The cervical spine provides the widest and most complex range of motion of all the spinal segments. It supports the mass of the head while allowing near-constant positional changes relative to the rest of the body. It is susceptible to degenerative misalignment with aging, and cervical deformity often necessitates surgical correction. Cervical kyphosis is one of the most prevalent adult spinal deformities and is often exacerbated by prior surgical destabilization; in comparison, cervical scoliotic deformities are encountered less frequently in adults and are more common in children with congenital and neuromuscular conditions.

Moderate to severe cervical kyphosis is often debilitating and leads to poor health-related quality of life (HRQOL). In addition, cervical deformity is a major cause of cervical myelopathy and can potentially lead to irreversible neurological damage.

The majority of deformity-related studies in the literature have focused on the thoracolumbar spine. Over the past decade, the pelvis’ influence on spinal deformity has been elucidated. Recently, several studies have explored the cervical spine’s role in influencing global spinal alignment, maintaining horizontal gaze, and affecting a person’s productivity and QOL. These studies review cervical alignment parameters and related outcome measures after deformity correction.

The decision-making process involved in choosing a surgical approach in cervical deformity correction, however, is not well summarized in literature. While there often is no single correct answer in spinal deformity surgery, we believe having a systematic algorithm for selecting a surgical approach may be of benefit and ultimately would improve outcomes. The purpose of this article is to introduce an algorithm for surgical approach selection based on morphological category.

Cervical Spine Alignment Parameters

Understanding the parameters to properly measure the degree of cervical deformity is critical for proper operative planning. Cervical alignment parameters are typically divided into 2 types: the first is to measure cervical lordosis (CL), the local measurement of cervical deformity.
mity; and the second is to measure the cervical spine in the sagittal plane, the global measurement of cervical deformity (Fig. 1).

The most commonly used method for determining CL is the Cobb angle, which involves measuring the angle between C-1 and C-7 or C-2 and C-7 on a sagittal cervical spine radiograph. This method includes drawing a line either parallel to the inferior endplate of C-2 or extending from the anterior tubercle of C-1 to the posterior margin of the spinous process and another line parallel to the inferior endplate of C-7. Perpendicular lines are then drawn from each of the two lines described above, and the angle subtended between the crossing of the perpendicular lines is the cervical curvature angle (that is, the cervical Cobb angle) (Fig. 2A).3

The Jackson physiological stress line method requires drawing two lines, both parallel to the posterior surface of the C-7 and C-2 vertebral bodies, and measuring the angle between them (Fig. 2B). Another popular measurement, the Harrison posterior tangent method, involves drawing parallel lines to the posterior surfaces of all cervical vertebral bodies from C-2 to C-7 and then summing the segmental angles for an overall cervical curvature angle (Fig. 2C). This method is considered to be the most accurate estimator of the CL, but the Cobb angle method remains the most commonly used due to its ease of use and reproducibility among the interpreters. Generally, C2–7 lordosis increases with aging, but a typical normal range is 15°–25° (± 15° [SD]).1

Successful cervical deformity correction needs to focus not only on restoring proper CL but also on achieving global balance of the cervical spine with other parts of the spine. Translation of the cervical spine in the sagittal plane is measured through the cervical sagittal vertical axis (SVA). Both C-2 SVA and C-7 SVA have been used to define sagittal alignment globally by measuring the distance between the C-2 and C-7 plumb lines from the superior corner of the sacrum (Fig. 3). Ideal sagittal balance is often defined as a C-7 plumb line less than 5 cm.8

Cervical SVA can also be defined regionally using the distance between a plumb line from C-2 and C-7 (C2–7 SVA). The C-2 SVA is especially clinically relevant to the HRQOL by many health surveys including neck disability index and Short Form 36-Item Health Survey (SF-36), in which a larger C-2 SVA relates to poorer HRQOL.1 As with CL, C2–7 SVA typically increases with aging, but the normal physiological range of the C2–7 SVA is reported to be 16.8 ± 11.2 mm in asymptomatic patients.9

Another helpful method of global measurement is the chin-brow vertical angle (CBVA). In advanced cases, patients develop severe rigid cervical kyphotic deformities that ultimately limit their horizontal gaze because of an inability to look up. Loss of horizontal gaze, which is measured using the CBVA, is significantly detrimental to one’s QOL.17

The CBVA is defined as the angle between a line drawn from a patient’s chin to the brow and a vertical line from the head straight down perpendicular to the floor (Fig. 4).7 It commonly ranges from −10° to +10°. Correcting CBVA has been shown to be associated with positive postoperative outcomes such as improved gaze, ambulation, and activities of daily living.17

The third global measurement concept predicting physiological sagittal cervical alignment is the neck tilt and the thoracic inlet angle (TIA) proposed by Lee et al.10 The T-1 slope is the angle of T-1 endplate to the horizontal plane, and the neck tilt is the angle between the vertical line to the sternum and the line connecting the sternum to the midpoint of T-1 endplate (Fig. 5).10 The TIA equals the sum of the T-1 slope and neck tilt angles. This concept is similar to that of the pelvic incidence for spinopelvic alignment where the pelvic incidence equals the sacral slope plus the pelvic tilt. It was found that the TIA had significant correlations with craniocervical sagittal balance, and to preserve a physiological neck tilt of around 44°, a large TIA increased the T-1 slope and CL and vice versa. Thus, TIA and T-1 slope can be used as parameters to predict physiological alignment of the cervical spine (or CL). The normal range of the T-1 slope is 22°–32°, and the average TIA in patients with no neck pain has been found to be 69.5°.2,10

A clinical photograph of a patient in an upright standing position with hips and knees extended while the neck is in a neutral position is used to assess CBVA, while sagittal scoliosis radiographs, of the patient in his/her usual standing position, from the head down to below the knee, will be used to measure accurate SVAs and T-1 slopes.
Determination of the degree of correction necessary requires deliberate consideration and recognition of the reciprocal relationships among craniocervical, subaxial, and thoracolumbar alignment (Fig. 6). Nojiri et al. conducted a radiographic evaluation of 313 asymptomatic volunteers to clarify the alignment relationship between the upper and lower cervical spine. They found a statistically significant negative correlation between occiput–C2 and C2–7 angles and between C1–2 and C2–7 angles.12

Essentially, patients who had subaxial kyphosis developed compensatory hyperextension of the craniocervical junction. This relationship should be taken into account when performing occipitocervical fusion procedures. If the surgeon only focuses on keeping the neck “straight” during an occipitocervical fusion, then a patient with subaxial kyphosis may end up having a limited upgaze. Lee et al. found significant correlations between the TIA and both the cranial offset and craniocervical alignment.10 A small TIA creates a small T-1 slope and a small CL angle to maintain the physiological neck tilting. These also may be used as parameters to predict physiological alignment and guide deformity corrections. The T-1 slope also varies based on global spinal alignment as measured by SVA and upper thoracic kyphosis (the larger the SVA and thoracic kyphosis, the larger the T-1 slope). Several studies have analyzed subaxial cervical alignment with thoracolumbar alignment. Hilibrand et al.4 and Hwang et al.7 emphasized that pelvic incidence correlates with lumbar lordosis, lumbar lordosis correlates with thoracic kyphosis, and thoracic kyphosis correlates with CL. Thus, an increase in pelvic incidence correlates with an increase in lumbar lordosis, which correlates with an increase in thoracic kyphosis. As thoracic kyphosis increases, CL also increases. However, this change in CL is not large enough to maintain the head over the pelvis, albeit providing adequate maintenance of horizontal gaze. Understanding these interplays between the segments below and above the surgical segment will prevent overcorrection or undercorrection, as well as tease out whether the deformity in cervical spine is actually a compensatory mechanism induced by other segmental deformity.

In their series of 113 patients who underwent posterior cervical fusion surgery for cervical kyphosis correction, Tang et al. realized that a postoperative C2–7 SVA larger than 40 mm was correlated with poor neck disability index despite overall improved cervical alignment.19 This shows that decreasing the degree of kyphosis without also reaching a certain correction threshold does not guarantee an improved clinical outcome. Not every deformity can be corrected to a normal C2–7 SVA of around 20 mm, but, in general, the literature suggests striving to achieve at least a straight spine.16 Several recent reports1,2 have provided data regarding the normal range of cervical alignment parameters stratified by patient age and sex. Though these ranges do not need to be committed to memory, perhaps they should be easily accessible to allow for deliberate calculation of ideal degrees of correction to achieve an agronomic sagittal balance rather than simply “eyeballing.”

Similarly crucial is the knowledge of the range of correction that each approach provides. The degree of deformity correction relies on biomechanical and geometrical properties of the spinal column, and some approaches cannot feasibly attain such a large correction in sagittal alignment. Etame et al.,2 in their review of 14 cervical kyphosis correction articles with a total of 399 subjects, summarized the average degrees of correction for different surgical approaches. They found that ventral release and fusion had the least amount of correction of 11°–32°, while dorsal pedicle subtraction osteotomy (PSO) had 23°–54°, which was similar to the ventral and dorsal combined approach that provided a range of 24°–61.4° in Cobb angle (Table 1). While dorsal-alone approach without osteotomy is feasible if the deformity is not fixed ven-
trally, it has been emphasized that dorsal instrumentation alone is not effective in restoring CL; rather, it only serves to help in reduction of degree of kyphosis.16

Algorithm of Surgical Approach Selection

After proper assessment of cervical deformity and clinical indications for surgery, one must choose the appropriate surgical approach for deformity correction. The approaches can be largely categorized into anterior (ventral), posterior (dorsal), and combined anterior and posterior (360°) surgeries. Though most spine surgeons are aware of these approaches and are technically capable of performing any of them, selecting the appropriate approaches is often not straightforward. This ambiguity stems from a lack of systematic approach selection based on the specific morphology of the deformity. Our institution has a tradition of a combined neurosurgery and orthopedic surgery daily morning spine conferences to discuss the operative cases of the day and to review the postoperative imaging studies from the previous day’s surgeries. Strategy for deformity correction is often discussed and agreed upon by consensus during this conference. This was our impetus to describe an algorithmic strategy for selecting a surgical approach in cervical deformity. Figure 7 summarizes the decision-making tree of this algorithm.

In this algorithm, we subdivide deformities into 2 broad categories: fixed (not passively correctable) and nonfixed (passively correctable). Fixed deformity can then be subdivided into those that are nonankylosed or those that are ankylosed based on the morphology of joints and bony elements. These can be further categorized into 5 different basic morphological categories (green highlighted boxes in Fig. 7). We propose 7 different surgical approaches to manage them according to their morphological and pathological features (yellow highlighted boxes in Fig. 7). We will address each surgical approach mentioned in this algorithm with a concrete case example to illustrate how one can make organized decisions in cervical kyphotic deformity management.

Approach 1. Fixed Deformity: Not Ankylosed → Anterior Release and Grafting With or Without Posterior Fusion

Case 1

A 45-year-old man presented with a 3-month history of severe neck and right arm pain. His neurological examination was positive for right-sided radicular pain along the C-5 distribution, but was otherwise normal.

Imaging and Assessment of Deformity

Cervical lateral radiography in flexion and extension showed kyphosis at C4–5 that was not reducible upon extension (Fig. 8A). Both CBVA (−10°) and T-1 slope (22°) were normal. The C2–7 CL showed 10° of kyphosis. Computed tomography scanning demonstrated no evidence of ossification of the posterior longitudinal ligament (OPLL) or facet joint fusion. Magnetic resonance
Algorithmic selection of cervical deformity surgery

imaging revealed mild ventral C4–5 compression of spinal cord with foraminal stenosis greater on the right larger than left, causing compression of the right C5 nerve root (Fig. 8B and C).

Surgical Strategy

This patient had cervical kyphosis morphology that fit Category 1 on the algorithm. To restore a normal amount of CL (around 15°), the degree of correction necessary is at least 25°. Since the patient had a T-1 slope within the normal range, his thoracolumbar spine sagittal balance should not impact the cervical deformity correction.

The patient underwent C4–5, C5–6, and C6–7 discectomies and placement of 3 trapezoid interbody allografts and a dynamic ventral plate (Fig. 8D). A ventral approach–alone strategy can correct 11°–32° of kyphosis, and since the patient did not have dorsal cord compression, posterior decompression and placement of instrumentation were not necessary. This multilevel discectomy and ventral fusion permitted 24° of lordosis with postoperative C2–7 CL of 14°. After surgery, the patient had relief of both his neck and arm pain. This correction was maintained during the follow-up period with minimal change in sagittal angle.

Discussion

A ventral approach–alone strategy such as that in this case may be used when the deformity is fixed and ankylosis of the facet joints is absent. This approach permits de-
compression of ventral pathology as well as reconstruction (deformity correction) with multilevel anterior interbody or strut grafting and instrumentation. This strategy uses both posture and biomechanical principles to correct cervical deformity.16

During surgery, after release of anterior soft tissue and discectomy/corpectomy, Caspar distraction pins are placed in a convergent fashion and the distraction of the posts provides segmental extension and overall lordosis. Notably, the ability to extend with the Caspar pins is only possible in the presence of nonfused facet joints and uncinated processes. Also, to attain optimal lordosis, multiple segmental discectomies and distraction at each level and the placement of wedged interbody grafts (large ventrally) provide combined results of greater and more physiological lordosis. This also avoids long-segment corpectomies and provides intermediate points of implant fixation, which reduces graft kickouts and pseudarthrosis. A plate contoured in lordosis is inserted, with screws first placed at craniocaudal ends. Subsequently, screws are placed in the intervening vertebral body to achieve multiple fixation point. This brings the spine to the implant plate, which helps to maintain the CL and fusion while minimizing terminal screw-bone interface degradation. With a ventral-alone strategy, because there is no posterior instrumentation acting as tension band to hold up the neck, using a dynamic ventral plate that allows deformation in the axial plane while preventing sagittal plane deformation can help with controlled subsidence and increased fusion rate.16

<table>
<thead>
<tr>
<th>Approach</th>
<th>Mean Correction (Cobb angle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ventral release &amp; fusion</td>
<td>11°–32°</td>
</tr>
<tr>
<td>dorsal PSO</td>
<td>23°–54°; 35°–52° in CBVA</td>
</tr>
<tr>
<td>combined</td>
<td>24°–61.4°</td>
</tr>
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FIG. 7. Schematics for algorithmic selection of cervical deformity surgical approaches based on morphology. ACDF = anterior cervical discectomy and fusion; AP = anterior-posterior.
Algorithmic selection of cervical deformity surgery

![Image](https://example.com/image.jpg)

**Fig. 8.** Case 1. Preoperative and postoperative images. **A:** Lateral radiograph measuring Cobb angle and T-1 slope. **B:** Axial T2-weighted MR image showing a C4–5 laterally herniated disc with right C-5 root compression. **C:** Sagittal T1-weighted MR image demonstrating ventral compression of spinal cord at C4–5 due to kyphotic deformity. **D:** Postoperative lateral radiograph showing results after ventral C4–5, C5–6, and C6–7 discectomy, allograft with dynamic plating.

revealed that C3–4 was autofused at a subluxated position and C5–6 was also auto-fused ventrally. Cord compression from C-2 to C-5 was demonstrated on MRI. His CBVA was normal (0°) (Fig. 9).

**Surgical Strategy**

This patient had the second type of fixed deformity (Category 2), with a fixed cervical kyphoscoliosis and ankylosed anterior segment. The goal of surgery was to restore normal CL and decompress the spinal cord to treat the patient’s myelopathy. The correction necessary was 45° (30° kyphosis + 15° normal lordosis). This degree of correction cannot be achieved by ventral release and fusion alone, whereas the combined anterior and posterior, or 360°, approach is conducive to this degree of correction.²

He was treated with anterior osteotomies and posterior decompression and instrumentation.

After the patient was positioned supine, an anterior approach for osteotomy was performed on the autofused levels, and discectomy was performed at the intervening levels. This permitted decompression and interbody allograft placements at C2–3, C3–4, C4–5, C5–6, C6–7, and C7–T1. The patient was then flipped to the prone position while making sure that the neutral position of cervical alignment in a Mayfield head holder was maintained. We then performed posterior decompression from C-3 to C-7 and fusion from C-2 to T-2, placing lateral mass and pedicle screws from C-7 to T-2. Postoperatively his bilateral arm weakness showed significant improvement within the 1st week and his myelopathic symptoms improved over time. Postoperative C2–7 CL was 10° (Fig. 10). By placing interbody grafts at each level, cervical re-duction was achieved not in only the sagittal plane but also in the coronal plane to correct the scoliosis.

**Discussion**

When the deformity is fixed and the anterior element is ankylosed with autofusions, as in the present case, the deformity cannot be corrected unless an anterior osteotomy is performed first. Often in a severe cervical kyphosis case such as this one, the patient has a neurological deficit necessitating decompression. An anterior osteotomy and subsequent posterior fusion permit ventral lengthening and dorsal shortening and, therefore, kyphosis reduction.³²

Even if the decompression is not necessary, a dorsal construct provides a long-moment arm, a strategy to aid in deformity prevention with the benefit of multiple fixation points.³³

Notably, performing multiple levels of osteotomy and/or discectomy to implant grafts over several levels is more favorable than corpectomies with a long strut grafting. Wang and Bohlman et al.,²¹ in their series of 249 consecutive patients treated with anterior corpectomies and strut grafting, demonstrated that 2 factors, a greater number of vertebral bodies removed and a longer graft, are directly related to an increased frequency of graft displacement. In addition to an increased failure rate, corpectomy with strut grafting is not effective in cervical kyphosis correction even with use of a lordotic graft. Villavicencio et al. conducted a randomized controlled trial of 122 patients to study whether the lordotic graft is superior to the parallel graft in restoring CL and found that there was no statistical difference between the two in terms of postoperative restoration of cervical Cobb angle; instead, maintaining a consistent segmental sagittal alignment or increasing segmental lordosis with multiple segmental discectomy and grafting was related to a higher degree of improvement in CL as well as clinical outcomes.²⁰


**Case 3**

A 69-year-old man, who underwent posterior C2–5 decompression and fusion for cervical myelopathy 4 years previously, presented with progressive neck pain and bilateral upper- and lower-extremity spasticity. His neurological examination was positive for bilateral triiceps weakness (Grade 4/5), hyperreflexia, Hoffman sign, Babinski sign, and clonus.

**Imaging and Deformity Assessment**

Flexion-extension radiography showed a C2–5 fusion in kyphosis and adjacent-level instability at C5–6 exacerbating the kyphotic deformity. The Cobb angle was 52° in kyphosis. Magnetic resonance imaging revealed C-1 posterior arch compression of spinal cord. The C2–7 SVA was 81 mm (the average C2–7 SVA in an asymptomatic
individual is 20 mm). The patient had loss of horizontal gaze and his CBVA was 40°. The T-1 slope was normal (15°) (Fig. 11).

Surgical Strategy

This is a typical example of a Category 3 deformity in which there is a fixed cervical kyphosis with ankylosed posterior elements (due to previous posterior cervical fusion). This patient developed a fixed kyphotic deformity at the level below the previous posterior cervical fusion, which contributed to even larger overall cervical kyphosis. The minimum correction necessary to attain straight sagittal neck alignment is 52°. As indicated in the algorithm, these deformities usually require 3-step surgery including posterior osteotomy, anterior release, and posterior fusion (also known as the “PAP” approach).

First, to achieve kyphosis correction, posterior osteotomy at C4–5 was carried out to release the previous fusion mass after removal of old instrumentation. A C-1 laminectomy was performed to decompress the spinal cord.
Algorithmic selection of cervical deformity surgery

dorsally; to address the craniocervical instability resulting from decompression, the instrumentation was extended up to the occiput for occipitocervical fusion. In addition, a C5–6 laminoforaminotomy was conducted to decompress the symptomatic C-6 nerve roots. Subsequently, instrumentation was extended down to T-2 to address the C5–6 instability (Fig. 12). The patient was then flipped to the supine position; C4–5 and C6–7 osteotomies were performed for the auto-fused segments; and C3–4, C7–T1, and T1–2 anterior discectomies and placement of interbody grafts were performed to correct kyphotic deformity. Lastly, the patient was flipped back to the prone position with great attention to maintaining stability of the cervical spine. Cervical lateral fluoroscopy was used to ensure that the cervical spine was in physiological alignment before fixing with Mayfield head holder. The dorsal construct rods were placed and posterior fusion was carried out from the occiput to T-2. Postoperatively, the patient had restoration of 3° CL with total of 55° of correction. His CBVA was 5° and his horizontal gaze improved.

Discussion

A combined approach is commonly required when there is a need for both dorsal and ventral decompression and/or osteotomies for release. Moreover, dorsal instrumentation is added if the ventral construct is not believed to provide adequate stability such as when only a bridging implant is used without anterior instrumentation. The choice of which approach to use first is generally surgeon specific. We typically choose a dorsal approach first and subsequently perform ventral release and correction. The ventral approach provides the greatest degree of leverage and overall correction.

At times, dorsal instrumentation is present as in this case example. In these circumstances, a posterior-anterior-posterior approach is undertaken to ensure full release of ankylosis before the kyphosis correction can be carried out safely.

Approach 4. Fixed Deformity: Circumferentially Fused Cervicothoracic Junction → Pedicle Subtraction Osteotomy

Case 4

A 72-year-old man presented with loss of horizontal gaze, worsening axial neck and back pain, and severely impaired activities of daily living. The patient exhibited no neurological deficit on examination.

Imaging and Deformity Assessment

Cervical radiography and CT revealed ankylosing spondylitis (AS), a large thoracic kyphotic deformity, large T-1 slope of 60°, and subaxial hypolordosis. There was rigid fusion circumferentially. No spinal cord compression was found on MRI. His CBVA was 40° (Fig. 13), and his C2–7 SVA was 86 mm.

Surgical Strategy

Ankylosing spondylitis and diffuse idiopathic skeletal hyperostosis (DISH) comprise a unique form of cervicothoracic kyphosis, a fixed and circumferentially ankylosed deformity (Category 4). These kyphotic deformities across the cervicothoracic junction (CTJ) are collectively called CTJ kyphosis. Deformity corrections in these cases are ideally performed by PSO across the CTJ. The osteotomy angle was determined from preoperative radiographic measurements including cervicothoracic alignment in the sagittal plane, the angle of CTJ kyphosis, and CBVA. The patient needed correction of approximately 50° to achieve normal CBVA, which would allow adequate horizontal gaze. This goal of correction would be achievable with 1-level vertebral body PSO (typically 23°–54° of correction).

The site of osteotomy was chosen to be C-7 because it was the site of maximal deformity. Also, the spinal canal at C7–T1 is larger than the than it is in the midcervical region, thereby preventing likelihood of cord impingement after osteotomy closure. Preoperative imaging was used to confirm the location of vertebral artery and the nerve roots to avoid their compression.

Following general anesthesia, the patient was placed in Gardner-Wells tongs for head fixation on a Jackson
Intubation was done with the patient in a sitting position because we were unable to lay him flat in a supine position. He was then turned prone on the Jackson table and the tongs was secured (Fig. 13). We routinely use neuromonitoring of somatosensory evoked potentials and motor evoked potentials and a cell saver in anticipation of large volume of blood loss resulting from the osteotomy. Standard posterior cervical exposure, extending 5 levels above and below the osteotomy level, was carried out. Prior to laminectomies, pedicle screws and lateral mass screws were placed, excluding the PSO level. A complete laminectomy was performed at the osteotomy level. Partial resection of the spinous processes and laminectomies of adjacent levels were performed to allow adequate room for the “buckling” of the dura mater and to prevent osseous impingement of the spinal cord after osteotomy closure. Partial facetectomies at C6–7 and C7–T1 were done to provide added exposure of the nerve roots. The nerve root caudal to the pedicle was exposed and the neural foramen was extensively decompressed.
Laminar decompression was extended from the pedicle above the wedge to the pedicle below the wedge to create a large foramen containing the 2 nerve roots. This construct prevents C-7 and C-8 nerve root impingement. A high-speed drill was then used to bur out the pedicles to their cortical shell, and a rongeur was used to resect the shell completely. Curettes and rongeurs were utilized to remove the cancellous bone from the vertebral body in a tapered wedge shape. Careful control of blood loss with a hemostatic agent and symmetrical resection of vertebral body to allow for uniform closure of “osteotomized” surface are paramount during this process. A temporary holding rod was placed on one side of the spine to prevent translation-induced neurological deficit. The wedge osteotomy was then closed by gentle elevation of the patient’s head held in Jackson table cranial fixation frame. The temporary rods prevent sudden translation during the osteotomy closure and enable a controlled correction. The lateral masses were tightly squeezed together to promote stability and facilitate fusion. The Gardner-Wells tongs were then locked into the physiological alignment, and an intraoperative lateral radiograph was obtained to check the sagittal alignment. The permanent rods were then attached to the screws. Further reduction was obtained using gentle compression across the osteotomy before screw tightening. In this case, the instrumentation was carried out from the C-2 to T-4 level (lateral mass screws up to C-6 and pedicle screws from T-1 to T-4). Postoperatively the patient was kept in a cervicothoracic orthosis for at least 4 months. His C2–7 CL was restored to $-5^\circ$ and his CBVA was corrected to $-8^\circ$ (Fig. 14).

**Discussion**

A CTJ deformity can be extremely debilitating because of the development of a chin-on-chest deformity, which significantly compromises horizontal gaze. Neurological deficits can also arise in addition to other debilitating symptoms, including limitation of chewing, speaking, and swallowing. In patients with AS, CTJ kyphosis poses a unique problem as the anterior portion of the spine is more vulnerable to compression forces, and thus multisegment anterior fusion construct will often result in failure. Additionally, this area is more difficult to access anteriorly than posteriorly owing to bony structures such as sternum and ribs. Though traditionally reported for correction of kyphotic deformity in the thoracic or lumbar region, the PSO has been increasingly used for CTJ kyphosis in light of recent advances in fusion tech-

![Fig. 12. Case 3. Intraoperative and postoperative images.](image-url)
Fig. 13. Case 4.  
A: Preoperative clinical photograph showing a CBVA of 40° and limited horizontal gaze.  
B: Cervical CT scan showing typical feature of AS with CTJ kyphosis.  
C: Intraoperative positioning of the patient in Gardner-Wells tongs. The patient was intubated in the sitting position due to inability to lay flat in a supine position. He was then turned 180° to a prone position on a Jackson table with the tongs fixed to the bed.  
D: A posterior approach was used to expose the spine from C-2 to high thoracic level, and instrumentation was placed.

Fig. 14. Case 4. Postoperative images.  
A and B: Postoperative cervical radiographs demonstrating instrumentation from C-2 to T-4 with PSO at C-7.  
C: Photograph showing CBVA correction to –8°.
Algorithmic selection of cervical deformity surgery

Techniques, anesthesia, and intraoperative neurophysiological monitoring. An intact anterior motion segment is not required when performing a PSO, and the procedure can be done through a previous fusion mass. This method has its fulcrum through the anterior spinal column and ultimately shortens the spinal canal. It also results in bone-on-bone contact, which facilitates fusion. These characteristics make the technique suitable for an AS patient with a solidly fused “bamboo” spine. Another possible and commonly used posterior osteotomy technique is Smith-Petersen osteotomy, which requires an intact anterior motion segment. Several studies suggest performing an osteotomy at T-1 rather than C-7 to avoid upper-extremity radiculopathy as much as possible.6,11

Approach 5. Flexible Deformity → Anterior Discectomy or Corpectomy With Fusion

Case 5

A 56-year-old woman who had undergone anterior C6–7 discectomy and fusion 5 years prior to presentation returned with neck pain, bilateral upper-extremity radiculopathy (right side worse than left), and gait disturbance. She had deltoid and biceps weakness (Grade 4/5), which was worse on the right side than left, and paresthesia in the distribution of the right C-5 nerve root.

Imaging and Assessment of Deformity

Cervical dynamic radiography showed a well-fused C6–7 segment and mild kyphosis of C-4 over C-5, which was exacerbated upon flexion and reduced upon extension. Magnetic resonance imaging showed a disc osteophyte complex at C4–5, with focal kyphosis and indentation of the spinal cord and bilateral foraminal narrowing at this level. The cervical Cobb angle showed 5° of kyphosis and the T-1 slope was normal (15°) (Fig. 15).

Surgical Strategy

This was a case of flexible or passively correctable kyphotic deformity that could be treated using an anterior approach alone because the degree of kyphosis was mild and limited to 1 level. This was a Category 5 deformity in which, despite the fact that the deformity was reducible, the patient was symptomatic with radiculopathy. As the instability at C4–5 progresses, the patient would likely experience worsening symptoms and focal kyphosis. The surgical goal was to decompress the spinal cord and nerve roots ventrally and to stabilize the motion segment at the kyphotic C4–5 segment while restoring CL. The desired degree of correction would be 15° to attain Cobb angle of 5° of kyphosis, which is reducible upon extension. We performed a standard anterior C4–5 discectomy and fusion, placing a trapezoid allograft and anterior plate construct. A bilateral C4–5 foraminotomy was also carried out for C-5 nerve root decompression to address her deltoid/biceps weakness and radicular pain. The decision was made not to include the C5–6 level in the fusion construct since MRI demonstrated no significant degenerative changes at the intervening level. Postoperative cervical radiography showed a C2–7 CL of 10°. The patient’s radiculopathy completely resolved at the 2-month follow-up.

Discussion

Typically, local kyphosis resulting from cervical degeneration can be managed with a single anterior decompression and fusion procedure. We believe this to be dependent on the decompression spanning only 3 disc spaces or 2 vertebral bodies. In contrast, the kyphosis resulting from an iatrogenic destabilization procedure

![Fig. 15. Case 5. A: Preoperative images demonstrating a Cobb angle of 5° of kyphosis, which is reducible upon extension. B: Sagittal T2-weighted MR image showing kyphosis at C4–5 abutting the spinal cord. C: Postoperative radiographs after anterior decompression (discectomy) and fusion at C4–5 that restored CL of 10°.](image-url)
such as multilevel laminectomy requires more extensive reconstruction.\textsuperscript{13}

Although the anterior-only approach improves sagittal alignment, it usually does not allow enough correction of a kyphotic deformity. It does, however, have the benefits of producing less postoperative pain, better fusion results, and shorter operative time.

**Approach 6. Flexible Deformity → Posterior Decompression and Fusion**

**Case 6**

A 71-year-old woman with a history of C5–7 laminoforaminotomies dating back to the 1980s presented having experienced frequent falls, worsening neck pain, and a change in handwriting. On examination, she exhibited unsteady gait, mild proximal leg muscle weakness, but no abnormal reflexes.

**Imaging and Assessment of Deformity**

Cervical flexion-extension radiography showed lower cervical spine kyphotic deformity with C-4 subluxated onto C-5 that reduced upon extension. Her C2–7 CL was 13° on flexion, and her T-1 slope was 18°. Cervical CT scanning revealed focal kyphosis forming below C-5, corresponding to the prior laminectomy site, but no ankylosis was observed in this deformity. Magnetic resonance imaging showed severe cord compression at C3–4 and C4–5 that corresponded to the junctional kyphosis and C4–5 instability (Fig. 16).

**Surgical Strategy**

This is an example of Category 6 deformity in which moderate but flexible cervical deformity resulting from postlaminectomy-related kyphosis is treated with posterior decompression and fusion. There was no ankylosis over the kyphotic segment, and C4–5 was reducible to a certain extent with extension. Since the patient had myelopathy due to cervical spinal cord compression at the unstable motion segment, decompression was necessary. Also, because of postlaminectomy kyphosis spanning from C-4 to C-7 (>3 levels), a posterior instrumentation and fusion procedure was more appropriate. In this case, a standard posterior cervical approach was used for C3–5 laminectomy to achieve decompression, and this was followed by lateral mass fusion from C-3 to C-7 to restore sagittal alignment. Postoperatively the patient’s Cobb angle was 4° in lordosis, and her gait disturbance improved over time.

**Discussion**

When the kyphosis spans more than 3 levels and the deformity is correctable with traction or postural change, a dorsal-alone strategy may be used. It is a reasonable selection for the mild to moderate postlaminectomy kyphosis as shown in this case. Some surgeons might use preoperative traction to reduce the deformity and then bring the patient into the operating room with continued traction.\textsuperscript{15}

Alternatively, the cervical alignment may be carefully corrected in the operating room by using the Mayfield head holder and lateral radiographs to confirm the proper alignment before performing fusion. This ensures adequate deformity correction before fusing the spine into the position. One downfall to the dorsal fixation using lateral mass screws is that, while it can correct kyphosis to a certain extent, it is not effective in restoring lordosis.\textsuperscript{16}

Although this approach is associated with the benefit of reduced morbidity, operative time, and surgical processes (for example, no need to turn the patient around and do the front-side fusion and so on) compared with the 360° technique, one must carefully select candidates who will benefit from the posterior approach alone in correction of sagittal balance.

**Approach 7. Flexible Deformity → Combined Anterior and Posterior Approach**

**Case 7**

A 67-year-old woman presented with progressive inability to lift her head, gait disturbance, and axial neck pain. She had mild hyperreflexia in the bilateral upper extremities and was unable to walk in a straight line using tandem gait.

**Imaging and Assessment of Deformity**

Lateral cervical radiography showed moderate, reducible cervical kyphosis over the entire cervical spine. The patient’s cervical Cobb angle was 36° of kyphosis while in flexion, but this reduced to 16° of kyphosis in extension. Computed tomography showed no evidence of ankylosis or OPLL. Magnetic resonance imaging revealed diffuse cord signal with cervical stenosis spanning from C-3 to C-6. The patient’s T-1 slope was 30°, her CBVA was normal at ~3°, but her C2 SVA was 15 cm (normal < 5 cm) (Fig. 17).

**Surgical Strategy**

This case represents a Category 7 cervical deformity in which a moderate to severe degree of reducible cervical deformity is treated with a combined anterior and posterior (360°) approach. Due to the large degree of kyphosis (35°) and involvement of multiple levels, to meet the goal correction of 45° (aiming for 10° lordosis), a 360° approach is often necessary. The patient underwent an anterior approach for discectomy at C3–4, C4–5, and C6–7, and trapezoid allografts were placed with the wide side on the ventral side (C-4 was partially “corpectomized” for decompression). Subsequently, the patient was turned prone with the Mayfield head holder and her neck was placed in a neutral position. Lateral mass screws were then placed from C-3 to C-6 and pedicle screws were placed at C-7 and T-1. A C3–7 laminectomy was conducted for posterior decompression. Intraoperatively, the C4–5 level was found to be ankylosed, so this level required osteotomy to attain better cervical alignment. Once the deformity had been reduced, her cervical spine was realigned into a more lordotic position and rods were secured with pedicle screw caps. Postoperatively, the patient’s neck was in the neutral position and we were able
Algorithmic selection of cervical deformity surgery

Fig. 16. Case 6.   A: Preoperative cervical radiographs showing postlaminectomy kyphosis that is worst at C4–5. The Cobb angle is 13°. The deformity is partially reducible upon extension. B: Cervical CT scan demonstrating no evidence of ankylosis. C: Preoperative MR image showing spinal cord compression at the C4–5 level, the beginning of kyphosis, and also the area of instability. D: Postoperative anteroposterior and lateral radiographs after a posterior-only approach for C3–7 fusion restoring near CL.

to correct 35°. Her C-2 SVA reduced to 3 cm and she was able to look up without difficulty on follow-up (Fig. 18).

Discussion

Even with a reducible cervical kyphotic deformity, a patient could benefit from a 360° correction in moderate to severe cases. Combined approaches will correct more degrees of kyphosis, provide ventral and dorsal support to the construct, and allow better decompression. In this particular case, kyphosis was only partially correctable on extension because of the ankylosed segment in the C4–5 facet that was found intraoperatively. However, even in cases in which the cervical kyphosis is completely reducible, a posterior approach alone may not be enough to restore CL and could be associated with a higher incidence of C-5 palsy. In their study of 72 patients with kyphosis who underwent posterior decompression and fusion, Takemitsu et al. found that there was a significantly higher incidence of C-5 palsy.18

A combined anterior and posterior approach to correct degenerative kyphosis is indicated in the following cases: 1) multilevel spondylosis requiring extensive anterior decompression in addition to posterior decompression, 2) degenerative kyphosis that is moderate to severe, and 3) postlaminectomy kyphosis and S-type curves. In most of these settings, the purpose of the posterior fusion is for stabilizing the long anterior strut graft or multisegmental allografts and obviating the need for external support. An anterior stabilization and arthrodesis procedure is a good way to allow for correction of a kyphotic deformity by safely hinging the correction on the posterior longitudinal ligament. Augmentation with a posterior arthrodesis assists in maintaining the graft under compression, and thus may lessen the tensile forces.

Complications of Cervical Deformity Surgery

Complications from cervical deformity correction surgery are not trivial and potentially include long-term morbidity and even mortality. Understanding potential complications associated with each approach is also necessary in the decision-making process. In a report on consecutive series of 76 patients who underwent cervical kyphosis corrections, Grosso et al.2 noted 26 perioperative complications (34%). Among these, the combined approach was associated with the highest complication rate (40%), and this was followed by the ventral approach (30%) and the dorsal approach (27%). The most common perioperative complications were deep vein thrombosis (10.5%), deep wound infection (7.9%), pneumonia (5.2%), pulmonary embolism (3.9%), postoperative hematoma (3.9%), and nontransient dysphagia (> 1 month) requiring a feeding tube (2.6%). They also found that there was a greater risk of complications with the degree of kyphosis
correction; however, those who did not meet the goal for the degree of correction and had persistent kyphosis postoperatively had worse long-term QOL scores than those who gained CL on follow-up, as measured by modified Japanese Orthopedic Association scores.\textsuperscript{3}

Etame et al.\textsuperscript{2} published their review of cervical kyphotic deformity outcomes from 14 clinical studies that involved a total 399 patients and found that 5 studies reported mortality rates ranging from 3.1\% to 6.7\% and major medical complications ranging from 3.1\% to 44.4\%, with a neurological injury rate of 13.5\% and a pseudarthrosis rate of 3.8\%. The most significant number of neurological complications was seen in patients treated by dorsal osteotomy at the cervicothoracic interface.\textsuperscript{2}

Westerveld et al.\textsuperscript{2} found that although serious complications, such as massive hemorrhage, aortic dissections, and strokes during immediate perioperative stage, occurred in association with surgical correction of CTJ kyphosis in these patients, long-term complications such as pneumonia, respiratory insufficiency, and nonunion and further neurological deficits were much more prevalent in the conservative management group.\textsuperscript{22}

Conclusions

We introduced an algorithm for selecting surgical approaches for cervical deformity correction based on the morphology of deformities and provided concrete case illustrations. Though this algorithm is not an abso-
Algorithmic selection of cervical deformity surgery

lute answer, it should help to eliminate ambivalence in choosing cervical deformity approaches for young spine surgeons and trainees. Secondly, this should provide a good comparative flow chart of the various approaches to act as a comparative decision-aiding tool. This algorithmic approach, in combination with proper assessment of cervical deformity, determination of the goal of correction based on global spinal alignment, and risk avoidance from studying the possible complications, can serve to promote more successful and safe cervical deformity correction. Future work should address thresholds for decision making on alignment and deformity correction establishment as well as what factors may have the largest impact on HRQOL.

Disclosure

Dr. Harrop is a consultant for DePuy and Bioventus. Dr. Albert is a stockholder in Paradigm Spine, ASIP, Biomirix, Breakaway Imaging, Crosstree Capital Partners, In Vivo Therapeutics, Invuity, Pioneer Surgical, Vertech, and Gentis; he is a consultant for Factel-link, DePuy, United Healthcare, and Biomet Spine; and he is an employee of the Rothman Institute.

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22. Westerveld LA, DePuy, United Healthcare, and Biomet Spine; and he is an employee of the Rothman Institute.

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