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Anterior cervical discectomy and fusion: Techniques, complications, and future directives

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A B S T R A C T

Anterior cervical discectomy and fusion is a well-established surgical intervention for a wide range of degenerative cervical spine pathology, including myelopathy and radiculopathy. Despite the emergence of technical advances including cervical disk arthroplasty, evidence continues to support use of anterior cervical fusion given its effectiveness and safety. Research continues to advance anterior cervical fusion with the development of patient-specific implants and hybrid arthroplasty-fusion surgical approaches. This review summarizes the indications, surgical approach, outcomes, and complications of anterior cervical fusion and offers perspective on future areas of research within the context of newer motion-preserving alternatives, including cervical disk arthroplasty.

1. Introduction

Anterior cervical discectomy and fusion (ACDF) is a widely-used surgical technique that has proven to be safe and effective for the treatment of cervical spine pathology. ACDF is among the most common surgical procedures in the cervical spine, with approximately 132,000 cases performed each year in the United States alone.[1]

ACDF first appeared in the literature in 1955 when Robinson and Smith described a novel surgical procedure to decompress the cervical spine through an anterior approach.[2] Their technique included the use of a horseshoe-shaped autograft harvested from the iliac crest and packed into the disk space to facilitate fusion. Three years later, Cloward detailed his own method for achieving interbody fusion in ACDF-a modification of Wiltberger's dowel fusion technique originally employed in the lumbar spine.[3] Cloward's initial results were promising with all patients reporting at least partial relief and 42 of 47 patients achieving complete symptomatic relief. As early as 1959, however, Scoville and others proposed that ACDF may be associated with an increased risk of postoperative adjacent segment degeneration (ASD), which provided an impetus for the advent of cervical disk arthroplasty (CDA) as a motion-sparing alternative to ACDF.[4] The debate between ACDF and CDA remains ongoing today, and current perspectives on this topic will be discussed in the present chapter.

Surgical indications for ACDF range broadly from spondylosis and disk herniation to OPLL and other pathologic conditions, some of which can be controversial. The number of affected vertebral levels should be considered in terms of indicating patients with multilevel disease for ACDF as opposed to a posterior cervical approach. Further, while the operative approach itself is firmly established, there are several technical elements of ACDF that can vary. Multiple types of cages and bone graft are available to facilitate fusion, each with their own set of advantages and disadvantages. Likewise, several anterior plate options exist on the market, and their utility continues to be an important point of discussion among cervical spine surgeons.

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In addition to the indications and technical elements, this chapter will also include a comprehensive summary of the postoperative outcomes and complications that can be expected following ACDF. While the procedure itself is typically well-tolerated and has demonstrated positive outcomes, the potential short-term and long-term complications of ACDF must not be minimized as they can have devastating consequences for affected patients. Finally, we will offer some perspective on future directions for ACDF, including the creation of patient-specific implants as well as hybrid surgical approaches that combine both fusion and disk replacement.

2. Indications

ACDF can be utilized to address a wide range of neck pathology. Given the prevalence of poorly characterized neck pain, great care must be taken to identify patients that are likely to benefit from a cervical discectomy and fusion procedure. In general, ACDF should be the preferred surgical intervention for symptomatic anterior cervical spine lesions that compress the spinal cord or nerve roots ventrally.

2.1. *Radiculopathy*

Cervical radiculopathy is among the most well-established indications for ACDF. Conservative therapy is the mainstay of treatment for radiculopathy as the vast majority of patients improve with non-operative intervention, which may consist of immobilization, physical therapy, NSAIDs, and epidural steroid injections.[5] Still, a substantial number of individuals fail conservative treatment and may ultimately require a surgical procedure to achieve symptomatic relief. ACDF has shown reliably positive outcomes for one- and two-level radiculopathy and remains the most commonly performed surgery among this cohort of patients.[6–8]

The duration of non-operative management that should be attempted before pursuing operative intervention remains uncertain. In a systematic review, Wong and colleagues reported that most patients experience improvement in their symptoms within a 4- to 6-month period, and that this may be a reasonable time frame to observe a radiculopathic patient before pursuing surgical intervention.[9] However, other studies have demonstrated poorer postoperative outcomes in patients with longer symptom durations before surgery.[10,11] Randomized controlled trials are thus necessary in order to define the optimal treatment course of cervical radiculopathy.

2.2. *Myelopathy*

Cervical myelopathy is a constellation of symptoms which may include neck pain, numbness, tingling, and fine motor difficulty of the upper extremities, and gait abnormality related to the spinal cord, usually due to cord compression (Fig. 1). Myelopathy can have several potential etiologies, the

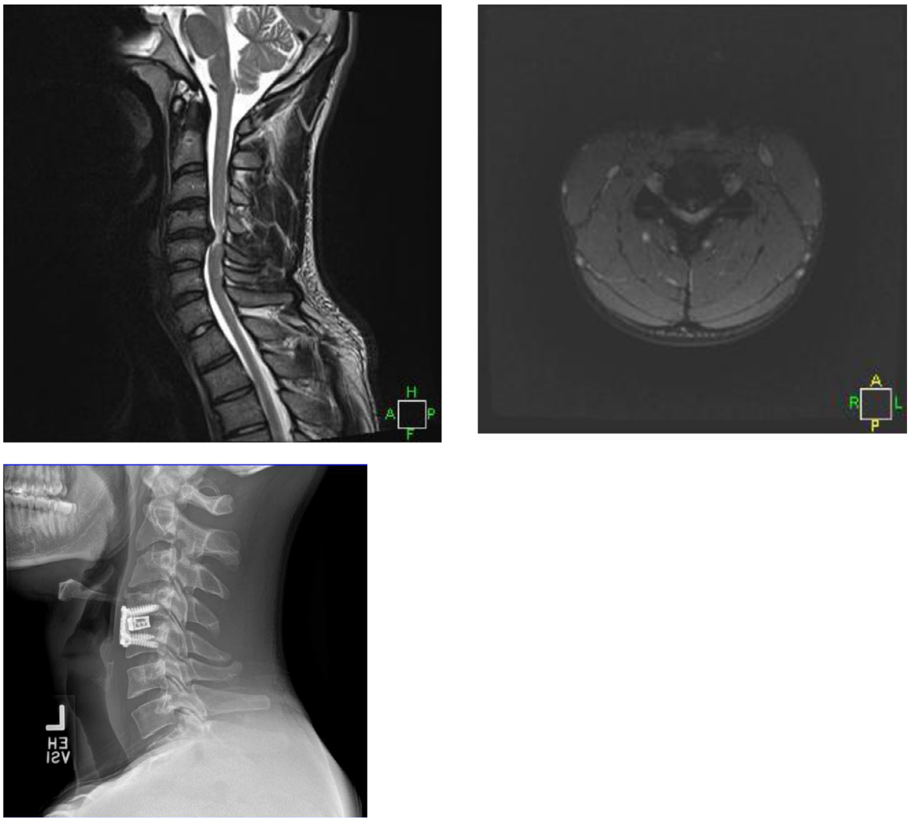

Fig. 1 – Disk Herniation at C4-C5 with Cord Compression and ACDF C4-C5. 22-year-old male with a disk herniation at C4-C5 causing cord compression with symptomatic myelopathy and myelomalacia on MRI, resulting in a single-level ACDF at C4-C5.

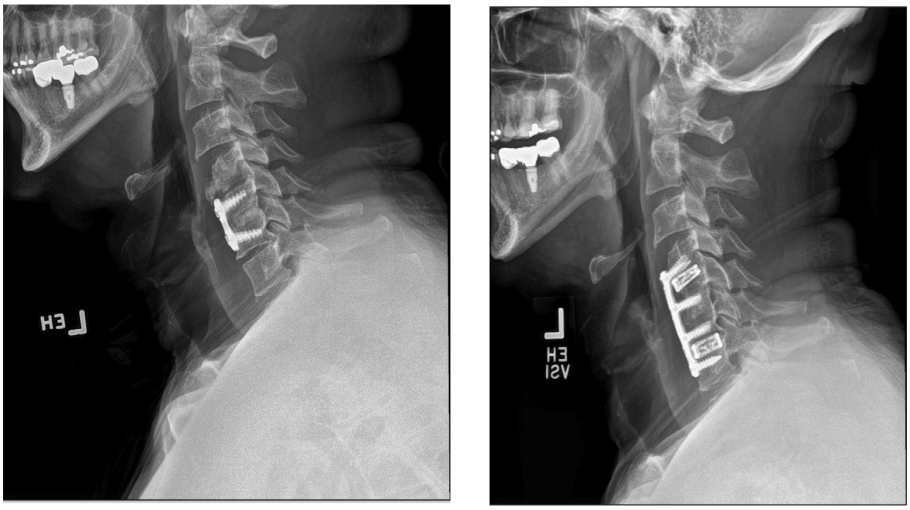

Fig. 2 – Development of Adjacent Segment Degeneration Following ACDF C5-C6. 66-year-old male with prior history of C5-C6 ACDF who developed adjacent segment degeneration at one year. He required a revision ACDF from C4-C7.

most common of which are cervical spondylosis and ossification of the posterior longitudinal ligament (OPLL). A number of clinical findings, including weakness, hyperreflexia, and upper motor neuron signs, may also be appreciated on physical exam.

Unlike radiculopathy, cervical myelopathy typically requires surgical intervention. The goal of surgery is not to reverse the symptoms, but rather to halt the progression of disability caused by neural compression. Operative techniques used to address myelopathy include anterior techniques including ACDF as well as posterior approaches such as laminoplasty and laminectomy with fusion. Classically, ACDF has been viewed as the preferred method for one- or two-level myelopathy, whereas posterior approaches have been more frequently utilized for multilevel pathology.[12]

Recently, practice guidelines for multilevel pathology have blurred, as ACDF has demonstrated utility in cases of three-, four-, and even five-level myelopathy.[13,14] Indeed, Zhang et al. reported similar clinical efficacy between ACDF and laminoplasty for multilevel cervical myelopathy without spinal stenosis.[15] Hou and colleagues also corroborated these results and further suggested that anterior approaches may actually be preferable for myelopathic patients with poor cervical curvature or severe central stenosis.[16]

2.3. *Degenerative disk disease*

ACDF has shown positive short- and long-term outcomes for cervical degenerative disk disease, with improvement in sagittal alignment and symptoms that can be sustained up to 10 years postoperatively.[17,18] In recent years, cervical disk arthroplasty (CDA) has made ACDF more controversial for patients with cervical spondylosis requiring substantial decompression in the absence of neural impingement. Findlay and colleagues aggregated the results of 14 randomized controlled trials comparing ACDF and CDA, reporting that CDA is at least as effective as ACDF, with a lower risk of adjacent segment disease (Fig. 2).[19] Still, there is significant uncertainty with regard to the durability of the total disk prosthesis, and further longitudinal investigation is needed to better elucidate the properties and failure rates of CDA. If the implant does prove to be viable long-term, CDA may fully supplant ACDF for the indication of symptomatic degenerative disk disease.

2.4. *Other indications*

ACDF is useful for many causes of instability, which may include trauma, tumor, or infection and has also shown efficacy for multiple fracture patterns, including certain vertebral body and facet fractures. Furthermore, significant ligamentous injuries, such as those that occur with facet subluxations and dislocations, are often amenable to fusion. In general, when significant instability exists, ACDF is favored over CDA.

Similarly, malignancy and infection are also common indications for fusion as opposed to disk replacement. Both of these pathologies often result in body erosion and neurologic impairment from mass effect. Because instability is common to both, fusion is predominately considered the gold standard as disk replacement has a high risk of subsidence or displacement and is therefore contraindicated in most scenarios.

3. Surgical technique

Although the technical details of ACDF can vary widely, the general approach remains consistent among spine surgeons. The following section will outline the anterior approach to the cervical spine, which may be utilized to expose vertebral bodies from C2 to T1.

3.1. *Positioning & preparation*

The patient is positioned supine on the operating table with the arms adducted. A gel pad or sandbag is placed in the nape of the neck to support the head. The typical head position is neutral, though slight head-up or head-down tilt may be used situationally to visualize a specific disk space. The neck is then prepped and draped in a sterile fashion. Prior to beginning the procedure, fluoroscopy is used to confirm the level of approach. Anatomic landmarks may also be helpful to identify the correct level (e.g. hyoid bone – C3, thyroid cartilage – C4, cricoid cartilage – C6). The decision of whether to approach from the left or the right side is a matter of surgeon preference.

3.2. *Approach*

A transverse skin crease incision is made at the desired level, extending from the midline to the anterior border of the sternocleidomastoid (SCM). The fascia over the platysma is then identified and incised. Finger dissection of the platysma is carried out in line with the muscle fibers to reveal the anterior border of the SCM, which should be retracted laterally. The strap muscles (sternothyroid, sternohyoid) are then encountered and retracted medially.

The dissection of the anterior triangle continues with identification of the carotid sheath. The carotid pulse may be palpated and the sheath is mobilized laterally with care. A dissection plane is developed between the carotid sheath laterally and the larynx and esophagus medially. Importantly, these visceral structures should be retracted as a single unit in order to avoid excessive traction on the recurrent laryngeal nerve (RLN). On the left, the RLN branches from the vagus nerve and hooks around the aortic arch before ascending in the tracheoesophageal groove. On the right, the RLN branches from the vagus and hooks around the right subclavian artery, traversing medially to ascend directly along the border of the trachea.

The pretracheal fascia is then encountered and incised. Depending upon the level of approach, the superior and inferior thyroid arteries may require ligation at this stage. An avascular plane is dissected down to the longus colli muscles, which are split using electrocautery. The longus colli muscles are then dissected subperiostially, with care taken to avoid the sympathetic chain. Self-retaining retractors are inserted to reflect the longus colli laterally.

3.3. *Decompression & fusion*

Fluoroscopy is used again to confirm the operative level. Caspar pins are typically used to distract the operative level. The annulus is incised and the anterior longitudinal ligament (ALL) is removed. A diskectomy is then performed under microscopy using a scalpel with microcurettes and microrongeurs. Anterior osteophytes may be removed from the endplates using a Kerrison rongeur or high-speed burr. The discectomy is carried out laterally to the uncovertebral joints and posteriorly to the posterior longitudinal ligament (PLL). The PLL may then be opened and resected as necessary to facilitate direct visualization of the dura and exiting nerve roots. Bilateral foraminotomies are also performed.

Under vertebral distraction, graft material is placed to promote fusion. Interbody cages and anterior cervical plates are used to improve stability and facilitate fusion. After the fusion procedure is complete, hemostasis is achieved and the wound is irrigated copiously. A surgical drain is typically placed in the deep space. Surgical closure is performed and the patient is placed into a soft cervical collar.

4. Implants

A variety of different materials are now available for ACDF. As a result, implant selection has become a critical aspect of the surgical decision-making process, both preoperatively and intraoperatively. In the following section, we will provide a comprehensive review of the various implants that can be used in ACDF.

4.1. *Anterior plate*

The anterior cervical plate was originally popularized in the 1980s as a stabilization tool for cervical spine trauma. More recently, however, the indications for plating have expanded to include degenerative pathology such as cervical myelopathy and cervical disk herniation.[19,20] Compared to ACDF without plate fixation, anterior plating has demonstrated superior surgical outcomes in terms of fusion, subsidence, and postoperative pain scores.[21] Supplementation with plate fixation has also been associated with reduced time-to-fusion as well as improved cervical height and sagittal alignment.[22,23] Anterior plating has demonstrated particular success for multilevel cervical fusions, with higher arthrodesis rates reported in this population compared to ACDF without plating.[24,25]

A wide range of anterior fixation systems have been developed over the years, with newer plates and screws offering several advantages compared to earlier designs. Some studies have suggested that dynamic plates are associated with faster arthrodesis and a decreased risk of hardware failure compared to conventional static plates.[26,27] However, a recent systematic review found no difference in total complication rate or fusion rate between static and dynamic constructs.[28] Variable-angle screws have also been developed and show similar clinical outcomes compared to the classic fixed-angle design.[29] However, anterior plating is not without its potential disadvantages, as some studies have suggested an increased risk of adjacent segment degeneration due to the more rigid cervical fixation.[30]

Recently, biodegradable plates have been designed to prevent the development of adjacent level pathology following ACDF with promising biomechanical and clinical results in early studies.[31,32] However, further investigation is needed in order to determine their long-term efficacy.

4.2. *Interbody cages & spacers*

Three main types of cages exist for ACDF – carbon fiber, titanium, and polyetheretherketone (PEEK). While carbon fiber and titanium cages have demonstrated positive results, PEEK cages remain the most commonly used because of its radiolucency and higher modulus of elasticity, which protect against stress shielding.[33–36]

An interbody cage may be used in stand-alone fashion or in conjunction with anterior plating. In a recent systematic review and meta-analysis, locking stand-alone cages demonstrated similar clinical and radiological outcomes compared to anterior plating for single-level ACDF.[37] For two-level fusions, locking stand-alone cages have shown inferior radiologic outcomes due to loss of lordosis compared to anterior plating, though clinical outcomes are comparable between the two techniques.[38,39] At four levels, ACDF with a stand-alone cage was associated with significant loss of lordosis and a higher rate of nonunion when compared to posterior laminectomy and fusion.[40] Furthermore, individual patient factors should play a substantial role in the decision of whether to use a cage, as better outcomes have been observed in patients with evidence of posterior column instability as well as those with healthier bone preoperatively.[41]

As mentioned, cages with integrated screw fixation may be used not only in place of anterior plating, but also in an adjunct capacity. For single-level cases, cage-and-plate fixation has not demonstrated any additional benefit compared to a stand-alone design.[42] For multilevel pathology, however, a recent meta-analysis suggests that cage-and-plate constructs are associated with better preservation of cervical lordosis compared to a stand-alone cage.[43] Importantly, the cage-and-plate group in this study also had greater surgical pain and a higher overall complication rate compared to their stand-alone counterparts. Other comparative studies have suggested a lower risk of subsidence with cage-and-plate constructs but a higher risk of dysphagia and adjacent segment degeneration.[44–46]

In recent years, stand-alone anchored spacers (SAAS) have been designed to integrate the functionality of an anterior cervical plate and cervical interbody spacer into a single device. While long-term outcomes data are not yet available, these implants (e.g. Zero-P, Perfect-C, Fidji, ROI-C) have shown promising results for one- and two-level ACDF.[47–57] In a recent meta-analysis, patients who underwent ACDF with SAAS had less operative blood loss, an improved C2-C7 Cobb angle, lower incidence of postoperative dysphagia, and adjacent segment degeneration compared to their traditional cage-and-plate method counterparts.[58] However, there were no significant differences in operative time, Japanese Orthopaedic Association score, Neck Disability Index score, and bony fusion rate between the two techniques. While the application of SAAS for three-level, four-level, and skip-level ACDF is less established, early studies do support their utility in these clinical scenarios.[59–62] Further investigation in the form of randomized controlled trials with long-term follow-up is needed in order to identify the optimal application of SAAS for ACDF.

4.3. *Bone graft*

Autologous bone graft remains the gold standard for spinal arthrodesis with arthrodesis rates above 75% documented in the literature.[63] Autologous graft is also advantageous because it has the capacity to promote osteogenesis, osteoinduction, and osteoconduction and can be obtained from a remote site (e.g. iliac crest) or from the surgical site in the form of local osteophytes, a vertebral endplate, or adjacent vertebral body.[21]

Traditional allograft is also a commonly-used substrate for spinal fusion, available either as a fresh-frozen or freeze-dried preparation, though the literature does not support superiority of one preparation over the other. Some studies suggest increased rates of pseudarthrosis in freeze-dried allograft, no such research exists for the cervical spine. One disadvantage of allograft is its potential for disease transmission – minimized in recent years with donor screening as well as the use of antibiotics during the preparation phase of the graft. Gamma irradiation is also used, but remains controversial as it may contribute to reduced graft strength.[64]

Few high-quality studies have directly compared allograft to autograft for ACDF. In a small randomized controlled trial, no significant difference was found between the two graft types with regard to clinical or radiologic outcomes.[65] Non-randomized studies have suggested that allograft may be a superior option for uninstrumented cases, particularly in smokers or in patients undergoing a multilevel fusion.[66–68] However, comparative studies for ACDF with instrumentation have not shown any difference between the two graft types in terms of fusion rate or clinical outcome.[69,70]

Aside from conventional autograft and allograft options, ceramics have recently gained traction for spinal arthrodesis. Ceramics provide a biocompatible osteoconductive scaffold for bone regeneration that eliminates many of the key shortcomings of allograft, namely donor-site morbidity and risk of infection.[71] Calcium phosphate ceramics (e.g. hydroxyapatite, beta-tricalcium phosphate, biphasic calcium phosphate) are increasing in popularity for ACDF, though limited evidence is currently available regarding their efficacy. In a level II study, biphasic calcium with a PEEK cage performed well compared to autograft in terms of clinical outcomes at 6 months postoperatively.[72] Further long-term clinical studies are needed before ceramics can be adopted as a mainstay substrate for cervical spinal fusion.

Bone morphogenetic protein (BMP) is also commonly used as an osteoinductive graft for spinal fusion procedures, including ACDF. Although the initial studies of recombinant human BMP-2 (rhBMP-2) reported perfect or near-perfect arthrodesis rates, its utility for ACDF remains controversial as several studies have reported catastrophic postoperative complications with rhBMP-2, most notably the onset of clinically significant neck swelling that can lead to prolonged airway compromise, dysphagia, and hoarseness.[73–77] As a result of these concerns, the United States Food & Drug Administration (FDA) issued a warning against use of rhBMP-2 for ACDF in 2008.

5. Outcomes

ACDF is well-established as a safe and effective treatment for degenerative pathologies of the cervical spine.[78] In a recent prospective study reporting long-term (>10 year) outcomes of ACDF, patients showed significant lasting improvement in outcome scores, neurological deficits, and use of narcotic pain medication.[17] These results remained consistent regardless of age, gender, number of levels, or preoperative indication (e.g. disk herniation, stenosis, degenerative disk disease). Importantly, the outcomes of ACDF are much less predictable for cervical myelopathy; although 50–80% of myelopathic patients who undergo this procedure report symptomatic improvement, 5–30% of individuals experience progression of their symptoms postoperatively.[79,80] Notably, however, ACDF is thought to have the lowest overall complication rate (15.6%) when compared to laminoplasty (22.4%), posterior fusion (29.2%), and combined anterior-posterior fusion (41.1%) in this patient population.[81]

ACDF has also performed well when directly compared to other anterior cervical spine procedures. ACDF was deemed to be superior to anterior cervical corpectomy and fusion (ACCF) in two separate meta-analyses.[82,83] In these studies, ACDF was associated with significantly lower blood loss, shorter operative time, greater cervical lordosis, higher segmental height restoration, higher fusion rate, less graft subsidence, and fewer total complications compared to ACCF. A separate meta-analysis reported that myelopathic patients who underwent ACDF had less blood loss and fewer total complications than those who underwent anterior corpectomy with discectomy. No significant differences were observed with regard to any of the other measured variables – operative time, fusion rate, C2-C7 Cobb angle, dysphagia, hoarseness, C5 palsy, infection, cerebrospinal fluid leak, epidural hematoma, and graft subsidence.[84]

With the growing popularity of CDA, several recent systematic reviews and meta-analyses have compared CDA and ACDF outcomes.[19,85–89] Together, these studies suggest that CDA is equally efficacious with regard to most metrics and is actually superior to ACDF in some short- and mid-term outcome measures for one-level and two-level cervical pathology. In particular, the preserved cervical motion and decreased risk of adjacent segment degeneration with CDA makes arthroplasty an attractive alternative where both ACDF and CDA are indicated.[90] Concerns, however, about the long-term durability of the prosthesis as well as the potential need for a complex revision arthroplasty do persist, and continue to be a primary barrier to the widespread adoption of CDA in favor of ACDF. Furthermore, the utility of CDA for three- and four-level pathology remains uncertain, without high-quality evidence exploring its efficacy.

As is the case for CDA, the appropriate number of operative levels is an important point of discussion for ACDF. One- and two-level ACDF procedures have the strongest record of success, as these operations have been associated with a significant reduction in neck and arm pain postoperatively.[91] One- and two-level ACDF have also been shown to produce a significant improvement in Visual Analog Scale (neck and arm) and Neck Disability Index scores from preoperative to postoperative time points.[92] Three- and four-level ACDFs are more controversial. Although the patient-reported outcomes appear to be comparable to single-level ACDF, some studies have reported an elevated risk of complications (e.g. pseudarthrosis) with multilevel procedures with revision rates as high as 35% at two years postoperatively.[93–95]

Although revision cervical fusion is substantially less common than primary surgery, ACDF continues to be commonly performed in the revision setting. The current literature suggests that the patient-reported outcomes are positive and tend to be similar for revision ACDF compared to primary procedures.[96–98] However, some studies have reported that revision ACDF is associated with greater cost, increased length of stay, and a higher risk of serious adverse events including wound infection, dysphagia, hematoma, thromboembolic phenomena, reoperation, and 30-day readmission.[99,100] Patients requiring a revision ACDF procedure must therefore be counseled with caution in order to appropriately manage their expectations for achieving a favorable postoperative outcome.

Over the past several years, ACDF procedures are increasingly performed in the ambulatory setting as it is advantageous particularly from a cost reduction standpoint with overall cost significantly lower than inpatient ACDF surgery.[101] Outpatient ACDF for one- or two-level pathology is generally regarded to be safe, with most studies reporting a readmission rate and an overall complication rate that is equivalent or lower than inpatient ACDF.[102–106] However, a recent nationwide database study suggests that outpatient ACDF is associated with a greater risk of perioperative complications and postoperative renal failure, as well as a higher rate of revision anterior or posterior fusion within 1 year postoperatively.[107] Thus, candidates for ACDF in the ambulatory setting must be selected carefully in order to mitigate these risks.

6. Complications

Although ACDF is a safe and efficacious procedure overall, the risk of complication is not insignificant.[108] Several factors may contribute to an increased risk of complications with anterior cervical surgery, including older age, higher comorbidity burden (ASA class > 2), COPD, bleeding disorder, diabetes mellitus, smoking, and longer operative duration.[109–111] In the section that follows, we will highlight several of the complications that are most frequently encountered with ACDF.

6.1. *Adjacent segment degeneration*

Degenerative changes occur frequently at the adjacent intervertebral discs following ACDF. A systematic review reported the average incidence of radiographic adjacent segment degeneration to be 47.3%, while the average incidence of symptomatic adjacent segment disease was 12.0%.[112] Indeed, adjacent level changes are asymptomatic in a vast number of affected ACDF patients and typically do not require intervention unless the patient begins to manifest symptoms. For those that do require reoperation, the primary surgical options include revision ACDF and posterior fusion. Patients who undergo revision ACDF are reported to have a higher recurrence rate of adjacent segment degeneration compared to those revised through a posterior approach.[113] However, there is a higher risk of re-hospitalization and postoperative complication observed with a posterior approach during revision. While there is no known strategy for avoiding adjacent segment degeneration after ACDF, a meta-analysis of

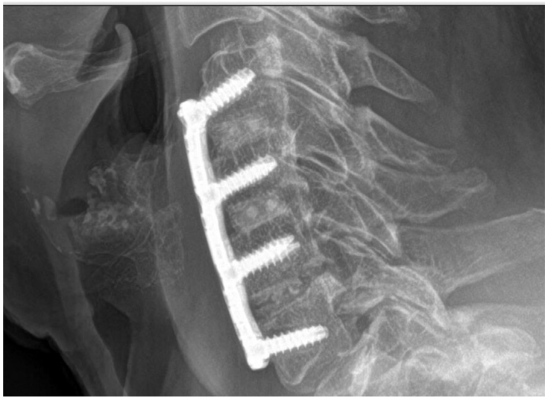

Fig. 3 – ACDF C4-C7 with Pseudarthrosis at C6-C7. 75-year-old female with history of ACDF C4-C7. There is fusion from C4-C6, but pseudarthrosis is evident at C6-C7 with lucency of the allograft cage and haloing of the C7 screws.

randomized controlled trials demonstrated a lower rate of adjacent segment degeneration and adjacent level reoperation with CDA compared to ACDF.[114] Thus, CDA may be considered as an alternative to ACDF to decrease the risk of adjacent segment degeneration in the properly selected patient.

6.2. *Pseudarthrosis*

Failure to achieve adequate fusion is a common complication of ACDF. A meta-analysis of 17 high quality studies (12 randomized controlled trials, 5 prospective cohort studies) reported an overall pseudarthrosis rate of 2.6%, with allograft demonstrating a higher rate of pseudarthrosis compared to autograft.[115] Multiple studies have also reported that multilevel ACDFs have a higher rate of pseudarthrosis than single-level procedures (Fig. 3).[116,117] Affected patients typically present with improvement in the initial postoperative period, followed by a recurrence or exacerbation of their neck pain several months after surgery. A number of imaging modalities are available to assess bony fusion postoperatively, including static plain radiographs, dynamic flexion-extension radiographs, and thin-slice computed tomography (Fig. 4). Symptomatic pseudarthrosis following ACDF can be managed surgically through an anterior or posterior approach and posterior approaches are associated with a higher overall fusion rate.[118] Still, preventative measures at the index procedure (e.g. optimal graft selection, smoking cessation) continue to be the gold standard of management for this complication in the context of ACDF.

6.3. *Durotomy*

The rate of dural tear during ACDF is reported to be 1% or lower.[117] If a CSF leak develops, it can lead to sequelae including orthostatic headaches, dysphagia, hoarseness, and hydrocephalus, which may require CSF diversion via shunting.[119] In a literature review pertaining to CSF leaks after ACDF, Syre et al. constructed a stepwise algorithm for their management.[120,121]

Upon recognizing a dural tear, the surgeon should attempt to repair it, typically with a combination of fibrin glue and synthetic dural replacement. If successful, in-hospital monitoring should be conducted with head-of-bed greater than 30 ° for the first 24 h postoperatively, after which the patient may be discharged with close follow-up in the outpatient setting. If the repair is unsatisfactory or if the patient continues to demonstrate signs of CSF leakage, lumbar drainage should be performed at 10–15 mL/hr for 3 days postoperatively. If no further leakage is suspected at that point, head-of-bed trials may be initiated in preparation for discharge. However, if CSF leakage does persist after lumbar drainage, reoperation

Fig. 4 – CT Imaging of Pseudarthrosis Following ACDF C4-C7. CT scan indicating three-level pseudarthrosis status-post C4-C7 ACDF, indicated by lack of bony bridging and lucency of bone around screws.

should be attempted for a primary repair. Should the leak still continue despite reoperation, a head CT should be performed to assess for hydrocephalus; if present, this would be an indication for ventriculoperitoneal shunting.

6.4. *Dysphagia*

Postoperative dysphagia is commonly encountered after ACDF, with incidence estimates as high as 83% in the literature.[122] Although the etiology of dysphagia in the context of ACDF has not been firmly established, several factors including female gender, two-level surgery, operative time, surgery at the C4-5 level, and anterior cervical plating have been associated with a higher incidence of postoperative dysphagia.[120,123] By contrast, a large database study reported a significantly lower incidence of dysphagia in patients who received local steroids intraoperatively, suggesting that steroid administration may be a viable strategy for decreasing the risk of this complication.[124] When dysphagia occurs postoperatively, it is typically transient and self-limiting in the majority of cases. However, dysphagia does occasionally persist following ACDF, significantly impacting the affected patient's global state of health and quality of life. The surgeon must be attentive to this potential for long-term disability when indicating patients for surgery and counseling them regarding risks and benefits preoperatively.

6.5. *Hoarseness*

Recurrent largyngeal nerve (RLN) injury is a relatively frequent complication of ACDF, with a frequency of 1−11% reported in the literature.[125] RLN palsy can lead to hoarseness and vocal cord paralysis, with the vast majority of cases resolving in 6−12 weeks and nearly all patients achieving full recovery within 1 year postoperatively.[126] Anatomically, the right RLN branches from the vagus nerve and loops under the subclavian artery, while the left RLN branches from the vagus nerve within the mediastinum and loops under the aortic arch. After branching, the left RLN ascends superiorly within the tracheoesophageal groove, while the right RLN does not typically enter the tracheoesophageal groove until it approaches the level of the cricothyroid joint. A high degree of knowledge regarding this anterior cervical anatomy is critical to minimize the risk of RLN injury during ACDF.

6.6. *Hematoma*

Postoperative hematoma is a rare but potentially devastating complication of ACDF, as it can lead to airway obstruction and require urgent reoperation in roughly 1 of every 250 ACDF cases.[127] Risks factors for the development of a postoperative hematoma causing airway compromise include multiple levels of operation, greater blood loss, longer operative time, elevated INR preoperatively, lower BMI, higher comorbidity burden (ASA $\geq$ 3), preoperative anemia, and male gender.[128] In a randomized prospective study, local administration of steroids into the retropharyngeal space was shown to significantly reduce prevertebral soft tissue swelling, suggesting that this may be an effective adjunct to protect against airway obstruction following ACDF.[129,130] However, the mainstays of prevention continue to be diligent hemostasis and avoidance of prolonged retraction time. When an ACDF patient presents with airway obstruction postoperatively, urgent surgical intervention is essential to evacuate the hematoma in order to prevent a catastrophic outcome.

6.7. *Esophageal injury*

Esophageal perforation is another relatively uncommon complication of ACDF, but carries a mortality rate of nearly 4% when it does occur.[131] The esophagus can be injured intraoperatively or postoperatively, typically due to erosion by the anterior cervical plate or frank hardware failure leading to migration of the implants. Patients with an esophageal injury typically present with some combination of dysphagia, fever, neck swelling, and wound leakage. If this complication is suspected, imaging should be performed promptly including modified contrast dye swallow studies, computed tomography, or upper endoscopy.[132] An esophageal surgeon should be consulted to repair the perforation, which typically requires a modified muscle flap technique coupled with a primary suture closure.

7. Conclusions & future directives

ACDF has long been the gold standard for management of cervical stenosis. In patients with marked degeneration, concomitant facet pain and radiculopathy, kyphosis, or instability, fusion remains the treatment of choice. However, nonfusion alternatives such as foraminotomy and disk replacement have supplanted fusions in many scenarios.

Regardless of the promise of motion preservation, ACDF remains a necessary procedure in many patients. To improve clinical outcomes, research is being aimed at improving fusion. Pseudarthrosis rates for multilevel ACDF have been shown to be as high as 40% for 3-level procedures. 3D printing is an area of excitement with the potential to improve fusion through bony ingrowth as well as ongrowth. In addition, 3D printing has potential for the development of more patient specific implants which has potential implications in sagittal balance restoration. Biologics are rapidly advancing, especially with the advent of regenerative medicine techniques. The literature is currently sparse on growth factor or stem cell supplementation but resources are being dedicated to their development.

Finally, and very importantly, the future of ACDF is tied to the future of disk replacement. As future generations of CDA are developed, the selection window of motion preservation grows. Ultimately, the market for fusions will likely contract as CDA becomes even more commonplace. However, the future of ACDF remains exciting as technological advances allow for better fusions, better spinal realignment, and better patient outcomes.

Disclosure

The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article.

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