demonstrated the importance of correcting and or maintaining cervical alignment for outcomes in patients with CSM. These studies demonstrate a significant advantage of anterior over posterior cervical procedures in the ability to improve neurological function in the presence of regional kyphosis as well as the ability to preserve or recreate cervical lordosis. A number of studies suggest that in the presence of cervical kyphosis, posterior decompression alone would not allow for adequate dorsal drift of the spinal cord to alleviate compression from anterior compressive pathology [60]. Suda et al. [64] showed that patients preoperative kyphosis $>13^\circ$ had worse modified Japanese Orthopaedic Association (mJOA) disease-specific outcomes postlaminoplasty and suggest that in the presence of kyphosis, anterior procedures may be preferable. Uchida et al. [66] reported retrospectively on a series of patients with a preoperative kyphotic deformity of $>10^\circ$ treated with either anterior or posterior surgeries and showed better neurological outcomes and improved postoperative sagittal alignment in patients who underwent anterior fusion procedures.

Recently, the relationship between cervical alignment and sagittal balance has been shown to have an impact on health-related quality of life outcomes following posterior cervical fusions. In a post hoc analysis of prospectively collected data, Tang et al. [65] demonstrated the severity of disability increases with postoperative sagittal malalignment. In their study, they showed that global cervical malalignment as measured by C2–C7 sagittal balance (distance between C2 plumb line and C7) and the center of gravity of the head–C7 (CGH–C7) sagittal vertical axis (SVA) were negatively correlated with function and positively correlated with neck disability scores. They also showed an important compensatory

relationship whereby increased C2–7 SVA leads to an exaggerated compensatory increase in C1–2 lordosis, in order to maintain horizontal gaze. The authors suggest that these adaptive changes require higher greater energy expenditure and are likely linked to adverse HRQOL scores. These results suggest that when planning decompressive surgery for CSM, consideration should be given to the correction and normalization of cervical sagittal balance.

Preoperative Neck Pain

The pathophysiology of axial neck pain in the setting of CSM is likely multifactorial and may be related to muscular or ligamentous strain, may be directly attributed to the degeneration of the cervical disc or facet joints, or may be a product of segmental instability [43]. The presence of significant preoperative neck pain is a relative contraindication for posterior decompression procedures; many surgeons prefer anterior fusion procedures in this setting. Advantages of anterior procedures include the ability to decompress the spinal cord through fascial planes with preservation of the stability of the posterior paraspinal musculature not possible through a posterior approach. It has been suggested that disruption of the posterior musculotendinous tension band from a posterior approach is associated with a higher incidence of axial neck pain compared to anterior surgical approaches, though other studies report similar rates between approaches [43, 6, 17].

Anterior Versus Posterior Options

The choice of surgical approach, anterior, posterior, or combined remains a source of ongoing debate among spine surgeons. To date, the literature is limited by the lack of well designed, prospective studies but several comparative studies have suggested that the clinical efficacy and complication rates are similar for anterior and posterior procedures for treatment of multilevel CSM. Despite numerous studies on this topic, uncertainty remains about which of these procedures is optimal for the treatment of CSM. In 2009, Mummaneni et al. performed a systematic review to compare the efficacy of different surgical techniques, including anterior and posterior fusion, for the treatment of CSM. The investigators found insufficient evidence to recommend anterior fusion over posterior fusion because both produced comparable improvement in patients with CSM [35].

Recent studies evaluating the comparative effectiveness of anterior and posterior surgeries based on quality of life outcomes, complication profiles, and cost effectiveness suggest that while both procedures are effective treatment options, anterior surgeries result in significantly improved postoperative QOL, may be as safe or safer than posterior surgeries, and are more cost effective. Boakye et al. [6] used the NIS database to review 58,115 patients with CSM between 1993 and 2002. They reported overall complication rate of 13.4% (16.4% for dorsal fusion, 11.9% for ventral fusion), dysphagia (3%), and hoarseness (0.2%) were more prevalent in the ventral cohort. Pulmonary complications (4.6%) and hematoma (3.3%) were more prevalent in the

dorsal group. According to this study, dorsal fusion surgery had significantly greater costs (US\$30,927) than ventral fusion surgery (US\$23,209). Ghogawala et al. [17] conducted a prospective study on 50 patients comparing anterior ($n=28$) to posterior ($n=22$) surgery group. Both groups showed significant improvements in mJOA (2.0 $p=0.01$ vs. 1.9 $p<0.01$) and SF-36 (9.9 $p<0.01$ vs. 5.7 $p<0.01$). The anterior surgery group showed significant improvement in NDI score (18.4 point decrease $p<0.01$). Although the dorsal group had a greater degree of myelopathy preoperatively and had more levels treated surgically. In this study, the authors also showed that complication profiles did not significantly differ between anterior and posterior cohorts (13.6 vs. 17.9%, respectively). The overall complication rate was 16.6%. The posterior cohort had greater rates of postoperative pain and disability compared to the anterior cohort. Of those patients in the anterior cohort who had complications, 80% had swallowing difficulties. The three patients (13.6%) in the posterior cohort with complications each had C5 palsy. They also showed that posterior fusion surgery was associated with significantly longer hospital stays (4.0 vs. 2.6 days) and greater costs (US\$29,465) than anterior fusion surgery (US\$19,245). Fehlings et al. [13, 12] analyzed 302 patients from the AOSpine North America Cervical Spondylotic Myelopathy Study who underwent surgical treatment for CSM. These investigators reported an overall perioperative complication rate of 15.6%, with an overall delayed complication (pseudarthrosis, hardware breakage, graft dislodgement) rate of 4.4%. The anterior and posterior cohorts had complication rates of 11 and 19%, respectively ($p=0.11$). The most common complications included cardiopulmonary (3%), dysphagia (3%), and wound infection (2.3%). Operative blood loss was significantly ($p<0.01$) greater in the posterior cohort compared with the anterior cohort. The posterior cohort also had a significantly ($p=0.03$) greater incidence of wound infection (4.7%) compared with the anterior cohort (0.6%). Direct costs on average for both fusion surgeries were US\$20,516.

Cervical spondylotic myelopathy is a progressive degenerative process that can lead to severe neurological impairment, pain, and disability. Surgical treatment can arrest progression and allow for recovery of neurological function. Currently, there are several anterior cervical decompression techniques that have been demonstrated to be safe and effective in the treatment of CSM. Given the heterogeneity of the disease process and the number of patient-specific variables that must be considered, the optimal surgical management of multilevel cervical spondylotic myelopathy has to date not been defined. While the current state of the literature does not provide definitive evidence of a superior technique, recent studies suggest that anterior surgeries may be preferable to posterior approaches, in particular in the patient with a kyphotic alignment, when considering health-related quality of life measures and cost effectiveness.

Disclosures

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