

Surgical Management of Complex Spinal Deformity

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KEYWORDS

- Surgical management • Complex spinal deformity
- Cervical deformity

Surgical treatment of complex cervical spinal deformities can be challenging operations. Patients often present with debilitating conditions ranging from generalized decreased quality of life to quadriplegia. Surgical treatment can be divided into anterior, posterior, or combined procedures. A thorough understanding of anatomy, pathology, and treatment options is necessary. This article focuses on the surgical treatment of complex spinal deformity.

PRESENTATION

Most commonly, patients present with cervical deformity as a chronic finding. Deformity may be incidentally found during the work-up of other congenital cardiac, renal, or intraspinal malformations.¹ Patients can present with a spectrum of physical complaints, including neck pain, radiculopathy, myelopathy, and cosmetic dissatisfaction. Neurologic deficits can be caused by central stenosis leading to myelopathy or foraminal stenosis leading to radiculopathy. The spinal cord can also be draped over the apex of a bony defect and become tethered by the dentate ligaments in what has been described as the bowstring effect. This condition can lead to chronic changes in the microvascular circulation of the cord, resulting in spinal cord atrophy or myelomalacia.² Patients may have complex radiculopathic complaints that can be unilateral or bilateral. Pain can radiate into the anterior chest, neck, or periscapular area. Patients typically have distal paresthesias and proximal arm pain (**Fig. 1**).³

Patients may present with acute deformity secondary to trauma. If patients have a chronic deformity from ankylosis of the cervical spine and experience sudden neck pain, a fracture is presumed until proven otherwise. These fractures are often 3-column injuries that are grossly unstable and can result in complete quadriplegia.

Kyphosis can adversely affect forward gaze, swallowing, and breathing. It can also result in compensatory lumbar hyperlordosis and associated low back pain. Cervical kyphosis causes the posterior musculature to be under constant contraction to maintain upright posture, contributing to neck pain.²

CAUSES

Complex cervical spine deformities can develop secondary to multiple causes. Degenerative disease usually causes symptoms that develop insidiously. Advanced degeneration can alter the normal biomechanics of the spine. The weight-bearing axis is translated anteriorly as the disk spaces decrease in height, leading to tensile load in the posterior elements. Ligaments become attenuated, and the progression of kyphotic deformity ensues.⁴

Iatrogenic deformity is most commonly caused by surgeries that were performed to treat uncomplicated neurologic symptoms.² Postoperative kyphosis has been reported after anterior-based surgeries, such as anterior cervical discectomy without fusion, anterior cervical discectomy and fusion (ACDF) without plating, ACDF with stand-alone cages, and corpectomies without posterior

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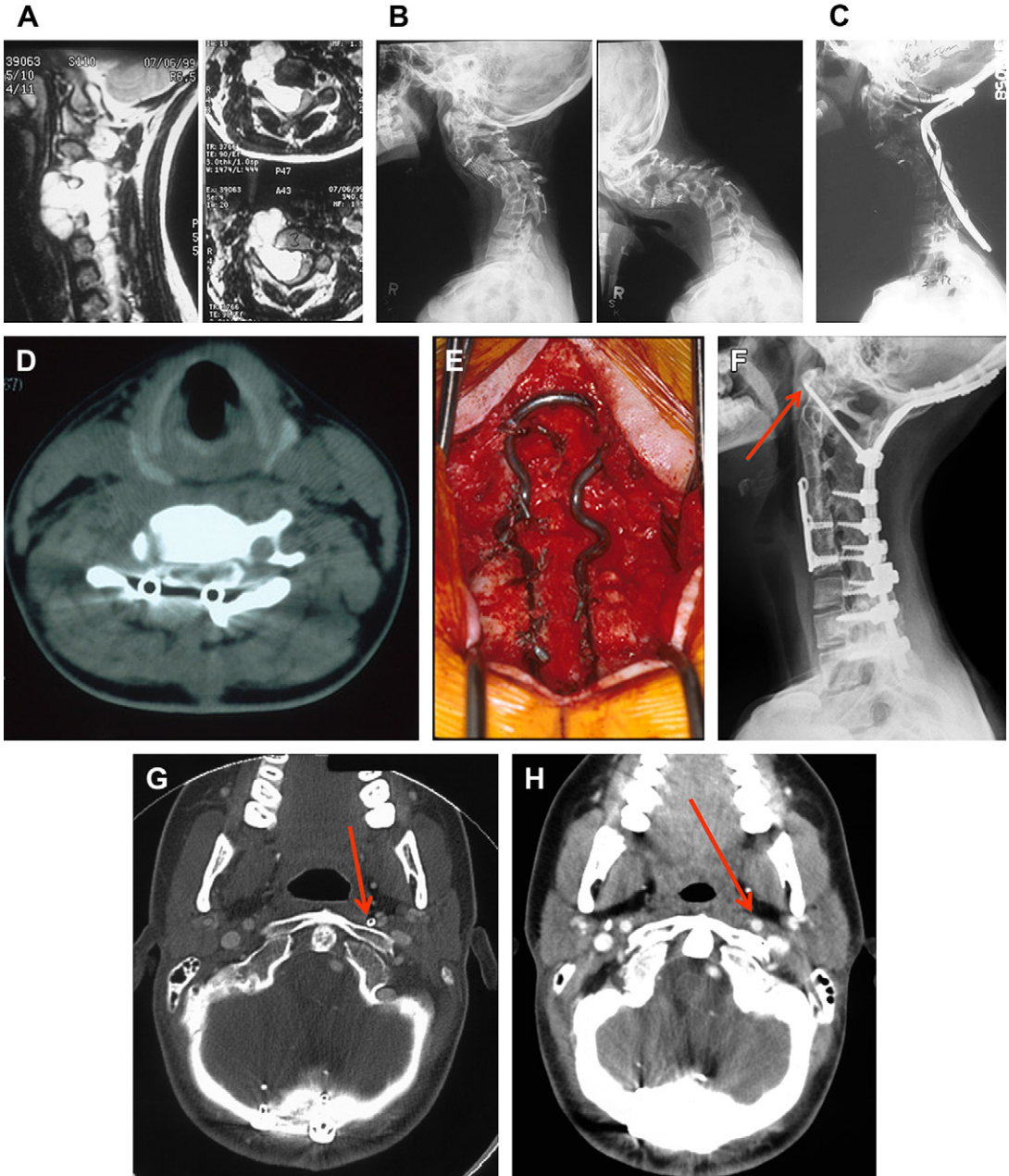
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instrumentation.⁵⁻⁸ Posteriorly, an excessive facetectomy can result in segmental instability that results in kyphosis. The incidence of postlaminectomy kyphosis has been reported to be as high as 21%.⁹ Younger age at the time of surgery, 4 or more laminectomy levels, laminectomy performed in conjunction with facetectomy, increased preoperative range of motion, and surgery involving the C2 lamina and its attachments have been shown to be risk factors. Suk and colleagues¹⁰ described

postlaminoplasty kyphosis occurring in 10.6% of patients with an average of 12° kyphosis.

Inflammatory disorders that commonly involve the cervical spine include rheumatoid arthritis (RA) and ankylosing spondylitis (AS). RA affects 0.3% to 1.5% of the population. Despite the improved medical management of RA, cervical spine manifestations occur in up to 86% of patients.¹¹ Atlantoaxial instability, basilar invagination, subaxial subluxation, and combinations of



the 3 can occur (Fig. 2A–D). AS is a debilitating inflammatory disorder. Bony syndesmophytes form across disk spaces. Early in the disease, facet joints are affected and patients tend to flex their spine to unload the facets. This state can ultimately lead to the classic chin-on-chest deformity.

Dropped head deformity (DHD) is a severe, flexible, cervicothoracic kyphosis caused by weakness of the neck extensor muscles. Primary DHD may be caused by a systemic neuromuscular disease, including myasthenia gravis, amyotrophic lateral sclerosis (ALS), congenital myopathy, chronic inflammatory polyneuropathy, and polymyositis, or an extrapyramidal disease (Parkinson disease). Primary DHD may also be caused by an isolated local condition, such as inflammatory myositis and dystonia. Secondary causes of DHD include prior treatment with radiotherapy and local botulinum toxin injection (Fig. 3A–D).¹²

EVALUATION

All patients should have a thorough clinical and radiographic evaluation. When obtaining the history, special attention is given to details that may elucidate underlying causes and factors that may alter the treatment plan or prognosis. Dystonia can affect biomechanical muscle balance and may put patients at an increased risk of recurrence. History of radiation therapy may put patients at a higher risk of wound healing.

Swallowing dysfunction may worsen postoperatively and impact nutritional status.

Physical examination should be thorough. Soft tissues surrounding the spine should be assessed, especially in patients who have had prior radiation or surgery. If soft tissue is tenuous, a plastic surgery consult can be obtained preoperatively. The chin-brow to vertical angle should be assessed by measuring the angle between a line from the brow to the chin and a vertical line when patients stand with the hips and knees extended with the neck in neutral. Suk and colleagues¹³ found that patients that underwent correction to a chin-brow vertical angle ranging from -10° to 10° had better horizontal gaze. Overall sagittal alignment should be assessed with knees extended because patients will often crouch at the knees to maintain horizontal gaze or overall balance. Posterior musculature should be inspected for tone. Patients should also be examined lying supine. The chin-brow to horizontal angle should be measured as well as the distance the occiput to the bed to assess the flexibility of the condition.

A complete spine examination can help localize the lesion. Central stenosis tends to have findings consistent with myelopathy. Foraminal stenosis can present with radiculopathy. Many patients will have mixed findings.

Plain films are used to assess the deformity and identify any congenital anomalies, prior fusions, and previously placed instrumentation. Flexion and extension films are used to determine

Fig. 1. A 12-year-old girl with a chordoma at C2 and 3 was referred following intralesional anteroposterior resection and motion-sparing reconstruction elsewhere. She had a laminoplasty posteriorly and placement of nonstructural graft and mesh at C2-4 anteriorly following her tumor resection. She developed a progressive swan-neck deformity, and her surgeon attempted a posterior occipital-cervical fusion with a Ransford loop (Srugicraft, UK). She developed a pseudoarthrosis, and the rods migrated into her spinal canal. She was eventually referred for complaints of cervical deformity, pain, and myelopathy. She underwent a multistage reconstruction as follows: stage I: posterior removal of rods with decompression and osteotomies through the partially fused facet joints; stage II: cervical traction for 5 days; stage III: anterior decompression and fusion with 2 grafts and kick plate; stage IV (same day as stage III): posterior O-C fusion with rod/screw construct with iliac crest autograft. She subsequently underwent proton beam radiation therapy for tumor control. The tip of the single transarticular screw used during the reconstruction was found to be compressing the internal carotid artery. It was removed without sequelae, and she is disease free and functioning well with minimal pain and no neurologic deficit 12 years following her tumor resection. (A) Sagittal and axial MRI images showing the chordoma before resection elsewhere. (B) Sequential lateral radiographs showing progressive swan-neck deformity following her tumor resection and motion-sparing reconstruction. (C) Lateral radiograph at presentation with progressive deformity, pain, myelopathy, and pseudoarthrosis. (D) CT myelogram image of C5-6 at presentation showing Ransford loop has migrated into the spinal canal causing cord compression. (E) Clinical photograph taken during stage I showing Ransford loop has migrated into the spinal canal. Fibrous tissue within the subaxial facet joints was removed to loosen up the spine in preparation for traction. (F) Final lateral radiograph showing sagittal alignment has been restored and fusion is solid. Only one transarticular screw could be used because the tumor resection caused the posterior elements to be deficient. Subsequent evaluation before proton beam therapy (see Fig. 1[G]) showed that the tip of the transarticular screw (arrow) was found to be abutting and compressing the ipsilateral internal carotid artery. (G) CT with contrast showing the tip of the transarticular screw (arrow) is abutting and compressing the left internal carotid artery at the anterior arch of the atlas. (H) CT with contrast following removal of the transarticular shows that the internal carotid artery (arrow) was not damaged. The authors now recommend a CT with contrast before placing screws into the lateral mass of the atlas.

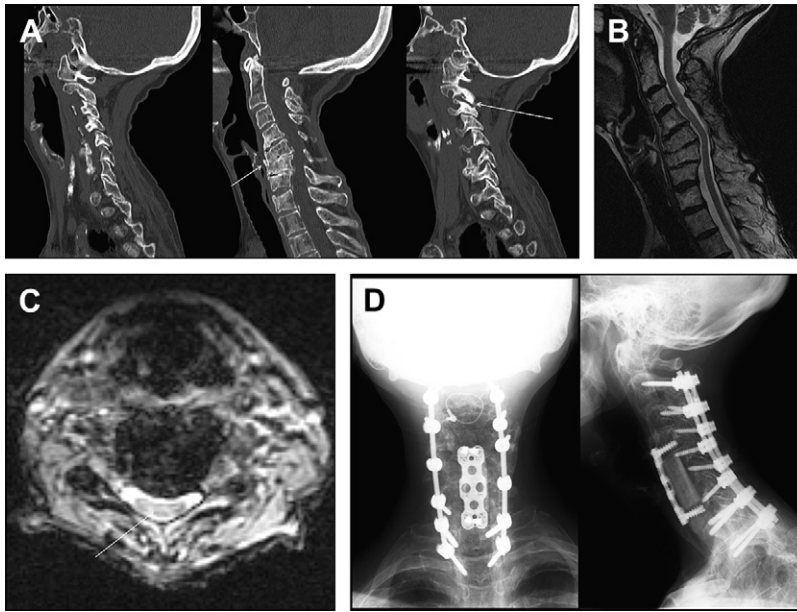


Fig. 2. A 63-year-old woman presented with complaints of progressive neck fatigue and deformity for 3 years. She had to hold her head up with her hand, otherwise her chin rested on her chest. She denied trauma but had fallen several times because of mild myelopathy. After a comprehensive evaluation, the cause of her DHD was thought to be posterior neck muscular weakness secondary to remote history of high-dose radiation therapy for Hodgkin disease. She underwent a 2-stage reconstruction. The first stage was done anteriorly because she had ankylosis of the C5-6 vertebral bodies, which was responsible for her fixed kyphosis, and she had no ankylosis of the facet joints. C5 and 6 corpectomies and allograft fibular strut graft fusion decompressed the stenosis and corrected the fixed deformity. The open facet joints permitted the reduction of the deformity from the front. C2-3, C3-4, and C7-T1 anterior cervical discectomies and allograft fusions enhanced the overall fusion rate and helped prevent late loss of correction. Stage II was done several days later and involved an instrumented C2-T2 fusion to maintain correction and enhance the fusion rate. One and one-half years postoperatively, she had no loss of correction, no neurologic deficit, no neck or arm pain, and her range of motion was approximately 50% of normal. (A) Sagittal reformatted CT images show spontaneous fusion C5-6 with kyphotic deformity (*small arrow*). None of the cervical facet joints were ankylosed. The right C2-3 facet joint was eroded (*large arrow*). The C2-3 level was found to be hypermobile on flexion/extension films. Note that only the fixed component of her deformity is appreciated on her CT images. Clinically, she had a chin-on-chest deformity. (B) Lateral MRI demonstrating fixed kyphotic deformity with stenosis at C4-7. (C) Axial MRI at C5-6 demonstrating stenosis and cord deformity with high T2 signal in the cord (*arrow*). (D) Postoperative anteroposterior and lateral radiographs demonstrate the multilevel anterior and posterior decompression and fusion with restored alignment.

flexibility of the deformity and status of prior fusions. Full-length standing films with knees extended are used to assess global balance. Magnetic resonance imaging (MRI) assesses soft tissue and should be used to evaluate for spinal stenosis and evidence of cord atrophy or myelomalacia. A computed tomography (CT) scan with coronal and sagittal reconstructions should be obtained to further characterize bony anatomy. Prior surgical or congenital fusion can be more accurately evaluated with CT than plain radiographs. Pedicle morphology and the course of the vertebral arteries are noted. Adjacent joints are assessed for degeneration and spontaneous fusion. If patients have torticollis, a dynamic CT can be obtained to compare images taken with

the patients' head turned maximally to each side to determine the mobility of the atlantoaxial joints. Contrast is used to assess the internal carotid arteries and vertebral arteries when upper cervical fusion is planned. Electromyography (EMG) can be used to localize radiculopathy and differentiate it from any peripheral neuropathy, shoulder complaints or referred pain.

Laboratory work-up includes standard preoperative laboratory tests. Any abnormalities in coagulation should be corrected preoperatively because blood loss can be significant, especially in revision cases. Nutritional and nicotine laboratory tests may be helpful to avoid problems with soft tissue healing and fusion. Blood tests that can screen for underlying myopathy include creatine kinase,

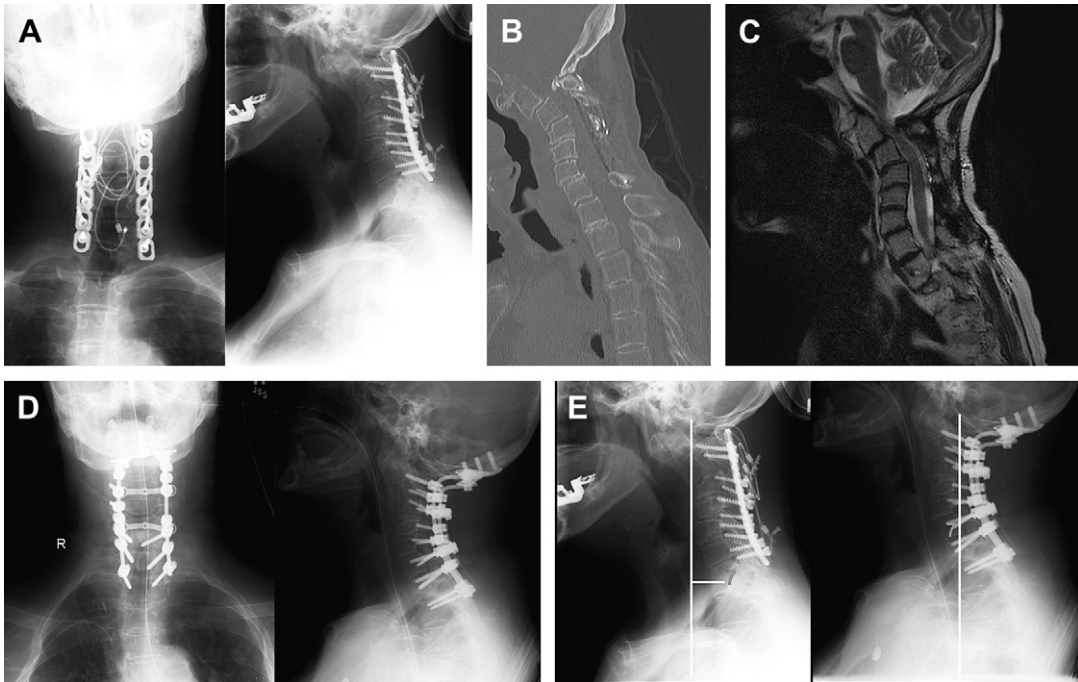


Fig. 3. A 61-year-old woman with RA presented with complaints of progressive occipitocervical neck pain, mild myelopathic symptoms, and kyphotic deformity. Ten years previously, she had undergone a C2-7 posterior decompression and fusion elsewhere. The authors were prepared to do a multistage procedure, with traction between stages as needed, but were able to achieve their goals with a single-stage posterior procedure. She had the instrumentation removed C2-7, laminectomies C1-4, osteotomies C2-3, C3-4, C4-5, and an occiput-T2 posterior fusion with a rod/screw construct and iliac crest bone graft. Following the decompression, the dura was kinked at the craniocervical junction, but an intraoperative ultrasound demonstrated good dural pulsation and CSF surrounding the spinal cord, so a duraplasty was not necessary. (A) Anteroposterior and lateral radiographs show prior laminectomies C5 and C6 and nonrigid posterior instrumentation C2-7. She has kyphosis C2-5, tilt to the right in the coronal plane, and cranial settling with impingement of the right-sided plate on the occiput. (B) Sagittal CT reformatted image shows cranial settling; the eroded tip of the odontoid has migrated into the foramen magnum. There is C1-2 subluxation with severe stenosis at the craniocervical junction. Other cuts showed occipitalization of C1. The spine is subluxed anteriorly at C2-3 and C3-4 and the spine is kyphotic from C2 to C5. The prior laminectomies of C5 and C6 are also seen. (C) Sagittal T2-weighted MRI demonstrates stenosis from the foramen magnum to C4. The stenosis is severe at the craniocervical junction. (D) Postoperative AP and lateral radiographs demonstrate improved alignment and stability following occiput-T2 fusion. (E) Preoperative (*left*) and postoperative (*right*) lateral radiographs demonstrate improved alignment. The spine is still kyphotic C2-4, but the global alignment is good and her head position allows comfortable forward gaze. A plumb line from the center of the foramen magnum now falls inside the C7 vertebral body.

aldolase, aspartate aminotransferase, alanine aminotransferase, and lactate dehydrogenase.

Patients often have multiple medical problems that can affect outcomes. Consideration should be given to obtaining preoperative consultations to optimize patient conditions before surgery. Neurology can rule out reversible causes of dystonia or other causes of neurologic deficits, such as peripheral neuropathy, multiple sclerosis, or ALS. Patients with previous anterior surgery should be evaluated by an ear, nose, and throat (ENT) specialist. Vocal cords should be assessed for dysfunction because this may dictate which operative side is used for the approach. If patients

already have unilateral vocal cord paralysis, the same incision should be used so as not to place the contralateral vocal cord at risk. ENT should also be consulted if patients have baseline swallowing dysfunction, prior esophageal injury, or if a difficult surgical exposure is anticipated. If the soft tissue condition is in question, a plastic surgery consultation should be obtained so that complex tissue coverage is available. If patients have documented sleep apnea or pickwickian habitus, obtain a preoperative sleep study from a pulmonologist. Endocrinology can help manage osteoporosis, potentially using perioperative teriparatide (Forteo) treatment. In addition, they can

optimize diabetic management to reduce the risk of wound healing problems. Rheumatology can evaluate for myopathy.

Medical photography is used to document preoperative clinical deformity and can be used as intraoperative reference. This is ideal for measuring and documenting the chin-brow vertical angle.

INDICATIONS, CONTRAINDICATIONS, AND GOALS OF SURGERY

Indications for surgery include neurologic deficit, pain, and intolerable deformity. The risk of inducing a neurologic deficit during surgery must be carefully weighed against presenting deficits and the risk of progression. Patients often find a deformity to be intolerable when it affects activities of daily living and quality of life. Deformity that causes respiratory compromise or swallowing difficulty should be corrected.

There are multiple relative contraindications to surgery. Patients with severe osteoporosis are at a higher risk of construct failure. If flap coverage is not possible over an area with poor soft tissue coverage, surgery should be avoided in that approach. Surgery should be performed in reversible dystonia only if medical management fails. Medical comorbidities may preclude lengthy, multistage procedures.

Surgical goals should be outlined with patients preoperatively to minimize unrealistic expectations. In general, the goals are to achieve a well-aligned and balanced spine, diminish pain, and correct or prevent neurologic deficits. Unfortunately, these benefits are typically counterbalanced by the loss of motion caused by a fusion. It takes a considerable amount of time to educate patients and allow them to participate in the decision making for complex cases, but that time is a good investment.

PREOPERATIVE PLANNING

Meticulous preoperative planning is necessary given the complexity of the surgery. Medical care of patients should be optimized preoperatively because their body will be in a state of catabolism postoperatively. Appropriate consultations should be obtained before surgery. If possible, chronic medical conditions should be stable and thoroughly assessed preoperatively.

When reviewing imaging, stenosis should be assessed. This condition is best seen on MRI. Stenosis can be central, foraminal, or both. The spinal cord should be assessed for myelomalacia. If stenosis is present and symptomatic, decom-

pression should be performed. Decompression can be performed directly from the anterior. Consideration is given to the number of levels to be decompressed. Anterior multilevel corpectomies with anterior plating without supplemental posterior fixation may be associated with a high risk of complications. Indirect decompression can be performed by laminectomy or laminoplasty, allowing the spinal cord to drift posteriorly. Isolated laminoplasty or laminectomy is not recommended if patients do not have an overall neutral or lordotic cervical alignment because indirect decompression relies on the ability of the spinal cord to drift back. Surgeons should anticipate additional areas of stenosis that may develop intraoperatively after correction of the deformity.

Imaging should also be assessed for fusion. The spine can be fused congenitally, spontaneously, or surgically. Fusion can occur anteriorly, posteriorly, or circumferentially. A pseudoarthrosis is best evaluated with a CT scan and flexion/extension films. Pseudoarthrosis may be mobile or fixed and result in dynamic or static stenosis. They are often pain generators but may be asymptomatic.

Stability is assessed with flexion and extension films. Localization of instability helps guide what segments to include in fusions. Segments adjacent to deformities should be assessed for abnormal motion. Integrity of the anterior column should be assessed. If patients demonstrate rounded or wedged vertebral bodies, caution should be used when using only posterior instrumentation.

The deformity itself should be fully appreciated. Sagittal deformity is most common, but coronal deformity can occur in conjunction or isolation. Deformity should be assessed for flexibility. If a deformity is flexible, the amount of correction should be noted. Specific measurements include chin-brow to vertical angle and C1 plumb line.¹⁴ C1 plumb line is measured with a plumb line from the tip of the odontoid in relation to the center of C7. A C7 plumb line is also measured from the center of C7 in relation to the posterior superior corner of the sacrum to assess for global imbalance in the thoracic or lumbar spine (Fig. 4A–G).

Special consideration should be given to patients who have had prior surgery. Prior operative reports should be obtained if possible. If planning an anterior approach on patients with previous anterior surgery, assessment of the vocal cords should be made. If paralysis on the side of previous incision is present, the contralateral side should not be used for revision surgery given the risk of complete vocal cord paralysis. Complications should be noted from previous surgeries, such as a cerebrospinal fluid (CSF) leak. Existing

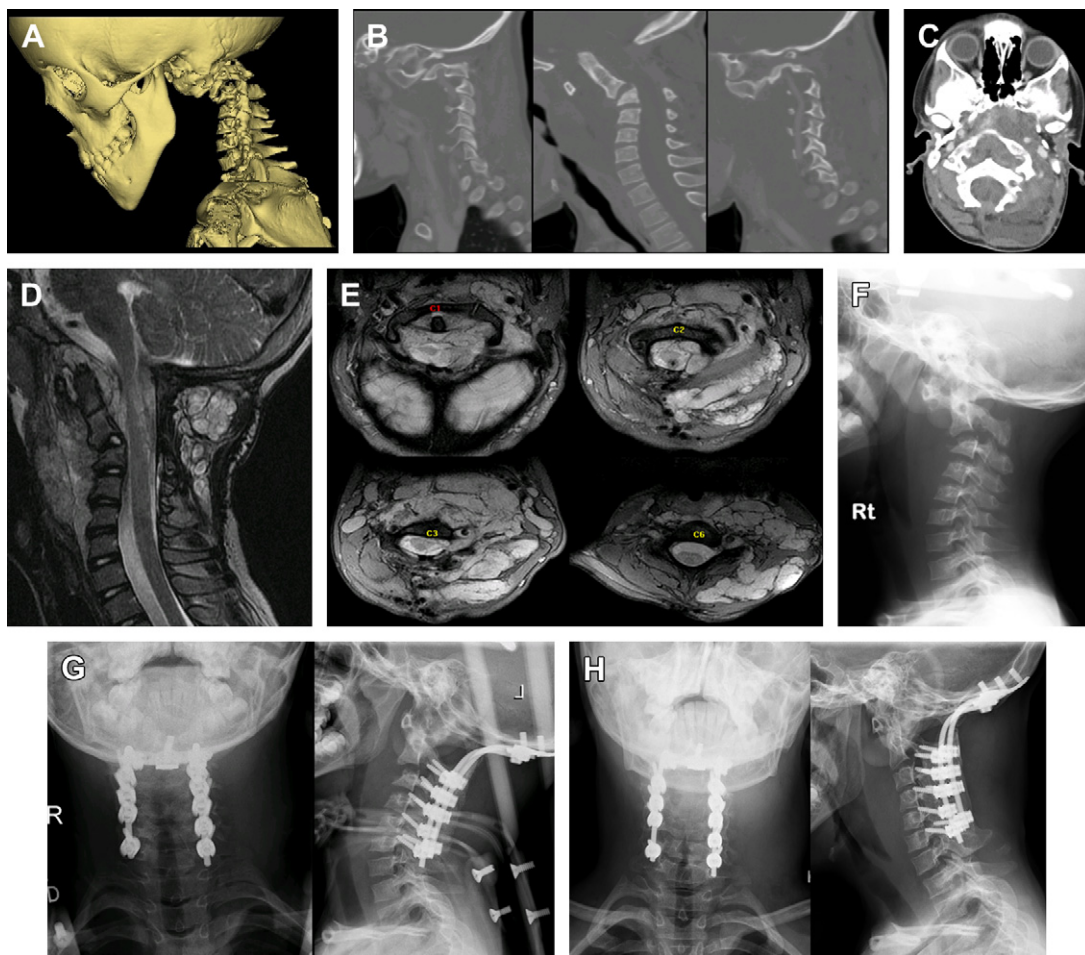


Fig. 4. A 7-year-old boy with type I neurofibromatosis. He underwent an occiput to C2 decompression in May 2007 to perform an intradural decompression of a plexiform neurofibroma that was causing myelopathy from spinal cord compression. He presented in November 2007 with progressive postlaminectomy kyphosis. His myelopathy had remained stable and he was still ambulatory with aids for his spastic gait. He was placed in halo traction for 10 days preoperatively and then underwent a single-stage posterior procedure. The intradural tumor was debulked further and the spine was fused with a rod/screw construct from occiput to C6 using BMP-2, MasterGraft (Medtronic, Minneapolis, Minnesota; off label) and iliac crest autograft. He was immobilized in a halo vest postoperatively for 3 months. Open reduction was achieved indirectly at the time of surgery through manipulation of the halo and directly by pressing anteriorly on C3 while translating the occiput posteriorly. The rods were compressed between C2 and 3 to reduce that level further after removing the facet capsules and cartilage from the facet joints. The authors did not expose the lateral masses of C1, rather C1 moved with the occiput and was reduced relative to C2 during the translation maneuver. The authors were prepared to do a subsequent anterior fusion if the posterior fusion did not heal or he started to lose correction but that was not necessary. He will need to be followed for life because of the likely tumor regrowth. (A) A 3-dimensional CT reformatted image demonstrating deformity. (B) CT sagittal reformatted images (*left, center, right*). He has cranial settling with the tip of the odontoid inside the foramen magnum. C1 is dislocated anteriorly relative to C2 on the right and markedly subluxed on the left. C2 has subluxed anteriorly relative to C3. The posterior elements are deficient from prior suboccipital craniotomy and laminectomies of C1 and C2. The C3 vertebral body is compressed anteriorly, and he has a severe postlaminectomy kyphotic deformity from C2 to 4. (C) Axial CT demonstrating the C1-2 dislocation. (D) Sagittal T2-weighted MRI from September 2007 demonstrating extensive plexiform neurofibroma involving intradural and extradural spaces C1-2 as well as the extraspinal soft tissues posteriorly and the retropharyngeal space. The progressive nature of the deformity can be appreciated by comparing this image with the reformatted CT in Fig. 4(B) taken just 2 months later. (E) Axial T2-weighted MRI images from September 2007 demonstrating extensive tumor involvement throughout the neck. (F) Lateral radiograph after 1 week in 4.5 kg of traction showing partial reduction of the deformity. Traction was begun with just 1.8 kg of weight and close observation. (G) Anteroposterior and lateral radiographs taken with the patient in a halo during the immediate postoperative period. (H) Anteroposterior and lateral radiographs taken nearly 3 years postoperatively showing solid posterior fusion, no loss of alignment, and remodeling of the C3 vertebral body. He had not had any additional surgery. His neurologic status is stable, he has no pain, and he is still ambulatory.

implants should be identified on operative reports or, if possible, on imaging. Instrumentation specific to the system in place should be on hand to help with removal. Otherwise, a universal removal set or metal cutting burr should be available. If a prior laminectomy was performed, its extent should be noted to try and decrease the chance of CSF leak or cord injury during exposure. Wide laminectomy makes the spine less stable and will more likely require anterior-posterior fusion.

Imaging should be used to assess degeneration of adjacent joints. The planned construct should be extended to include adjacent degenerated joints to prevent junctional breakdown.

In upper cervical fusions, contrast imaging should be used to assess the course and dominance of the vertebral arteries and the location of the internal carotid arteries relative to the anterior arch of the atlas. In the subaxial spine, the anatomy of the vertebral arteries can be assessed with plain CT and MRI scans. Congenital bony anomalies should be noted in addition to vascular anomalies.

Soft tissue assessment is vital. If there is contracture or poor integrity of the soft tissues, patients may require soft tissue flap coverage postoperatively. If the anterior tissues have been contracted for an extended period of time, patients may develop difficulty swallowing postoperatively and require a percutaneous feeding tube for nutrition. If the posterior musculature is poor from myopathy or extensive radiation therapy, the posterior construct will likely need to be extended to C2.

SELECTION OF LEVELS

The extent of the instrumentation and fusion should be decided based on multiple factors. The cause, location, type of prior surgery (if any), and quality of bone are all factored into the decision.^{2,15} In general, the most cephalad and caudal vertebral bodies involved in the deformity curve are the beginning and end of the extent of the fusion. However, if the posterior musculature is weak, the bone is severely osteoporotic, or the cause is metastatic disease, the fusion should be extended longer, often to C2. Posteriorly, C2 offers a stronger point of fixation compared with C3 and allows for improved correction and stabilization. The C7 lateral mass is often difficult to instrument because of its size; a pedicle screw can be used at this level. The position of a C7 pedicle screw can be challenging to connect to a C6 lateral mass screw. In addition, stopping a construct at C7 is often avoided because of the concentration of stress at the cervicothoracic junction. For these

reasons, C2 and T2 are common endpoints on posterior constructs, with C7 sometimes remaining uninstrumented.⁴ If a prior laminectomy has been performed, the length of the laminectomy should be fused, plus one normal vertebrae above and below the fusion segment.

STAGING

Determination of the number and sequence of stages of surgery should be planned. Isolated anterior surgery is an option provided that there is not a fusion posteriorly or ankylosis of the facet joints. In addition, the construct itself should be short because the risk of pseudoarthrosis increases with longer anterior constructs.

Posterior procedures can be performed in isolation with specific indications. The deformity can be a flexible kyphosis with an unfused anterior column. Posterior procedures can also be performed when kyphosis is caused by ankylosing spondylitis.² Kyphosis in the setting of rounded vertebral bodies indicates that the anterior column has lost its integrity and an isolated posterior fusion may fail.

Two-stage combined procedures, also referred to as 360° reconstructions, are indicated when stability needs to be augmented. Instability may be caused by prior laminectomy, adjacent level disease in a previous 360° reconstruction, trauma with significant ligamentous injury, or multilevel corpectomies. A 360° reconstruction should also be considered in patients who are at significant risk for developing a pseudoarthrosis, such as a smoker with anterior cervical discectomy and fusion at 3 or more levels.¹⁶ The addition of the posterior approach also allows for dorsal decompression of the spinal cord, if necessary.² A 360° reconstruction permits immediate rigid stabilization and eliminates the need for halo immobilization postoperatively. Higher rates of fusion have been demonstrated with the combined approach compared with the isolated anterior approach.¹⁷ Correction of deformity with a 360° reconstruction is typically possible when only the anterior or posterior aspect of the spine is fused.

If both the anterior and posterior aspects of the spine are fused, a 3-stage combined procedure (540°) is usually required. This procedure allows for osteotomies to be performed anteriorly and posteriorly. In general, the first stage serves as a release osteotomy with partial correction. The second stage completes the correction and provides some fixation. The third stage augments the fixation across initial releases. Wollowick and colleagues¹⁸ reported performing anterior osteotomies that partially correct the deformity through

plastic deformation through a weak posterior fusion followed by further deformity correction via posterior osteotomies and fusion. The authors prefer a 3-stage procedure for more control and less risk of anterior vertebral body disruption caused by forceful manipulation of the spine with distracting devices. Three-stage procedures are also indicated when prior posterior instrumentation is in place and requires removal before anterior correction. All 3 stages are not done on the same day because of the length of surgical time required. In general, the first stage can be done on the first day. The second and third stages are done on a second day because the third stage normally involves placing instrumentation and is relatively quick.

PREOPERATIVE TRACTION

The need for preoperative traction should be determined. Traction can be used to gradually straighten an unfused but stiff deformity. In addition, it allows us to monitor neurologic status during correction, which is especially helpful in cases whereby it is unclear if a single approach would be adequate or in cases whereby neurologic status is tenuous. If reduction is significant after a few days in traction, a posterior instrumentation and fusion can be used to maintain the correction. If there is no correction with traction over a few days, it is unlikely that traction will provide correction, and a 360° approach is necessary. Preoperative traction should be used sparingly. Patient compliance can be an issue. Complications of transient neurologic deterioration and medical complications have been reported.¹⁹ In addition, patients must remain in the hospital preoperatively, placing them at higher risk of a nosocomial infection (**Fig. 5A–H**).

OSTEOTOMIES

The location, type, and magnitude of osteotomies to be performed should be determined. Smith-Peterson osteotomies of the spine were first described in 1945.²⁰ Use of osteotomy in the cervical spine was reported by Mason and colleagues.²¹ Simmons²² was the first to publish a series of corrective osteotomies at the cervicothoracic junction.

The Smith-Peterson osteotomy involves the resection of posterior elements through the facet joints and pars intra-articularis. Laminectomies are performed at C6, C7, and T1. The C8 nerve roots are widely decompressed. The posterior column is closed, and the anterior column opens through the disk space. All 3 columns are

disrupted, rendering the spine unstable until it is reconstructed.¹⁸

Pedicle subtraction osteotomy (PSO) is indicated in large deformities, especially those that are sharp and angular. It involves a closing wedge osteotomy that hinges on the anterior longitudinal ligament and anterior aspect of the vertebral body. Bilateral lamina and facets are resected. The pedicles and vertebral body are decancellated. The posterior vertebral cortex is collapsed into the decancellated vertebral body defect, and the lateral cortex is resected. The osteotomy site is closed, creating bony apposition of the vertebral body and posterior elements. An asymmetric osteotomy can be done to correct a coexistent coronal deformity.²³ Greater blood loss occurs with PSO, but greater correction is obtained. The correction obtained in a PSO is comparable with that obtained with 3 Smith-Peterson osteotomies.²⁴

Osteotomies are performed in the region of maximal deformity while also taking into account possible complications. The cervicothoracic junction is most commonly chosen because of the large size of the spinal canal at this level, safety in relation to the location of the vertebral artery, and the mobility of the spinal cord and C8 nerve roots. In the event of a C8 nerve injury, most hand function is still possible.¹⁸

ANESTHESIA AND POSITIONING

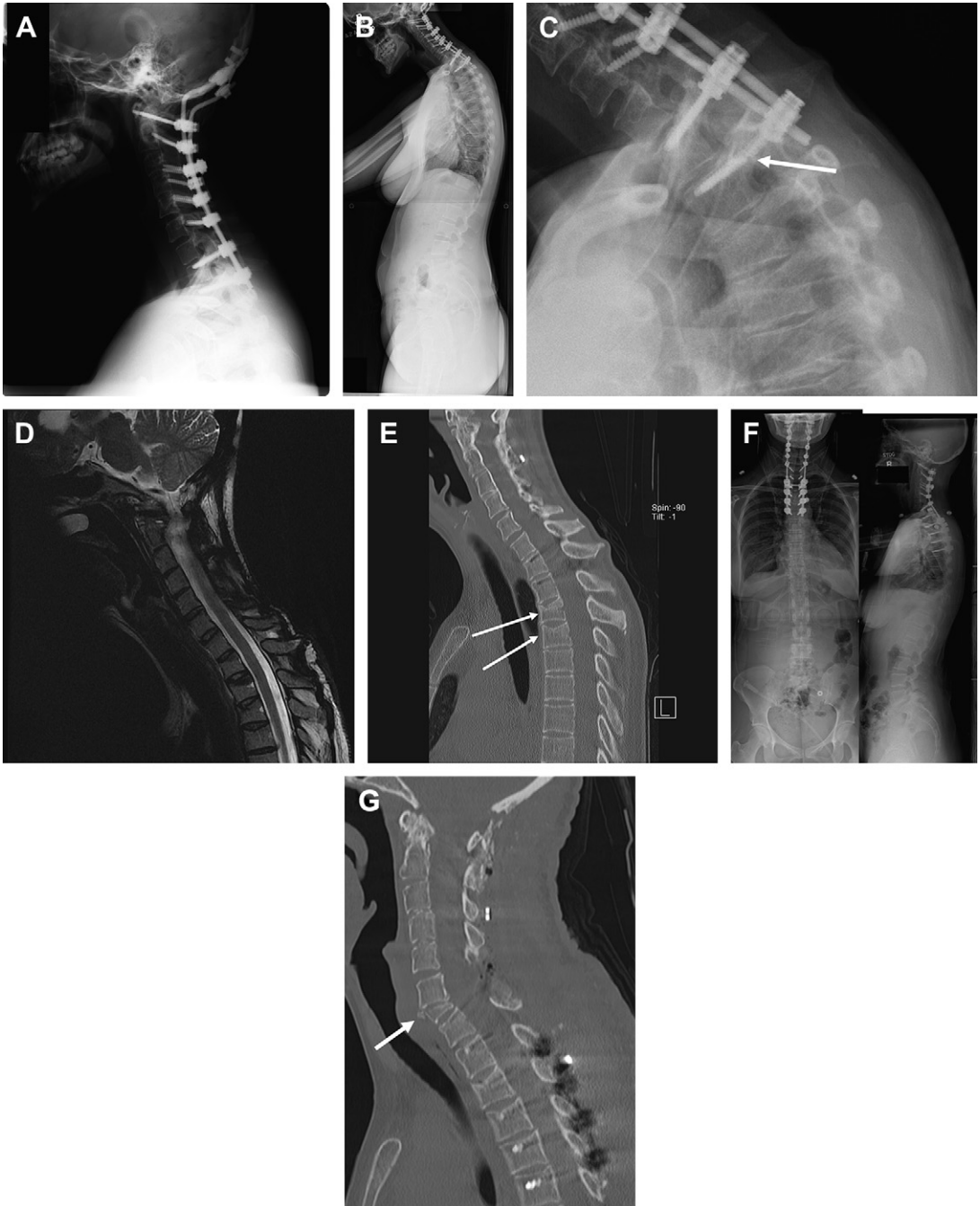
Surgical correction of complex deformity can be performed with patients under local anesthesia and conscious sedation in a sitting position. This practice allows for an easier wake-up test and gradual, controlled correction of deformity.²⁵ However, neurologic deficits, including quadriplegia, have been reported even when surgery is performed in this position.²⁶

General anesthesia with monitoring can be used. Langeloo and colleagues²⁷ studied 16 patients who underwent C7 osteotomy with internal fixation. Eleven patients were in a sitting position and 5 were prone. Longer fusion constructs down to T4–T6 were able to be done in the prone group, allowing them to be immobilized in a cervical orthosis postoperatively. The sitting group required halo-cast immobilization postoperatively. All patients achieved union without loss of correction.

The authors prefer to use general anesthesia with patients in the prone position and multimodality intraoperative monitoring (IOM). Intravenous anesthetic is used because of the interference of gas anesthesia with IOM. In a recent report, 102 consecutive adults underwent IOM during

corrective surgery for spinal deformity, and the accuracy of IOM was compared with postoperative examination. Multimodality IOM via somatosensory-evoked potentials (SEPs), motor-evoked potentials (MEPs), and EMG were found to have an overall sensitivity of 100% and specificity of 84.3%. Sensitivity was 67% and specificity was 98% in patients undergoing major deformity

correction. The investigators concluded that IOM allowed for the early detection of neural injury that allowed them to restore blood pressure and avoid overcorrection or forgo the osteotomy to try and avoid postoperative paraparesis.²⁸ In 2010, Fehlings and colleagues²⁹ performed a meta-analysis of IOM. They found that multimodality intraoperative neuromonitoring is sensitive



and specific for detecting intraoperative neurologic injury and should be considered during deformity correction and instrumentation. The authors prefer anesthesia to maintain mean arterial pressures (MAPs) more than 80 mmHg throughout the procedure and increase it to 90 mm Hg at the time of osteotomy closure. In addition, if IOM demonstrates an amplitude loss of at least 60% and is sustained for more than 10 minutes, MAPs are increased to 90 mm HG.³⁰ If there continues to be concern regarding IOM, a wake-up test is performed.

When performing posterior osteotomies, the authors prefer to use the prone position. A Jackson frame (Mizuho OSI, Union City, CA, USA) is set up with a chest bolster, anterior iliac crest pads, anterior thigh pads, and a leg sling. Additional padding or pillows may be necessary to accommodate thoracic or thoracolumbar deformity. The authors prefer the use of a Mayfield head clamp (Ohio Medical Instrument Co., Cincinnati, OH, USA) with pinions because of its stability. Other authors prefer securing the head with Gardner-Wells tongs with 6.8 kg of weight in

bivector traction. If bivector traction is used, one rope should be in line with deformity and the other rope directs the head into extension.¹⁸

Once patients are in the prone position, it is important to assess the position of the spine clinically. The chin-brow to Jackson table angle should be noted and compared with the goal correction angle. The coronal and axial alignment is best checked by looking at the patients' head position from underneath the operating table. The table is placed in the reverse Trendelenburg position to decrease facial swelling and to attempt to make the surgical field level for surgeon comfort.

SPINAL NAVIGATION

The authors prefer to use spinal navigation during complex deformity correction. In a recent systematic review and meta-analysis, the use of navigation allowed more accurate pedicle screw placement than conventional techniques and the accuracy was even greater for deformity cases.³¹ The benefit of navigation is a possible improvement in safety and accuracy. This navigation is

Fig. 5. A 27-year-old woman with juvenile RA presented in January 2008 with complaints of right occipital pain for 5 years and bilateral radicular symptoms for 6 months. She was found to have spontaneous fusions occiput to C1 and C2-C5, marked destruction of the right C1-2 joint with minimal basilar invagination. She had foraminal stenosis at C5-6 and C6-7. She underwent occiput to T2 posterior instrumented spinal fusion with bilateral C5-6 and left C6-7 foraminotomies. She did well initially with resolution of occipital neuralgia and radiculopathy. She developed upper thoracic pain and progressive flexion deformity of her neck and was found to have developed compression fractures of T3 and T4 and fractures of the T2 pedicle screws. She underwent a C7 pedicle subtraction osteotomy and fusion with reinstrumentation C1 to T6 with iliac crest and local bone graft. Intraoperative image guidance, multimodality neural monitoring, and an operating microscope were used. No changes were detected with the SEPs or MEPs, and there were no neurotonic discharges on free-running EMG. However, the patient awoke with partial left C7 and C8 palsies. CT and MRI did not reveal any significant problems, but the foramen on the left that now contained both the C7 and C8 roots was snug. She was given intravenous steroids and observed initially, but after several days she elected to undergo another procedure to widen the foramen. The authors partially opened the osteotomy site and inspected neural elements. They found that the C7 and C8 roots were touching and there was a minor degree of foraminal stenosis, which was decompressed. The dura was kinking on closing the osteotomy site, but an intraoperative ultrasound revealed good CSF flow around the cord and no stenosis. The instrumentation was reinserted and the patient made an uneventful recovery. Her palsies had markedly improved after 2 months. At her 1-year follow-up, her palsies were almost completely resolved, she had rhomboid discomfort but was more functional and was pleased with her head alignment. (A) Standing lateral cervical radiograph after her index occiput-T2 fusion operation. Her chin-brow-vertical angle was 10°, as she had requested preoperatively. (B) Long-standing spine radiographs 1.5 years following her index procedure and before the PSO show that the C7 plumb line falls just at the back of the L5-S1 disk. In this position, her chin-brow-vertical angle measures 39°. (C) Enlarged view from Fig. 5(A) showing the broken screws at T2 (arrow) and compression fractures at T3 and T4. (D) Sagittal T2-weighted MRI before the PSO shows no stenosis but she has compression fractures of T3 and 4. Her bone mineral density was normal (T-score was 0.3 at the hip and -0.5 L at spine). (E) CT sagittal reformatted image demonstrates same findings as MRI in Fig. 5(D), compression fractures T3 and 4 (arrows). No pseudoarthrosis was seen on the lateral images despite the broken screws at T2. (F) Final long-standing posteroanterior and lateral radiographs show excellent alignment with chin-brow-vertical angle 0°. The authors normally strive to place the neck in slight flexion because it is thought to be a more functional alignment, but the patient requested that they make the chin-brow-vertical angle neutral because she thought that the initial 10° achieved at the first operation was too flexed. The broken screws were left in the vertebral bodies of T2. (G) Final postoperative sagittal reformatted CT demonstrating the PSO at C7. There is a small fracture on the anterior aspect of the C7 vertebral body (arrow). Ideally, the osteotomy would not involve the anterior wall of the vertebral body to avoid instability with translation.

most helpful when the spine is already fused from prior surgery or AS and the landmarks are distorted. Navigation is also helpful in patients with small pedicles and bony anomalies. The disadvantage is increased operative time and added expense to a surgery that is already lengthy and costly. In addition, there is always the possibility of registration error that could give the surgeon a false sense of security.

SURGICAL TECHNIQUE

In anterior cases, a standard Smith-Robinson approach is used with patients on a radiolucent table. If patients have had prior anterior surgery and preoperative work-up identified that the vocal cord has normal function on the side of the incision, the contralateral side is used for the approach to avoid scar tissue and provide an easier dissection. If the vocal cord has lost function on the side of the incision, the same incision should be used so as not to risk complete paralysis of the vocal cords.

In posterior cases, a midline incision is used. Subperiosteal dissection is performed to the lateral border of the lateral masses. Additional dissection laterally will lead to unnecessary bleeding. Meticulous hemostasis is maintained to minimize blood loss. Care is taken not to disrupt facet joints that are not to be included in the fusion. After exposure, an intraoperative CT scan may be obtained for use with navigation, if available. Pedicle screws are typically placed at C7 and in the thoracic spine, and lateral mass screws are placed from C3 to C6. If extending up to C2, the authors prefer to use pars screws; however, pedicle screws or laminar screws can also be used.

If an osteotomy is required, a temporary rod is used to provisionally hold the spine secure during the osteotomy and to prevent inadvertent translation. This rod is made by contouring a malleable rod template to fit into the screws before osteotomy. A titanium rod is bent to match the rod template and is provisionally secured to the screws. A second rod is bent similarly and then further contoured to conform to the planned corrective bend at the osteotomy site. The second rod replaces the first one at the time of osteotomy closure. Alternatively, commercially available hinged rods can be used for this purpose.

Cervical extension osteotomies are most commonly performed at C7. A complete laminectomy of C7 is performed with a high-speed bur. If the lamina and spinous process can be removed as a single unit, it should be saved for bone graft. Bone removed with Kerrison rongeurs can also be saved for bone graft. The inferior half of the C6

lamina and the superior half of the T1 lamina are removed. The facets and lateral masses of C7 are removed. The caudal aspect of the inferior facet of C6 and the cranial aspect of the superior facet of T1 should be excised. The C7 and C8 nerve roots are visualized and protected. The C7 pedicles and vertebral body are decancellated with a bur and curettes. The remaining C7 pedicle walls are resected. A Woodson elevator or reversed curette is placed in front of the posterior longitudinal ligament and used to push through the dorsal cortex into the cavity created in the C7 vertebral body. The first temporary rod is removed and the precontoured rod is connected to the thoracic pedicle screws. The MAP is increased to 90 mm, and an unscrubbed assistant unlocks the Mayfield and extends the neck. If bivector traction is used instead of the Mayfield device, the traction weight is switched to the extension rope at this point. The Mayfield is locked into position with the surgeon watching the spine and the unscrubbed assistant assessing the postcorrected chin-brow to table angle and coronal and axial alignment. The spinal cord, C7, and C8 nerve roots should be visualized to ensure that adequate bone was resected to prevent postoperative central or foraminal stenosis. The rod is seated in the proximal screws, and the opposite-side rod is contoured and secured to the spine. Multimodal IOM is checked throughout the procedure. If there are significant changes in latency or amplitude on the SEPs or MEPs or neurotonic discharges on the free running EMG monitoring, the MAP is elevated, the rods are released proximally, correction is reduced, and the decompression site is inspected. Further decompression is performed as needed. Images should be obtained to determine if translation has occurred. A wake-up test may be required. Assuming the IOM returns to baseline, the correction maneuver may be repeated. If the IOM does not return to baseline, it may be necessary to temporarily secure the spine in the uncorrected position and abort the procedure to assess the patients' neurologic status and perform further imaging.

Once the osteotomy site is closed, the spine is stabilized with the rods and cross-links are added, if deemed necessary. The wound is thoroughly irrigated. Local autograft is used as bone graft and augmented as needed. Typically, one drain is placed deep to the fascia and another is placed superficial to the fascia (see [Fig. 5D-F](#)).

POSTOPERATIVE MANAGEMENT

If patients are undergoing staged procedures, they may be kept intubated for airway protection

between stages. Regarding extubation, a cuff-leak test should be performed before extubation, and patients may remain intubated overnight. Risk factors for delayed extubation include extended operative time greater than 10 hours, obesity, transfusion of greater than 3 to 4 units of blood, 4-level anterior surgery, and revision anterior surgery.^{32,33}

Immobilization type and duration are based on stability and bone quality. Variation exists with surgeon preference. Most patients are immobilized in a soft or hard cervical collar for 6 to 12 weeks. Occasionally, immobilization is extended up with a halo or down with a cervicothoracic orthosis if fusion includes C2 or the cervicothoracic junction, respectively.³⁴

Patients are encouraged to ambulate. Their pain is initially controlled with patient-controlled intravenous analgesia until they demonstrate the ability to swallow. If they have difficulty swallowing, a swallowing study is obtained to avoid aspiration.

ADDITIONAL PEARLS

Preoperative planning is the key to success. It is important to incorporate contingency options into the preoperative plan, and these should be discussed with patients. Considerable time should be spent with patients preoperatively so they have realistic expectations and a firm understanding of the high-risk nature of cervical deformity surgery. Additional surgical stages may be required if adequate correction is not achieved, stability is questionable, or delayed union occurs. The fusion construct may need to be extended intraoperatively. If additional points of fixation are needed. Additional decompression may be required if IOM suggests a problem. Different fixation options should be planned in case fixation points are inadequate. For example, if fixation is to include C2, intralaminar screws can be used if pedicle or pars screws are not possible or have poor fixation. Finally, postoperative debriefing and good communication are essential. If multidisciplinary teams are involved, clarification should be given about the type of suction to be used on drains, dressings, and activities because common practice in some disciplines can be deleterious in specific circumstances. For example, placing a drain to wall suction in the setting of an unrecognized CSF leak can exacerbate the leak.

SUMMARY

Complex spinal deformities can be debilitating for patients, affecting quality of life. It is important to understand the cause, clinical manifestations,

and the patients' goals because these factors may impact treatment options. Multiple techniques exist, and surgical treatment should be individualized. Regardless of the approach chosen, careful preoperative planning and meticulous surgical technique are essential.

REFERENCES

1. Basu PS, Elsebaie H, Noordeen MH. Congenital spinal deformity: a comprehensive assessment at presentation. *Spine (Phila Pa 1976)* 2002;27:2255–9.
2. Han K, Lu C, Li J, et al. Surgical treatment of cervical kyphosis. *Eur Spine J* 2011;20:523–36.
3. Chi JH, Tay B, Stahl D, et al. Complex deformities of the cervical spine. *Neurosurg Clin N Am* 2007;18:295–304.
4. Hiratzka J. Degenerative cervical kyphosis: treatment, complications, and outcomes. *Semin Spine Surg* 2011;23:165–9.
5. Barsa P, Suchomel P. Factors affecting sagittal malalignment due to cage subsidence in standalone cage assisted anterior cervical fusion. *Eur Spine J* 2007;16:1395–400.
6. Rhee JM. Iatrogenic cervical deformity. *Semin Spine Surg* 2011;23:173–80.
7. Wang JC, McDonough PW, Endow K, et al. The effect of cervical plating on single-level anterior cervical discectomy and fusion. *J Spinal Disord* 1999;12:467–71.
8. Wang JC, McDonough PW, Endow KK, et al. Increased fusion rates with cervical plating for two-level anterior cervical discectomy and fusion. *Spine (Phila Pa 1976)* 2000;25:41–5.
9. Kaptain GJ, Simmons NE, Replogle RE, et al. Incidence and outcome of kyphotic deformity following laminectomy for cervical spondylotic myelopathy. *J Neurosurg* 2000;93:199–204.
10. Suk KS, Kim KT, Lee JH, et al. Sagittal alignment of the cervical spine after the laminoplasty. *Spine (Phila Pa 1976)* 2007;32:E656–60.
11. Hohl JB, Grabowski G, Donaldson WF. Cervical deformity in rheumatoid arthritis. *Semin Spine Surg* 2011;23:181–7.
12. Gerling MC, Bohlman HH. Dropped head deformity due to cervical myopathy: surgical treatment outcomes and complications spanning twenty years. *Spine* 2008;33:E739–45.
13. Suk KS, Kim KT, Lee SH, et al. Significance of chin-brow vertical angle in correction of kyphotic deformity of ankylosing spondylitis patients. *Spine (Phila Pa 1976)* 2003;28:2001–5.
14. Hardacker JW, Shuford RF, Capicotto PN, et al. Radiographic standing cervical segmental alignment in adult volunteers without neck symptoms. *Spine (Phila Pa 1976)* 1997;22:1472–80 [discussion: 1480].

15. Steinmetz MP, Kager CD, Benzel EC. Ventral correction of postsurgical cervical kyphosis. *J Neurosurg* 2003;98:1–7.
16. Nottmeier EW, Deen HG, Patel N, et al. Cervical kyphotic deformity correction using 360-degree reconstruction. *J Spinal Disord Tech* 2009;22:385–91.
17. Schultz KD Jr, McLaughlin MR, Haid RW Jr, et al. Single-stage anterior-posterior decompression and stabilization for complex cervical spine disorders. *J Neurosurg* 2000;93:214–21.
18. Wollowick AL, Kelly MP, Riew KD. Osteotomies for the treatment of cervical kyphosis caused by ankylosing spondylitis: indications and techniques. *Semin Spine Surg* 2011;23:188–98.
19. Herman JM, Sonntag VK. Cervical corpectomy and plate fixation for postlaminectomy kyphosis. *J Neurosurg* 1994;80:963–70.
20. Smith-Petersen MN, Larson CB, Aufranc OE. Osteotomy of the spine for correction of flexion deformity in rheumatoid arthritis. *Clin Orthop Relat Res* 1969;66:6–9.
21. Mason C, Cozen L, Adelstein L. Surgical correction of flexion deformity of the cervical spine. *Calif Med* 1953;79:244–6.
22. Simmons EH. The surgical correction of flexion deformity of the cervical spine in ankylosing spondylitis. *Clin Orthop Relat Res* 1972;86:132–43.
23. Mummaneni PV, Mummaneni VP, Haid RW Jr, et al. Cervical osteotomy for the correction of chin-on-chest deformity in ankylosing spondylitis. Technical note. *Neurosurg Focus* 2003;14:e9.
24. Cho KJ, Bridwell KH, Lenke LG, et al. Comparison of Smith-Petersen versus pedicle subtraction osteotomy for the correction of fixed sagittal imbalance. *Spine (Phila Pa 1976)* 2005;30:2030–7 [discussion: 2038].
25. Bouchard JA, Feibel RJ. Gradual multiplanar cervical osteotomy to correct kyphotic ankylosing spondylitic deformities. *Can J Surg* 2002;45:215–8.
26. Belanger TA, Milam RA 4th, Roh JS, et al. Cervicothoracic extension osteotomy for chin-on-chest deformity in ankylosing spondylitis. *J Bone Joint Surg Am* 2005;87:1732–8.
27. Langeloo DD, Journee HL, Pavlov PW, et al. Cervical osteotomy in ankylosing spondylitis: evaluation of new developments. *Eur Spine J* 2006;15:493–500.
28. Quraishi NA, Lewis SJ, Kelleher MO, et al. Intraoperative multimodality monitoring in adult spinal deformity: analysis of a prospective series of one hundred two cases with independent evaluation. *Spine (Phila Pa 1976)* 2009;34:1504–12.
29. Fehlings MG, Brodke DS, Norvell DC, et al. The evidence for intraoperative neurophysiological monitoring in spine surgery: does it make a difference? *Spine (Phila Pa 1976)* 2010;35:S37–46.
30. Hilibrand AS, Schwartz DM, Sethuraman V, et al. Comparison of transcranial electric motor and somatosensory evoked potential monitoring during cervical spine surgery. *J Bone Joint Surg Am* 2004;86:1248–53.
31. Tian NF, Huang QS, Zhou P, et al. Pedicle screw insertion accuracy with different assisted methods: a systematic review and meta-analysis of comparative studies. *Eur Spine J* 2011;20:846–59.
32. Kwon B, Yoo JU, Furey CG, et al. Risk factors for delayed extubation after single-stage, multi-level anterior cervical decompression and posterior fusion. *J Spinal Disord Tech* 2006;19:389–93.
33. Epstein NE, Hollingsworth R, Nardi D, et al. Can airway complications following multilevel anterior cervical surgery be avoided? *J Neurosurg* 2001;94:185–8.
34. Mummaneni PV, Dhall SS, Rodts GE, et al. Circumferential fusion for cervical kyphotic deformity. *J Neurosurg Spine* 2008;9:515–21.