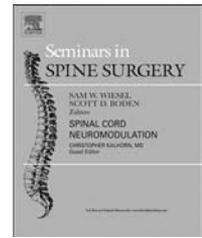


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# Considerations for revision cervical spine surgery

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## ABSTRACT

Elective spine surgery becomes more popular every year. Unfortunately, a significant number of these patients report persistent or recurrent symptoms, and/or develop late sequelae. Revision spinal surgery can be a complex and risky endeavor, and this patient population represents a challenge to spine care teams. Indications for cervical revision surgery can include pseudarthrosis, adjacent segment disease, incomplete decompression, failure of instrumentation, and progressive deformity. Determining whether or not a patient is a candidate for revision surgery is crucial. This chapter reviews the patient evaluation and treatment strategies for conditions that require cervical spine surgery.

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## 1. Introduction

Procedures performed in the cervical spine have been known to enjoy relative success compared with those performed in the lumbar spine. However, cervical spine surgery sometimes fail to achieve initial goals and/or develops late sequelae. Revision spinal surgery can be a complex and risky endeavor and it has been shown to have considerable impact on patient's quality of life as well as significant economic burden. Poor patient selection is one of the primary causes of failed spine surgery.<sup>1</sup> Some indications for cervical revision surgery include infection, pseudarthrosis, adjacent segment disease, failure of instrumentation, and progressive deformity.<sup>2</sup> The evaluation, diagnosis, and management of this patient population can become a challenge for the spine care provider, and determining whether or not a patient is a good candidate for revision surgery is crucial. Establishing the principal problem as primarily axial neck pain, radiculopathy, or myelopathy is fundamental in formulating a treatment strategy. The spine care team must consider the underlying

problem, the potential for complications, and clinical outcomes that can be reasonably expected.

## 2. Patient evaluation

### 2.1. History

A thorough history must be obtained to determine if a patient is a candidate for revision cervical spine surgery. In some cases, the surgeon evaluating a potential candidate for revision surgery was not involved in the initial care. Essential points that must be discussed include the nature and duration of the preoperative symptoms as well as any perioperative complications. An in-depth discussion should include the type of surgery, timing and the patient's expectations of the initial procedure. Efforts should be made to obtain any preoperative imaging and medical records that can assist in identifying the original problem leading to the index surgery. These can also help in identifying the type of implants, if any,

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that were used. Identifying any period of relief following the index procedure, and if the current symptoms are similar to the ones prior to surgery can help determine if the initial problem was successfully addressed, or whether the existing symptoms represent persistence or recurrence of the initial problem, or a new problem at an adjacent level.

Exploring the presence of constitutional symptoms can help identify problems such as infection or tumor. Red flags such as progressive weakness, constitutional symptoms, or unrelenting pain may suggest an urgent or emergent situation. The patient should be also asked for hoarseness and/or swallowing difficulty that may be attributed to the initial procedure and may affect the surgical approach for the current problem.

Along with a full medical history, medications should be reviewed to rule out narcotic abuse, as well as any mental health condition.<sup>3</sup> Additionally, social history including work status and motivation for return to work, as well as involvement in litigation should be explored.<sup>1</sup>

## 2.2. Physical examination

As with primary patients, those being evaluated for a potential cervical spine revision should undergo a thorough physical examination including inspection, palpation, range of motion testing, a full neurologic evaluation, and provocative tests specific to the cervical spine. Although the physical examination findings can be nonspecific, a systematic examination may exclude other conditions with similar presentations. Frequently, shoulder, elbow, and wrist pathology can mimic the symptoms caused by cervical spine pathology, hence these conditions must be ruled out during patient evaluation to avoid unnecessary revision cervical spine surgery. This is particularly true if the initial procedure did not provide relief of the preoperative symptoms, suggesting that the cause of the original symptoms may originate from the upper extremity rather than the cervical spine.<sup>2</sup> The location and appearance of the surgical incision should be noted with particular attention to any erythema, drainage, and/or tenderness that could suggest the presence of an infection. The side of the incision is particularly important when performing anterior cervical surgery because most times it dictates the side of the approach during revision surgery. Although a left-sided approach is preferentially used for most primary anterior cervical cases, the decision to attempt a revision surgery exposure through the same incision must be considered carefully. Obliteration of the tissue planes leaves the trachea, esophagus, and vascular structures vulnerable. This concern may outweigh the risk of injury to the recurrent laryngeal nerve through a contralateral right-sided approach.<sup>1</sup>

Nonorganic physical findings should also be documented.<sup>4</sup>

## 2.3. Imaging

Modalities that are most commonly used to evaluate potential cervical spine revision patients include plain radiographs, computed tomography<sup>5–7</sup> and magnetic resonance imaging (MRI). Upright plain radiographs should be obtained to evaluate the integrity and position of any existing instrumentation and/or bone grafts. Implant failure in the form of screw pullout and screw and/or rod breakage should be noted. Overall alignment

should be measured and the levels adjacent to a previous fusion should be assessed for degeneration.<sup>1</sup> Flexion-extension lateral views should be obtained to evaluate the status of the existing fusion. Radiographic features that suggest a pseudarthrosis include the lack of bridging trabecular bone between graft and adjacent vertebral body and segmental motion on flexion-extension films.<sup>8–10</sup> Subtle loosening of existing screws in the form of haloing can also indicate pseudarthrosis. In anterior cervical discectomy and fusion (ACDF), a change of 2-mm or more in the distance measured between the spinous processes on flexion and extension radiographs suggests that the fusion is not fully healed.<sup>11</sup> Flexion-extension radiographs may also show movement of loose screws and angular motion that also suggests pseudarthrosis and/or instability. Instrumented posterior cervical fusions that develop pseudarthrosis may show no motion on flexion-extension radiographs but rather screw fracture or loosening.<sup>2</sup>

CT scan is frequently used as the imaging modality of choice for the evaluation of failed cervical spine surgeries. Coronal and sagittal reconstructions are particularly helpful in assessing the fusion and the position and status of the instrumentation. Loosening of the instrumentation such as haloing and/or screw pull-out can be appreciated. Position and fusion of the lateral masses, facet joints and anterior cervical fusion be assessed with great detail using CT scan. Bridging trabecular bone in these areas indicates a solid fusion. Lucency at the graft-vertebral body junction, absence of bridging trabecula or fracture and graft resorption suggest pseudarthrosis.<sup>2</sup> Residual spondylotic bony compression or ossification of the posterior longitudinal ligament (PLL) can be readily assessed. Bone stock and status should be evaluated, especially if revision instrumentation is planned.<sup>1</sup> Bony destruction can develop because of loose instrumentation, infection, and/or tumor and can alter the surgical plan, leading to proximal and/or distal extension of the construct into areas of preserved bone.

MRI provides great detail of the soft tissue structures of the cervical spine. It can be used to aid in the diagnosis of same segment disease as it can demonstrate missed soft disc herniations beneath the PLL, as well as to evaluate adjacent levels for disc herniation or internal disruption. In patients who have had cervical surgery, MRI with and without gadolinium can aid to differentiate recurrent disease and/or fluid collections from scar tissue. The latter is vascular and enhances with high signal intensity in T1-weighter image after the administration of gadolinium. In patients who cannot have an MRI, CT myelography is helpful when assessing the neurologic structures for evidence of compression.<sup>1,2</sup>

Findings on these imaging modalities should be correlated with preoperative imaging and with the patient's clinical presentation before any decision to proceed with revision surgery.

## 2.4. Additional testing

Reports of shoulder pain with overhead activities or signs of impingement should be evaluated with imaging of the shoulder.<sup>12</sup> Numbness in the hands, or positive findings on provocative tests of the carpal or cubital tunnel suggest peripheral nerve compression which may be further assessed by electromyography/nerve conduction studies.<sup>13</sup>

If there is concern for infection, a complete white blood cell count with differential, an erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) levels should be obtained. ESR and CRP are both nonspecific inflammatory markers. Elevation of at least 1 of these markers should raise suspicion of infection. The normal serum concentration of CRP is 10 mg/L.<sup>14</sup> Elevated levels of CRP from 40 mg/L to more than 200 mg/L may suggest postoperative infection. The normal ESR level is considered to be less than 15 to 20 mm/h.<sup>14,15</sup> Both the CRP level and ESR are elevated after uncomplicated surgery and unless an infection develops, the CRP level should normalize within 1 to 2 weeks and the ESR within about 6 weeks. Also, it is important to understand that in the setting of postoperative spinal infection, the CRP level is critical in following response to treatment as the ESR can remain persistently elevated, despite a normalized CRP level and clinical evidence of a successfully treated infection.<sup>16</sup>

It may be necessary to refer the patient to an otolaryngologist for vocal cord evaluation to determine if the recurrent laryngeal nerve was injured during the initial procedure, which has been reported in as high as 3.5% primary and 9.5% revision anterior cervical spine surgery cases.<sup>17</sup> If there is vocal cord paralysis on the side the previous anterior cervical surgery was approached, the anterior revision procedure should be performed from the same side to avoid injury to the normal vocal cord. If the vocal cords are normal, it is preferred that the anterior revision surgery be performed from the contralateral side to avoid scar tissue that can complicate the approach. Furthermore, attention must be given to the esophagus, since esophageal injury can occur either as a result of erosion of anterior instrumentation through the esophageal wall or from intraoperative injury. It may be necessary for patients to undergo preoperative evaluation of the esophagus by an otolaryngologist if there is persistent dysphagia, prominent anterior instrumentation, or anterior instrumentation that is backing out. If there is any suggestion of a compromised esophageal wall, the otolaryngologist should be available for intraoperative assistance during the revision procedure.<sup>2</sup>

### 3. Common conditions leading to cervical spine revision surgery

#### 3.1. Adjacent segment disease

Adjacent-level degeneration is widely reported after both anterior and posterior fusions, single and multi-level. Biomechanical studies suggest that this may happen due to increased adjacent-segment motion at the levels above and below a cervical fusion, and this effect is increased with multilevel fusions.<sup>18</sup> It is important to differentiate between adjacent-level degeneration, which is radiological evidence of degeneration at the levels adjacent to a previous fusion, from adjacent segment disease (ASD), which is the development of clinically significant signs and symptoms that correlate with the imaging findings. Cervical adjacent segment disease is noted in roughly 3% of patients per year; however, incidence increase to approximately 25% of patients within the first 10 years after the index fusion procedure is expected.<sup>19</sup>

Multiple factors probably contributes to the development of ASD, including the increased biomechanical stress placed on the disks adjacent to a fusion and the natural history of cervical spondylosis in patients known to have such pathology.<sup>20</sup>

Presenting signs and symptoms of ASD may include myelopathic and/or radiculopathy-related complaints.<sup>2</sup> In the absence of a progressive neurologic condition, nonoperative measures are initially tried which include physical therapy, nonsteroidal antiinflammatories, and injection therapy.<sup>21,22</sup> Those who fail nonoperative management should be considered for surgical intervention. Patients with radiculopathy due to a lateral disc herniation may be considered for a laminoforaminotomy provided that there is no substantial axial pain or instability. However, the role of this procedure for ASD is unknown, since its success has been demonstrated when used as an index procedure in patients with this pathology.<sup>23</sup> Theoretical concerns exist that abnormal stress transfer may lead to recurrent problems if used in a previously fused spine. For those patients with ASD and substantial axial pain, bilateral radiculopathy, or myelopathy, anterior surgery should be considered with the goal of performing a plated interbody fusion of the involved adjacent-level. If the previous fusion used an anterior plate, removal may be required to allow proper position of the plate for the adjacent level. The specific design of the existing plate should be identified preoperatively so that appropriate extraction instruments can be made available.<sup>1</sup>

Newer devices such as threaded cages, staples, or cage-staple hybrids have been introduced as alternatives to plate removal and re-plating. Recent studies have attempted to compare their performance versus traditional methods, but literature to document their suitability for revision situations is currently lacking. Cage dislocation and subsidence have been reported as potential complications of these devices.<sup>1</sup> Studies comparing the efficacy of a two-level ACDF with cage alone and with cage and plate constructs found similar clinical outcomes between the two groups. Solid fusion was achieved in 96% of patients in each group, with shorter time to fusion in the cage and plate construct group. Subsidence occurred in 10 of 28 (35%) patients in the cage alone group versus 3 of 26 patients (11%) in cage and plate group. Overall, although cage and plate constructs result in shorter time to fusion and lower subsidence rate, both resulted in similar clinical outcomes.<sup>24,25</sup>

#### 3.2. Same segment disease/incomplete decompression

Same segment disease usually suggests inadequate decompression at the levels addressed in the index procedure. However, failure to improve after decompression may be due to advanced and irreversible neurologic changes, missed confounding diagnoses, inadequate surgical decompression, iatrogenic spinal cord/nerve root injury, postoperative instability, adjacent segment disease, and/or pseudarthrosis. In these cases, further imaging studies should be obtained to evaluate for continued compression. MRI can evaluate the status of the spinal cord and quantify myelomalacia and cord atrophy and whether reversible (low-intensity T2 changes) or irreversible (high-intensity focal T2 and low-signal T1 changes) changes are present.<sup>26</sup> In symptomatic patients, it

may reveal continued anterior thecal sac compression in up to 40% of patients.<sup>27</sup> CT myelography is excellent for evaluating adequacy of the decompression, presence of fusion or pseudarthrosis, graft and hardware location and status, presence of residual bony compression, infolding of redundant ligamentum flavum, and facet arthrosis.<sup>28</sup> CT myelography is also indicated in those patients who cannot undergo MRI.<sup>29</sup>

Revision anterior cervical surgery for inadequate decompression is more technically challenging than the index procedure including the presence of scar tissue and potential need for takedown of prior hardware and bone graft material. After identifying the offending structures, the surgical plan is decided based on multiple factors. If compression is located anteriorly, presence of 1- or 2-level disease is best approached with ACDF with excellent results. If the posterior longitudinal ligament (PLL) was preserved in the index procedure, it is recommended to resect the PLL in the revision procedure to perform a direct uncovertebral decompression and ensure that the compressive pathology is adequately removed.<sup>2</sup> The need to perform a corpectomy versus multilevel ACDF must be discussed with patients who have multilevel anterior cervical compression and kyphotic alignment. Multilevel ACDF provides increased biomechanical stability and increased lordosis but higher risk of pseudarthrosis given the presence of more fusion surfaces.<sup>30–32</sup> Multilevel anterior cervical corpectomy and fusion (ACCF) has higher fusion rates but an increased rate of graft dislodgement, and usually necessitates posterior fixation for more than 2-level corpectomies.<sup>33,34</sup> Anterior cervical compression over multiple levels that have a neutral or lordotic sagittal alignment can be approached posteriorly. Laminectomy with fusion, if preexisting instability or axial neck pain is noted, or laminoplasty with or without foraminotomies if no instability or neck pain exists preoperatively, has shown good results in more than 90% of appropriately selected patients.<sup>35,36</sup>

### 3.3. Pseudarthrosis

Pseudarthrosis has been described in both anterior and posterior cervical fusions and occurs at the most caudal level in 82% of the cases.<sup>1,2</sup> The incidence of pseudarthrosis ranges from 0% to 20% after single-level ACDF and has been reported to be as high as 40% to 50% for multilevel procedures.<sup>32,37–40</sup> The presence of a pseudarthrosis does not necessarily implies a failed procedure,<sup>41</sup> but recent studies have suggested that successful bony fusion increases the likelihood of a favorable outcome. In a retrospective study of 48 patients who developed pseudarthrosis after ACDF, 67% developed symptoms.<sup>42</sup> Symptomatic patients typically complain of axial neck pain and radiculitis, or recurrent or persistent radiculopathy similar to the patient's preoperative symptoms.<sup>2,37,38</sup> A younger age at the time of the index procedure increases the likelihood of the pseudarthrosis becoming symptomatic.<sup>1</sup>

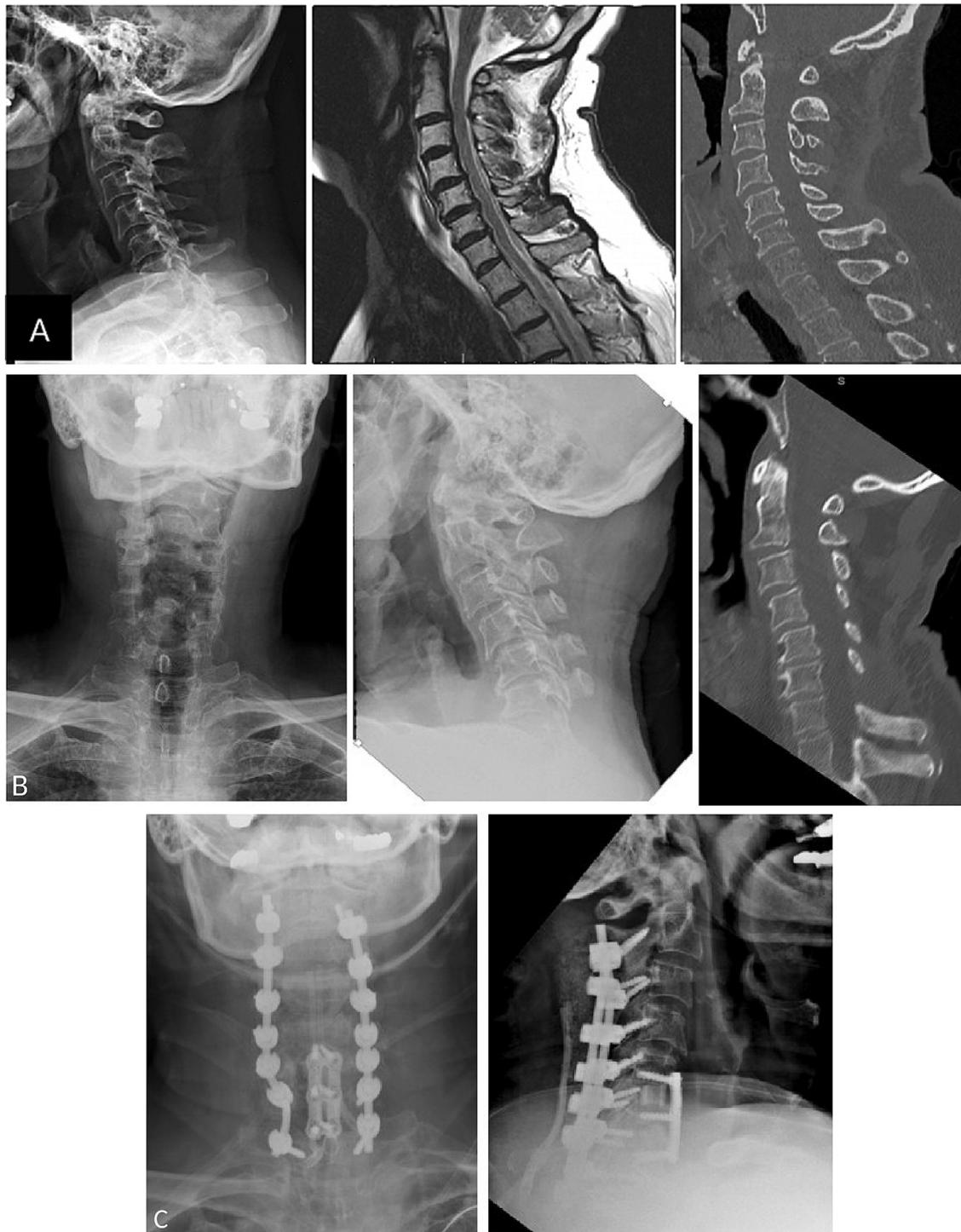
Flexion and extension radiographs may show gross instability at the level of the pseudarthrosis and fracture and/or migration of the instrumentation. CT scan is the preferred imaging modality to evaluate for pseudarthroses, status of the instrumentation, bone quality, and presence of any

compressive elements in patients with neurologic signs and symptoms. Intraoperative confirmation of motion at the segment, lack of bony bridging trabeculae, and graft resorption are indicative of a pseudarthrosis.<sup>2</sup>

Asymptomatic patients are typically managed non-operatively. Surgical intervention is recommended for patients who have neck pain, neurologic symptoms, or instability.<sup>43</sup> Modifiable underlying factors that contribute to the risk of pseudarthrosis include metabolic abnormalities, smoking, and noncompliance with postoperative instructions.<sup>6,44</sup> These should be addressed and optimized prior to pursuing revision surgery. Surgical options for anterior pseudarthroses typically involve repeat anterior fusion, posterior fusion, or circumferential fusion. The typical observation has been that an anterior pseudarthrosis eventually fuses once a posterior fusion is achieved.<sup>8</sup> Treatment of posterior pseudarthrosis can be complicated if prior posterior decompression has been performed because there is an increased risk of iatrogenic dural tears during exposure. In these cases, an anterior cervical fusion is preferred. If the dura has not been exposed, a posterior fusion, anterior fusion or circumferential fusion can be performed depending on the amount of stabilization required.<sup>2</sup>

Anterior repair typically has lower blood loss and shorter hospital stays but lower union rates than posterior procedures. Posterior fusion in patients with anterior cervical pseudarthrosis has been reported to have a 94% fusion rate, compared to 57% in patients who had revision anterior fusion.<sup>6,7</sup> Additional surgery has been reported to be required in 44% of anterior revision fusion cases due to persistent pseudarthrosis, compared with 2% for anterior cervical pseudarthrosis treated with posterior fusion. Therefore, despite higher blood loss, longer hospital stay, and higher complication rates, posterior fusion is typically preferred over anterior revision due to the higher fusion rate and much lower incidence of repeat revision surgery.<sup>45</sup> However, a recent meta-analysis found no difference in clinical outcomes in pseudarthroses treated with an anterior revision fusion versus posterior fusion.<sup>46</sup>

Cervical revision surgery due to pseudarthrosis must focus in adequate decompression of the affected neural structures, preparation of an adequate fusion bed, and achieving solid arthrodesis. Posterior fusion alone is usually the treatment of choice since it provides a high rate of fusion in the revision setting. Decompression can be achieved with a laminoforaminotomy. Stabilization is typically achieved with posterior lateral mass screw and rod constructs.<sup>2</sup> Lateral mass screws can be augmented with spinous process wiring if there is concern of suboptimal screw purchase after the laminoforaminotomy.<sup>1</sup> Main indications for anterior revision include the presence of kyphotic deformity and unstable or migrating anterior implants, since these can erode through the esophagus if left untreated. During anterior revision surgery, careful evaluation of the esophagus is necessary to detect any evidence of perforation.<sup>1,47–50</sup> Thorough decompression of the neural elements and complete resection of fibrous nonosseous material is required. Iliac crest autograft is a reliable option for grafting in the revision situation to maximize chances of a solid arthrodesis.<sup>1,2</sup>

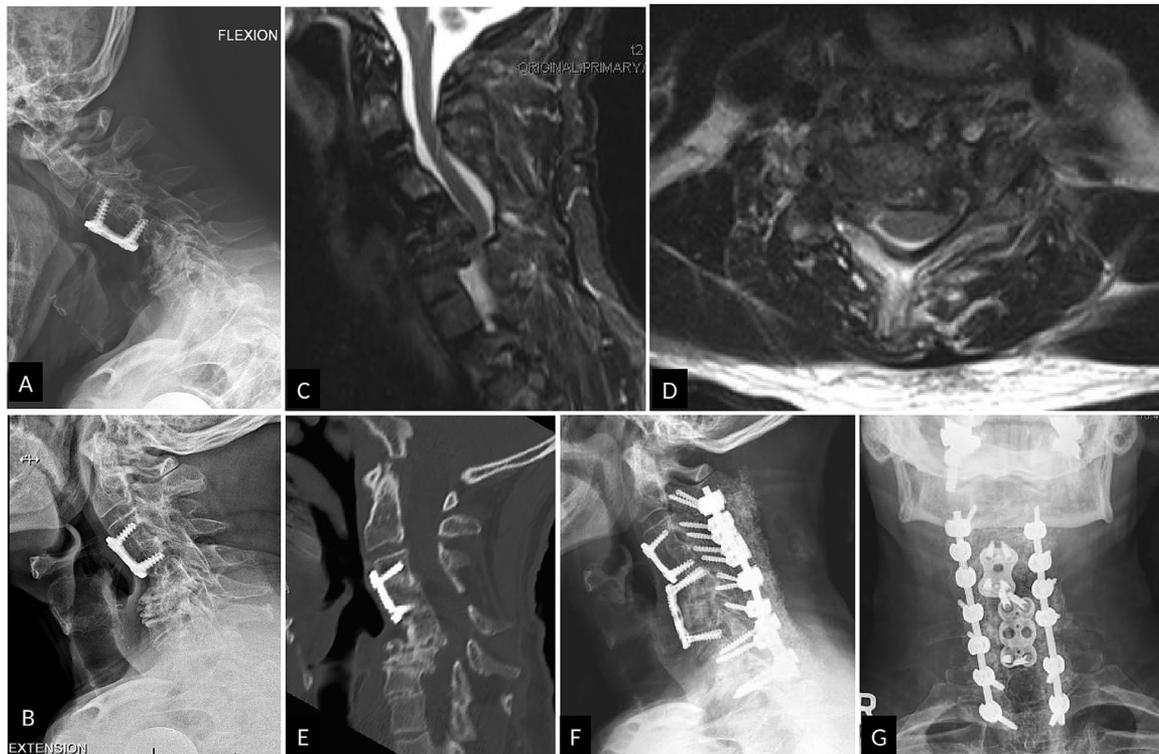


**Fig. 1** – 74-year-old male noting symptoms of cervical myelopathy with loss of fine motor function and lack of coordination. (A) XR, MRI and CT sagittal imaging illustrate cervical stenosis for which the patient underwent a C3–C6 laminoplasty. (B) Subsequently, the patient developed worsening axial neck pain and a progressive downward gaze with notable cervical kyphosis seen on radiographs and CT imaging. (C) Revision post-operative films demonstrate a C5–C7 ACDF with supplemental C2–T1 posterior instrumentation following sagittal alignment correction.

### 3.4. Progressive Kyphotic deformity

Progressive kyphotic deformity most commonly occurs after posterior decompressive procedures (Fig. 1) which involve

disruption of the posterior ligamentous complex, muscular denervation and weakness, and excessive capsulectomy and/or facetectomy, although it can also be seen in anterior cervical procedures (Fig. 2).<sup>51–53</sup> Deformity can develop in the



**Fig. 2**—66-year-old male with a remote history of a prior cervical C3-4 ACDF noting complaints of neck and radiating shoulder pain with upper extremity paresthesias. (A) Cervical spine x-rays shows a stable ACDF C3-4 with severe disc degeneration and vertebral body collapse worst at C6 but also present at C5 and C7. (C-D) Notable severe central compression on MRI most prominently at the C5-C6 level on axial and sagittal T2 imaging. (E) Collapse of C6 with adjacent level disc degeneration and resulting focal cervical kyphosis. (F-G) revision post op films demonstrate C5–C7 anterior cervical fusion with C6 corpectomy and allograft insertion with supplemental C2-T2 posterior instrumentation.

coronal and sagittal planes, although the dominant deformity is typically kyphosis as the center of gravity shifts anteriorly due to the weight of the head, muscular weakness, and ligamentous and articular disruption.<sup>2</sup> Risk factors include increased age, preoperative sagittal kyphotic alignment, poor intraoperative positioning, inadequate grafting techniques or subsidence, and aggressive facetectomies.<sup>54</sup> Patients present with muscular fatigue, neck pain, difficulty maintaining a horizontal gaze, a kyphotic sagittal appearance with the head protruding forward, and possible neurologic symptoms and signs, including myelopathy or radiculopathy.<sup>54</sup> Workup begins with radiographs to assess imbalance and maximum deformity, flexion and extension views help evaluate the amount of correction that can be obtained (fixed vs flexible deformity). CT scan assists in detecting the presence of bony ankylosis dorsally or ventral fusion in patients with fixed deformities as well as in surgical planning.<sup>2</sup> MRI is useful to determine where decompression is needed as well as to evaluate for and quantify the amount of myelomalacia, cord atrophy, and syringomyelia, which can complicate as well as increase risk of treatment.<sup>2,54</sup>

Management goals are decompression, deformity correction, and long-term stabilization with instrumented arthrodesis. Determination of a fixed versus flexible deformity is crucial. Patients who can correct to neutral on extension radiographs can be candidates for either anterior- or

posterior-only procedures.<sup>2</sup> If no ventral compression is noted in a patient with flexible deformity, posterior arthrodesis with stable lateral mass/pedicle instrumentation yields good results.<sup>2</sup> Patients with fixed focal kyphotic deformity without dorsal ankylosis are candidates for anterior release and reconstruction, with correction of up to 20° possible.<sup>44</sup> For global flexible kyphosis, multilevel ACDF is preferred because it allows increased lordotic correction and number of fixation points, with lower graft dislodgement than a long corpectomy.<sup>54–56</sup> Circumferential stabilization is recommended for multilevel reconstructions involving 3 or more levels, due to the high incidence of graft-related complications in patients treated with multilevel ACCF with struts.<sup>2,57</sup>

#### 4. Summary

Cervical spine revision surgery typically involves adjacent segment disease, incomplete decompression, pseudarthrosis and/or instrumentation failure. In general, outcomes are less favorable than primary surgery regardless of the diagnosis. Systematic evaluation through detailed history taking, physical examination, imaging studies, and laboratory tests can yield accurate diagnoses and guide treatment plans. Modifiable risks for pseudarthrosis should be addressed before pursuing revision surgical intervention. Revision principles are

based on adequate decompression of the affected neural structures, preparation of an adequate fusion bed, and solid stability to achieve arthrodesis. The spine care team should discuss common complications and limitations of the revision procedure with patients preoperatively rather than after their occurrence. While revision cases are more complex with increased potential for complications compared to primary surgery, adherence to fundamental principles may allow acceptable clinical outcomes.

## Disclosures

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

## REFERENCES

- Vives MJ, Hauser SB, Chaudhary SB. S.H.a.S.B.C. Revision spine surgery. In: Steven FJE, Garfin R, Bell GR, Bono CM, Fischgrund JS, eds. Rothman-Simeone and Herkowitz's: The Spine, Philadelphia: Elsevier, Inc.; 2018. p.1867–1887.
- Rihn JA, Harrod C, Albert TJ. Revision cervical spine surgery. *Orthop Clin North Am.* 2012;43(1):123–136. ix-x.
- Diebo BG, et al. The impact of comorbid mental health disorders on complications following cervical spine surgery with minimum 2-year surveillance. *Spine.* 2018. (Phila Pa 1976).
- Sobel JB, et al. Cervical nonorganic signs: a new clinical tool to assess abnormal illness behavior in neck pain patients: a pilot study. *Arch Phys Med Rehabil.* 2000;81(2):170–175.
- Alander DH, Cui S. Percutaneous pedicle screw stabilization: surgical technique, fracture reduction, and review of current spine trauma applications. *J Am Acad Orthop Surg.* 2018;26(7):231–240.
- Brodsky AE, et al. Repair of symptomatic pseudoarthrosis of anterior cervical fusion. Posterior versus anterior repair. *Spine.* 1992;17(10):1137–1143. (Phila Pa 1976).
- Lowery GL, Swank ML, McDonough RF. Surgical revision for failed anterior cervical fusions. Articular pillar plating or anterior revision? *Spine.* 1995;20(22):2436–2441. (Phila Pa 1976).
- Farey ID, et al. Pseudoarthrosis of the cervical spine after anterior arthrodesis. Treatment by posterior nerve-root decompression, stabilization, and arthrodesis. *J Bone Joint Surg Am.* 1990;72(8):1171–1177.
- Hilibrand AS, Dina TS. The use of diagnostic imaging to assess spinal arthrodesis. *Orthop Clin North Am.* 1998;29(4):591–601.
- Martin Jr. GJ, et al. Anterior cervical discectomy with freeze-dried fibula allograft. Overview of 317 cases and literature review. *Spine.* 1999;24(9):852–858. (Phila Pa 1976). discussion 858-9.
- Cannada LK, et al. Pseudoarthrosis of the cervical spine: a comparison of radiographic diagnostic measures. *Spine.* 2003;28(1):46–51. (Phila Pa 1976).
- Manifold SG, McCann PD. Cervical radiculitis and shoulder disorders. *Clin Orthop Relat Res.* 1999(368):105–113.
- Epstein NE, Epstein JA, Carras R. Coexisting cervical spondylotic myelopathy and bilateral carpal tunnel syndromes. *J Spinal Disord.* 1989;2(1):36–42.
- Clyne B, Olshaker JS. The C-reactive protein. *J Emerg Med.* 1999;17(6):1019–1025.
- Jupe D. The acute phase response and laboratory testing. *Aust Fam Phys.* 1996;25(3):324–329.
- Khan MH, et al. Serum C-reactive protein levels correlate with clinical response in patients treated with antibiotics for wound infections after spinal surgery. *Spine J.* 2006;6(3):311–315.
- Beutler WJ, Sweeney CA, Connolly PJ. Recurrent laryngeal nerve injury with anterior cervical spine surgery risk with laterality of surgical approach. *Spine.* 2001;26(12):1337–1342. (Phila Pa 1976).
- Prasarn ML, et al. Adjacent-level biomechanics after single versus multilevel cervical spine fusion. *J Neurosurg Spine.* 2012;16(2):172–177.
- Hilibrand AS, et al. Radiculopathy and myelopathy at segments adjacent to the site of a previous anterior cervical arthrodesis. *J Bone Joint Surg Am.* 1999;81(4):519–528.
- Eck JC, et al. Biomechanical study on the effect of cervical spine fusion on adjacent-level intradiscal pressure and segmental motion. *Spine.* 2002;27(22):2431–2434. (Phila Pa 1976).
- Ellenberg MR, Honet JC, Treanor WJ. Cervical radiculopathy. *Arch Phys Med Rehabil.* 1994;75(3):342–352.
- Weinstein SM, Herring SA, Derby R. Contemporary concepts in spine care. Epidural steroid injections. *Spine.* 1995;20(16):1842–1846. (Phila Pa 1976).
- Herkowitz HN, Kurz LT, Overholt DP. Surgical management of cervical soft disc herniation. A comparison between the anterior and posterior approach. *Spine.* 1990;15(10):1026–1030. (Phila Pa 1976).
- Oh JK, et al. Stand-alone cervical cages versus anterior cervical plate in 2-level cervical anterior interbody fusion patients: clinical outcomes and radiologic changes. *J Spinal Disord Tech.* 2013;26(8):415–420.
- Shi S, et al. Comparison of plate-cage construct and stand-alone anchored spacer in the surgical treatment of three-level cervical spondylotic myelopathy: a preliminary clinical study. *Spine J.* 2015;15(9):1973–1980.
- Chen CJ, et al. Intramedullary high signal intensity on T2-weighted MR images in cervical spondylotic myelopathy: prediction of prognosis with type of intensity. *Radiology.* 2001;221(3):789–794.
- Okamoto A, et al. Postoperative magnetic resonance imaging in patients with cervical myelopathy. *Spine.* 1991;16(10 Suppl):S530–S533. (Phila Pa 1976).
- Ploumis A, et al. Prospective assessment of cervical fusion status: plain radiographs versus CT-scan. *Acta Orthop Belg.* 2006;72(3):342–346.
- Fager CA. Evaluation of cervical spine surgery by postoperative myelography. *Neurosurgery.* 1983;12(4):416–421.
- Bolesta MJ, Rehtine 2nd GR, Chrin AM. Three- and four-level anterior cervical discectomy and fusion with plate fixation: a prospective study. *Spine.* 2000;25(16):2040–2044. (Phila Pa 1976) discussion 2045-6.
- Emery SE, et al. Anterior cervical decompression and arthrodesis for the treatment of cervical spondylotic myelopathy. Two to seventeen-year follow-up. *J Bone Joint Surg Am.* 1998;80(7):941–951.
- Papadopoulos EC, et al. Three-level anterior cervical discectomy and fusion with plate fixation: radiographic and clinical results. *Spine.* 2006;31(8):897–902. (Phila Pa 1976).
- Vaccaro AR, et al. Early failure of long segment anterior cervical plate fixation. *J Spinal Disord.* 1998;11(5):410–415.
- Zdeblick TA, et al. Failed anterior cervical discectomy and arthrodesis. Analysis and treatment of thirty-five patients. *J Bone Joint Surg Am.* 1997;79(4):523–532.
- Herkowitz HN. A comparison of anterior cervical fusion, cervical laminectomy, and cervical laminoplasty for the surgical management of multiple level spondylotic radiculopathy. *Spine.* 1988;13(7):774–780. (Phila Pa 1976).
- Herkowitz HN. Cervical laminoplasty: its role in the treatment of cervical radiculopathy. *J Spinal Disord.* 1988;1(3):179–188.
- Bohlman HH, et al. Robinson anterior cervical discectomy and arthrodesis for cervical radiculopathy. Long-term follow-up of one hundred and twenty-two patients. *J Bone Joint Surg Am.* 1993;75(9):1298–1307.

38. Newman M. The outcome of pseudarthrosis after cervical anterior fusion. *Spine*. 1993;18(16):2380–2382. (Phila Pa 1976).
39. Wang JC, et al. Increased fusion rates with cervical plating for two-level anterior cervical discectomy and fusion. *Spine*. 2000;25(1):41–45. (Phila Pa 1976).
40. Wang JC, et al. Increased fusion rates with cervical plating for three-level anterior cervical discectomy and fusion. *Spine*. 2001;26(6):643–646. (Phila Pa 1976). discussion 646–7.
41. Fernyhough JC, White JI, LaRocca H. Fusion rates in multilevel cervical spondylosis comparing allograft fibula with autograft fibula in 126 patients. *Spine*. 1991;16(10 Suppl):S561–S564. (Phila Pa 1976).
42. Phillips FM, et al. Anterior cervical pseudarthrosis. Natural history and treatment. *Spine*. 1997;22(14):1585–1589. (Phila Pa 1976).
43. Koerner JD, Kepler CK, Albert TJ. Revision surgery for failed cervical spine reconstruction: review article. *HSS J*. 2015;11(1):2–8.
44. Steinmann JC, Herkowitz HN. Pseudarthrosis of the spine. *Clin Orthop Relat Res*. 1992(284):80–90.
45. Carreon L, Glassman SD, Campbell MJ. Treatment of anterior cervical pseudoarthrosis: posterior fusion versus anterior revision. *Spine J*. 2006;6(2):154–156.
46. McAnany SJ, et al. A meta-analysis of the clinical and fusion results following treatment of symptomatic cervical pseudarthrosis. *Global Spine J*. 2015;5(2):148–155.
47. Fountas KN, et al. Extrusion of a screw into the gastrointestinal tract after anterior cervical spine plating. *J Spinal Disord Tech*. 2006;19(3):199–203.
48. Gazzeri R, et al. Delayed migration of a screw into the gastrointestinal tract after anterior cervical spine plating. *Spine*. 2008;33(8):E268–E271. (Phila Pa 1976).
49. Lu DC, et al. Esophageal erosion 9 years after anterior cervical plate implantation. *Surg Neurol*. 2008;69(3):310–312. discussion 312–3.
50. Pompili A, et al. Asymptomatic esophageal perforation caused by late screw migration after anterior cervical plating: report of a case and review of relevant literature. *Spine*. 2002;27(23):E499–E502. (Phila Pa 1976).
51. Kumaresan S, et al. Finite element modeling of cervical laminectomy with graded facetectomy. *J Spinal Disord*. 1997;10(1):40–46.
52. Nowinski GP, et al. A biomechanical comparison of cervical laminoplasty and cervical laminectomy with progressive facetectomy. *Spine*. 1993;18(14):1995–2004. (Phila Pa 1976).
53. Zdeblick TA, et al. Cervical stability after foraminotomy. A biomechanical in vitro analysis. *J Bone Joint Surg Am*. 1992;74(1):22–27.
54. Albert TJ, Vacarro A. Postlaminectomy kyphosis. *Spine*. 1998;23(24):2738–2745. (Phila Pa 1976).
55. Herman JM, Sonntag VK. Cervical corpectomy and plate fixation for postlaminectomy kyphosis. *J Neurosurg*. 1994;80(6):963–970.
56. Zdeblick TA, Bohlman HH. Cervical kyphosis and myelopathy. Treatment by anterior corpectomy and strut-grafting. *J Bone Joint Surg Am*. 1989;71(2):170–182.
57. Riew KD, et al. Anterior cervical corpectomy in patients previously managed with a laminectomy: short-term complications. *J Bone Joint Surg Am*. 1999;81(7):950–957.