Assessment and Treatment of Cervical Deformity

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KEYWORDS

• Cervical deformity • Cervical spine osteotomy • Cervical alignment • Pedicle subtraction osteotomy

KEY POINTS

- The significant mass of the head is supported by the cervical spine, and significant deviation from normal alignment increases cantilever loads and muscular activity. In addition, the flexible, mobile cervical segment is connected to the relatively fixed thoracic spine.
- The T1 inclination will determine the amount of subaxial lordosis required to maintain the center of gravity of the head in a balanced position and will vary depending on global spinal alignment as measured by the sagittal vertical axis (SVA) and by inherent upper thoracic kyphosis.
- The radiographic parameters that effect health-related quality of life scores are not well defined in comparison with global/pelvic parameters in thoracolumbar deformity. Chin-brow vertical angle, cervical SVA (C2 SVA), and regional cervical lordosis should all be considered in preoperative planning strategies involving standing 3-ft radiographs in which the external auditory canal (approximation of head center of mass) to femoral heads are visible.
- At the craniocervical junction, an anterior approach with initial anterior linear osteotomy, posterior release and reduction of facet-joint subluxation, and segmental stabilization may be used. A SmithPetersen osteotomy, a pedicle subtraction osteotomy, or a circumferential osteotomy may be used at the mid cervical to cervicothoracic junction to achieve the desired correction.
- Intraoperative imaging guidance systems and intraoperative neuromonitoring can help prevent complications related to the osteotomy. Furthermore, all-posterior approaches may reduce, but do not eliminate, swallowing dysfunction.
- 360 and 540 techniques are best for restoring mid subaxial lordosis while C7 pedicle subtraction osteotomy is best for correction of cervical sagittal imbalance.

INTRODUCTION

The cervical spine is complex, supports the mass of the head, and also allows the widest range of motion relative to the rest of the spine.[1–5] Because of this complexity, the cervical region is susceptible to a variety of disorders and complications, which may lead to malalignment causing significant deformity that may warrant surgical consideration. Abnormalities of the cervical spine can be very debilitating and can induce adverse effects on the overall functioning and health-related quality of life (HRQoL) of the patient.

Indications for surgery to correct cervical malalignment are not well defined and there is no set

Disclosures: None.
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Neurosurg Clin N Am 24 (2013) 249–274
http://dx.doi.org/10.1016/j.nec.2012.12.010

standard to address the amount of correction to be achieved. Furthermore, classifications of cervical deformity have yet to be fully established, and treatment options defined and clarified. Therefore, this article focuses on normal cervical parameters, deformity evaluation and examination, and treatment options for the proper management of cervical deformity.

NORMAL CERVICAL ALIGNMENT

The cervical spine is primarily responsible for the location of the head over the body as well as the level of horizontal gaze. The center of mass of the head in the sagittal plane directly overlies the occipital condyle approximately 1 cm above and anterior to the external auditory canal (**Fig. 1**),[6] and any deviations from the normal alignment of the mass of the head result in an increase in cantilever loads, which subsequently induces an increase in muscular energy expenditure. The weight of the head is borne through the condyle to the lateral masses of C1 and then to the C1-C2 joint. This load is then divided via the C2 articular pillars into the anterior column and C2-C3 disc, and posterior column and C2-C3 facet.[7] The load distribution of the cervical spine is primarily in the posterior columns, with 36% in the anterior column and 64% in the 2 posterior columns,[7] in contrast to the lumbar spine where the anterior loads (67%–82%) have been reported as higher than the posterior loads (18%–33%).[8,9] The natural curvature of the cervical spine maintains a lordotic shape[10] as a result of the wedge-shaped cervical vertebrae and the need to compensate for the kyphotic curvature of the thoracic spine.[10] This thoracic kyphosis permits expanded lung volumes in the normal range and has been shown to increase with age. The caudal end of the lordotic cervical spine joins the rigid kyphotic thoracic inlet at the cervicothoracic junction (CTJ). Deviations from this curvature, such as a loss of lordosis or the development of cervical kyphosis, are associated with pain and disability.[1,10–13]

Because the cervical spine is the most mobile part of the spinal column, a wide range of normal alignment has been described (**Table 1**).[1,12,14,15]

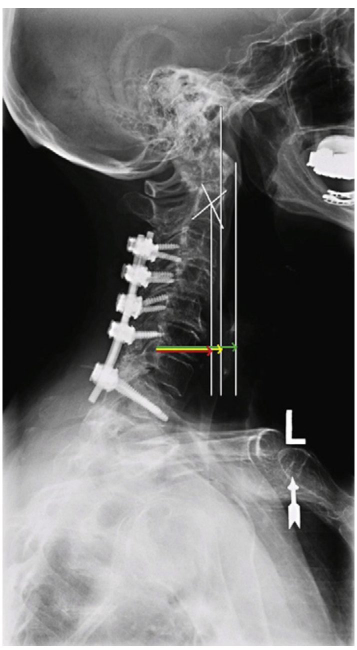

Fig. 1. Technique used to measure cervical sagittal vertical axis (SVA). The green arrow represents C1-C7 SVA (distance between plumb line dropped from anterior tubercle of C1 and posterior superior corner of C7), the red arrow represents C2-C7 SVA (distance between plumb line dropped from centroid of C2 and posterior superior corner of C7), and the yellow arrow represents center of gravity–C7 SVA (distance between plumb line dropped from anterior margin of external auditory canal and posterior superior corner of C7).

Table 1
Normal cervical spinal values in asymptomatic adults from the literature

Segmental Cervical Angles[1]

Level	Angle (°)
C0-C1	2.1 ± 5.0
C1-C2	−32.2 ± 7.0
C2-C3	−1.9 ± 5.2
C3-C4	−1.5 ± 5.0
C4-C5	−0.6 ± 4.4
C5-C6	−1.1 ± 5.1
C6-C7	−4.5 ± 4.3
C2-C7	−9.6
Total (C1-C7)	−41.8

Cervical Sagittal Vertical Axis[1]

Odontoid marker at C7	15.6 ± 11.2 mm
Odontoid marker at sacrum	13.2 ± 29.5 mm

C2-C7 Lordosis[14]

Age Group (y)	Men (°)	Women (°)
20–25	16 ± 16	15 ± 10
30–35	21 ± 14	16 ± 16
40–45	27 ± 14	23 ± 17
50–55	22 ± 15	25 ± 11
60–65	22 ± 13	25 ± 16

Values are presented as the mean ± standard deviation, and the negative sign indicates lordosis in the segmental values.

In asymptomatic normal volunteers, a large percentage of cervical standing lordosis (approximately 75%–80%) is localized to C1-C2[1,16] and relatively little lordosis exists on the lower cervical levels. Similarly the majority of lumbar lordosis is at the caudal end, with L5-S1 having the largest segmental lordotic angle.[17] That the majority of cervical lordosis is localized to C1-C2 may be explained by the finding of Beier and colleagues[6] that the center of gravity of the head sits almost directly above the centers of the C1 and C2 vertebral bodies. The mean total cervical lordosis is approximately -40°, with, on average, the occiput-C1 segment being kyphotic.[1] Only 6° (15%) of lordosis occurs at the lowest 3 cervical levels (C4-C7).[1] The loss of subaxial lordosis has been reported in occipital-C2 fusions whereby excessive hyperlordosis is created at occipital-C2.[18,19] This type of unfavorable reciprocal change is also seen in lumbar and thoracic osteotomy, and has been reported by Lafage and colleagues.[20] Furthermore, in total cervical lordosis there is no difference between asymptomatic men and women, and there is a positive correlation with cervical lordosis and increasing age.[1,14] The average odontoid-C7 plumb-line distance ranges from 15 to 17 $\pm$ 11.2 mm.[1] Normal chin-brow vertical angle (CBVA) (**Fig. 2**) has not been characterized, but postoperative values of $+10^\circ$ to -10° have been well tolerated in patients.[21–26]

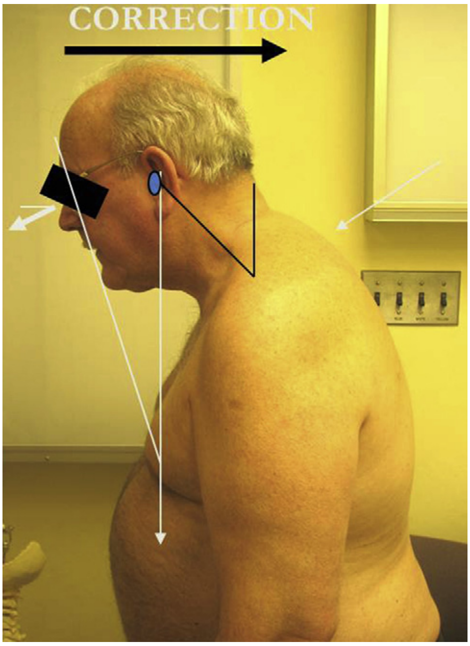

Fig. 2. Chin-brow vertical angle (CBVA) measurement method portrayed on a clinical photograph of a patient standing with hips and knees extended while his neck is in a neutral or flexed position. CBVA is defined as the angle subtended between a line drawn from the patient's chin to brow and a vertical line. Surgical correction of CBVA requires extension of the cervical spine.

Cervical lordosis may be dependent on the anatomy of the CTJ, which typically involves the C7 and T1 vertebrae, the C1-C7 disc, and the associated ligaments. This definition may extend to T2 and T3 in terms of osteotomy planning.[27] The CTJ also includes the thoracic inlet, a fixed bony circle that is composed of the T1 vertebral body, the first ribs on both sides, and the upper part of the sternum. Biomechanically, the CTJ is a region where highly mobile cervical spine, which supports the head (average weight 4.5 kg),[28] transitions into the fairly rigid thoracic spine whose mobility is significantly reduced by the rib cage. Furthermore, the CTJ is the site at which the lordosis of the cervical spine changes to kyphosis in the thoracic spine. This change in curvature causes a significant amount of stress at the CTJ, in both the static and dynamic states.[27,29]

The sagittal alignment of the cranium and cervical spine may be influenced by the shape and orientation of the thoracic inlet to maintain a balanced, upright posture and horizontal gaze, similar to the relationship between the pelvic incidence and lumbar lordosis.[30] Lee and colleagues[30] found significant correlations between the thoracic inlet angle and both the cranial offset and craniocervical alignment. The relative contributions of the C0-C2 angle and the C2-C7 angle to the overall cervical lordosis have been reported to be 77% and 23%, respectively, in asymptomatic individuals.[30] The relative contributions of cervical tilting and cranial tilting to the overall angle of the occipital-cervical region have been reported to be 70% and 30%, respectively, in asymptomatic individuals.[30]

In the study by Lee and colleagues,[30] neck tilting was maintained around 45° to minimize energy expenditure of the neck muscles. These results indicate that a small thoracic inlet angle creates a small T1 slope and small cervical lordosis angle to maintain the physiologic neck tilting, and vice versa. According to the study, the thoracic inlet angle and T1 slope may be used as parameters to evaluate sagittal balance, predict physiologic alignment, and guide deformity correction of the cervical spine.[30] The T1 inclination will determine the amount of subaxial lordosis required to maintain the center of gravity of the head in a balanced position, and will vary depending on global spinal alignment as measured by SVA and by inherent upper thoracic kyphosis. In patients with scoliosis, the T1 sagittal angle (tilt, **Fig. 3**) has been shown

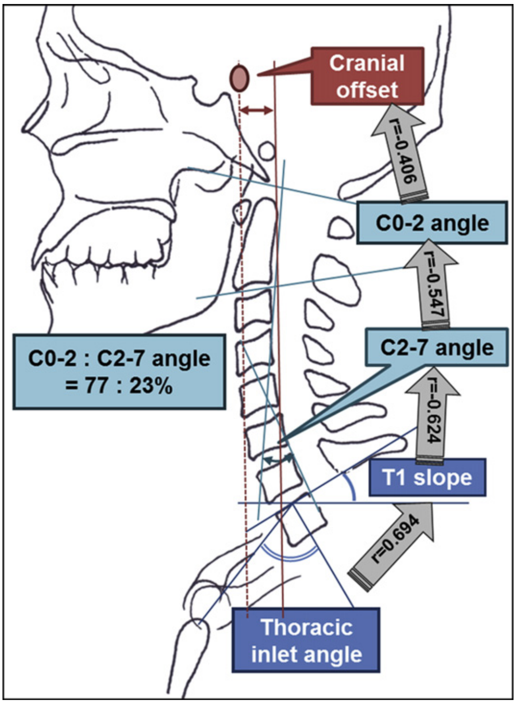

Fig. 3. Sequential linkage of significant correlation from the thoracic inlet angle to the cranial offset and craniocervical alignment. The *r* values within the arrows between each segment illustrate the Pearson correlation coefficient between the two segments. The sequential correlations between adjacent segments link the correlation between the thoracic inlet angle and the cranial offset. (*From* Lee SH, Kim KT, Seo EM, et al. The influence of thoracic inlet alignment on the craniocervical sagittal balance in asymptomatic adults. J Spinal Disord Tech 2012;25:E41–7; with permission.)

to correlate directly with SVA measured from the C2 dens plumb line to provide a measure of overall sagittal alignment (see **Fig. 3**; **Fig. 4**).[31]

ASSESSMENT OF CERVICAL DEFORMITY

Deformities of the cervical spine present many challenges to the surgeon, one of which is determining the ideal treatment option. The most common type of cervical spine deformity occurs in the sagittal plane (**Fig. 5**), malalignment in the coronal plane being much less common.[32–34] Furthermore, the most common type of cervical kyphotic deformity occurs as iatrogenic, specifically after multilevel laminectomy, with an incidence of 20%.[34–36] The primary goal of the various treatment options is restore cervical sagittal alignment, thus to improve horizontal gaze, reduce neck pain and, if the deformity is severe enough, improve swallowing and respiration.[2,32]

The primary goal during the preoperative assessment of a patient with a cervical kyphotic deformity is to determine the ideal amount of correction and where along the spine the correction needs to be applied. At present, there exist no clear indications for the correct amount of cervical lordosis to be obtained postoperatively; however, a general rule of completely correcting the cervical kyphosis to neutral has been accepted.[34] Current research is likely to define cervical sagittal parameters similar to C7 SVA but instead measured on standing 36-in (91.5-cm) films measured from C2 or head center of mass (see **Fig. 1**; **Fig. 6**). The initial evaluation of the patient includes a complete medical history and physical examination. Many of these patients are high-risk surgical patients, and pertinent history (ie, smoking, use of nonsteroidal anti-inflammatory drugs, and so forth) can be used to tailor treatment. The physical-examination component should include assessing the patient standing upright with hips and knees fully extended, and in the sitting and supine positions. Sitting position will remove the effect of lumbar and pelvic/hip deformity, and the supine position can be used to assess the rigidity of semirigid curves under the direct effect of gravity. CBVA is measured before surgery and after surgery using the CBVA method (see **Fig. 2**). This angle is measured between the chin-brow line and the vertical line with the patient standing with the hips and knees extended and the neck in its neutral or fixed position. Based on this angle, the size of the wedge to be removed posteriorly can be determined. Despite lying flat, patients with fixed primary cervical deformity have persistent cervical flexion (**Fig. 7**), whereas patients with thoracic, lumbar, or hip deformities correct in the sitting or supine positions.

Following the physical examination, initial radiographic evaluation includes 36-in standing plain radiograph films and dynamic flexion/extension cervical plain radiograph films (**Fig. 8**). The 36-in standing film allows for global spinal assessment while the dynamic films aid in determining the presence of any atlantoaxial instability and the relative flexibility of the spine.

Further radiographic studies such as computed tomography (CT) and magnetic resonance imaging (MRI) are usually performed to assess osseous landmarks for instrumentation and spinal cord tethering or impingement. CT scans are used to determine the extent of facet fusion and osteophytic bridging at disc to assess the need for osteotomy anteriorly and posteriorly in fixed deformity.

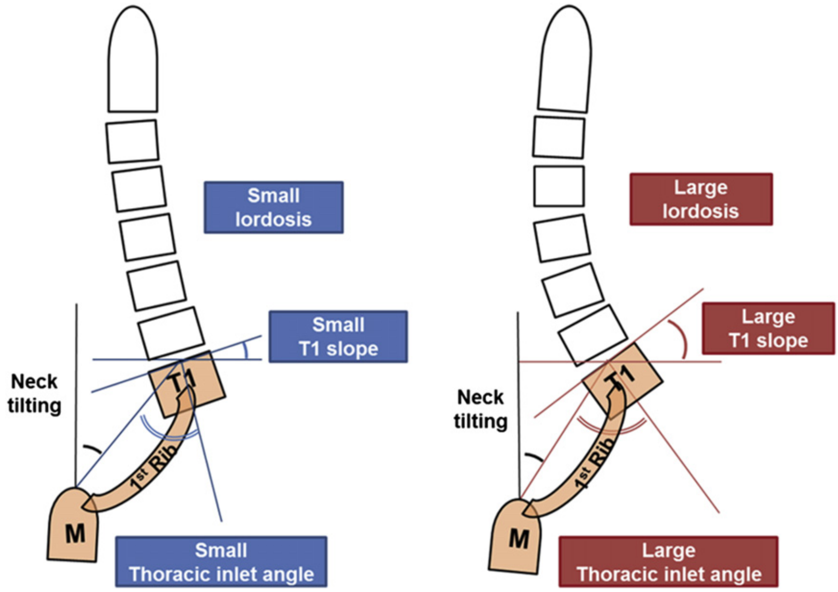

Fig. 4. Relationship between thoracic inlet angle, T1 slope, and cervical lordosis. A small thoracic inlet angle yields a low T1 slope, therefore less cervical lordosis is required to balance the head over the thoracic inlet and trunk. Conversely, a large thoracic inlet angle yields a greater T1 slope so that a greater magnitude of cervical lordosis is required to balance the head over the thoracic inlet and trunk. (*From* Lee SH, Kim KT, Seo EM, et al. The influence of thoracic inlet alignment on the craniocervical sagittal balance in asymptomatic adults. J Spinal Disord Tech 2012;25:E41–7; with permission.)

TREATMENT OF CERVICAL DEFORMITY

Conservative Management

The patient may attempt several conservative treatment options before considering surgical intervention. Conservative treatment of cervical deformity is primarily aimed at reducing symptoms, usually targeting pain. Some options include physical therapy, chiropractic care, cervical traction, brace therapy, steroid injections, and nonsteroidal anti-inflammatory agents. Surgical treatment may be indicated in patients with severe mechanical neck pain, neurologic compromise, and progressive deformity causing significant disability such as dysphagia or loss of horizontal gaze.

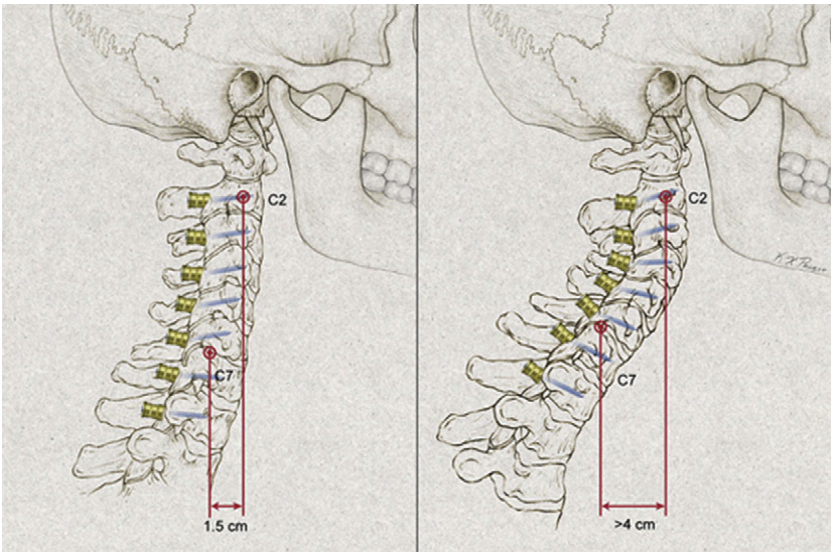

Fig. 5. (*Left*) Normal cervical lordosis, highlighting a small difference between the C2 and C7 plumb lines. (*Right*) cervical sagittal malalignment, highlighting a large difference in the C2 and C7 plumb lines.

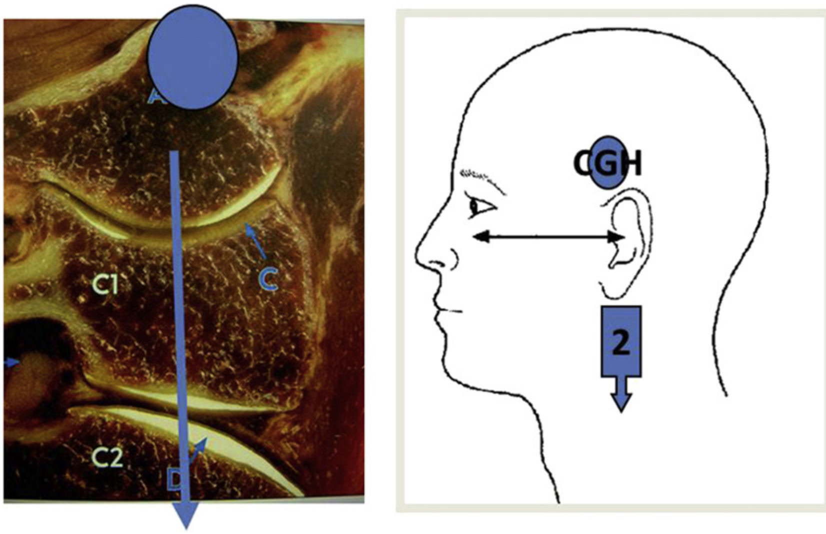

Fig. 6. (*Left*) Sagittal cut through a cadaver cervical spine, illustrating the center of gravity of the head (CGH; *blue oval*) being transmitted through C1 and C2 (*blue plumb line*). (*Right*) Location of the CGH in relation to the ear and C2 plumb line.

Patients who present with cervical camptocormia (head ptosis or neck drop) have a flexible deformity of the spine in the sagittal plane that is corrected on laying supine.[37] The various causes of camptocormia include amyotrophic lateral sclerosis (ALS), different myopathies, parkinsonism disorders, and idiopathic origins.[37] Thus, the initial workup a patient with camptocormia (or other flexible deformity) should include appropriate electromyography and nerve-conduction studies to rule out a primary myopathy or ALS. Furthermore, they should be referred to physical therapy before considering treating with surgical correction and fusion.

Cervical traction may be used to attempt deformity correction before surgical intervention. In general, 3 to 5 days of traction may be sufficient to reduce the deformity.[34] If the deformity is not reduced following 5 days of traction, further traction is unlikely to benefit the patient. In addition to the traction, muscle relaxants may also be used to aid in the reduction. If successful reduction of the cervical kyphosis does occur, posterior fixation and fusion may be used to prevent the deformity from progressing.

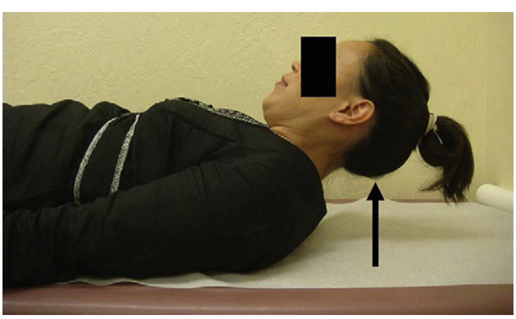

Fig. 7. The supine physical examination component, demonstrating a patient with fixed cervical kyphosis.

Surgical Management

Evaluation of the flexibility of the cervical spine may determine the surgical intervention needed. If the spine is flexible, an anterior-only or posterior-only correction strategy may be used. If the spine is rigid without ankylosed facets, an anterior-only strategy may be used. If the spine is rigid with ankylosed facets, a combination of anterior and posterior strategies may be used to correct the deformity.

The anterior-only strategy allows for correction of the deformity as well as instrumentation to maintain the correction, using both posture and biomechanics to obtain the cervical lordosis needed. The patient is placed in the supine position with the head slightly extended. After exposure, anterior release including disc and osteophytes is performed, and distraction pins are placed in the vertebral bodies to allow for segmental extension of the vertebral bodies and, thus, cervical lordosis. Anterior release is usually by means of a discectomy, as multiple lordosing discectomies are generally more effective than a single long corpectomy at creating lordosis. Following release and distraction, struts and/or lordotic cages or grafts may be placed to facilitate bone fusion. Lastly, a plate is contoured to the desired lordosis and

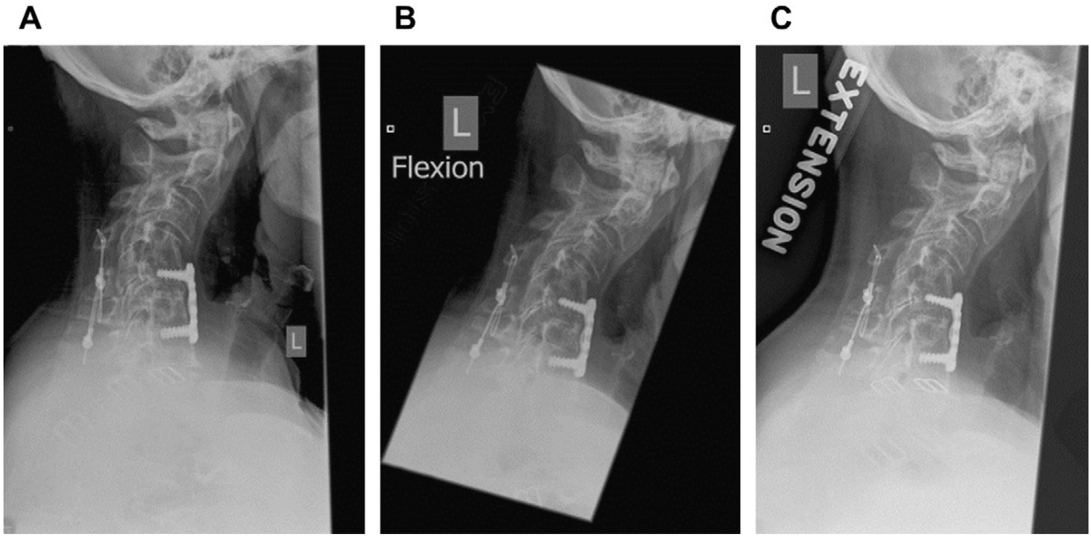

Fig. 8. (*A*) Preoperative lateral radiograph of a patient with fixed cervical kyphosis. Dynamic radiographs assess the extent of rigidity by (*B*) flexion and (*C*) extension.

fixated anteriorly to the cervical spine. Lordotic plates can be used to generate additional lordosis using a 3-point bending technique to "pull" the spine up to the plate once the plate is fixated at the ends. This technique relies on the spine being flexible after discectomy and anterior osteotomy.

When the cervical deformity is rigid with ankylosed facets, a combined anterior-posterior strategy may be used.[38] The side of correction is chosen first and the contralateral side is then released. In general, the posterior strategy is performed first with placement of screws and facetectomy and Smith-Peterson osteotomy. The patient is then turned to the supine position and disc release, anterior osteotomy, and lordotic plating are performed. The patient is then turned prone, and instrumentation and posterior compression applied. In certain cases with significant fixed subaxial kyphosis it may be advantageous to perform an anterior osteotomy first, including release of the vertebral arteries from the foramen transversarium followed by posterior osteotomy and correction using head manipulation after circumferential release. For this technique, the authors prefer the halo ring over the Mayfield clamp to allow a better grip on the head during manual reduction. Usually more lordosis is possible using an anterior release followed by posterior correction than with a posterior release followed by an anterior fixation, as generally it is possible to generate more lordosis from the posterior position.

If the cervical deformity is very kyphotic and rigid with ankylosed facets, an osteotomy or combination of osteotomies may be used to correct the deformity. Traditionally the Smith-Petersen osteotomy has been used to correct cervical spinal deformities in the sagittal plane. This type of osteotomy may be used in cases where less than 30° of correction is needed.[39] The Smith-Petersen osteotomy does have a few significant limitations. First, there may be a need for multiple osteotomies at different levels to obtain the desired correction. Having multiple osteotomies increases the risk for pseudarthrosis. Second, there is a need for a flexible anterior column (or the creation of an anterior osteotomy) to obtain complete closure, which generally requires an anterior-posterior approach unless osteoclasis is possible, as in cases of ankylosing spondylitis. Simmons popularized the Smith-Petersen osteotomy (opening wedge) allowing for a posterior-only approach in patients with ankylosing spondylitis.[40,41] In patients with anterior bridging osteophytes and a calcified anterior longitudinal ligament, such as with ankylosing spondylitis, controlled anterior osteoclasis, creating an opening wedge in addition to the modified Smith-Petersen osteotomy, may be performed.[40,41] This technique is frequently used for chin-on-chest deformities in ankylosing spondylitis.[40,41]

If the patient has a rigid deformity and requires greater than 15° correction and correction of cervical sagittal imbalance, a cervical or cervicothoracic pedicle subtraction osteotomy (PSO) may be used.[21,42] PSO is becoming increasingly used and has the ability to correct large kyphotic deformities. PSO is a posterior-only approach allowing for all 3 spinal columns to make contact on closure of the osteotomy, thus increasing the likelihood of successful fusion as well as biomechanical stability.[21,43] PSO also can be used in nonankylosed patients in whom anterior osteoclasis is not likely to occur. Furthermore, PSO allows for a controlled closure. If neurologic injury is a concern, PSO may be an appropriate option. However, it is a technically demanding procedure.

Coronal cervical deformities may be isolated or in combination with sagittal deformities. Patients with fixed multiplanar deformities (**Figs. 9** and **10**) may require large 3-column osteotomies to correct the spine in both planes and decompress the cord and nerves. A 540° circumferential osteotomy or, possibly, a cervical vertebral column resection may be used.[44]

Cervical Deformity and Myelopathy

It is worth mentioning the relationship between cervical deformity and myelopathy and surgical considerations regarding treatment. Progressive cervical kyphosis has also been associated with myelopathy. The deformity leads to draping of the spinal cord against the vertebral bodies and anterior abnormality, increasing the longitudinal cord tension caused by the cord being tethered by the dentate ligaments and cervical nerve roots (**Fig. 11**).[35,45] As the curve becomes more pronounced over time, the spinal cord becomes compressed and flattened.[46] The anterior and posterior margins of the cord compress while the lateral margins expand. Tethering of the cord can produce increased intramedullary pressure.[47–49] This compression leads to neuronal loss and demyelination of the cord.[46] Furthermore, there are significant adverse angiogenic effects of the mechanical compression. The small feeder blood vessels on the cord become flattened, leading to reduced blood supply. There is a large reduction in the number of vessels and the network size, as well as interruption and abnormal arrangement of the blood vessels.[46] As the kyphotic angle increases these changes become greater, especially on the anterior side that is exposed directly to the mechanical compression.[46] Greater cord tension increases intramedullary cord pressure,[47–50] and has been shown to lead to apoptosis in animal models.[46] Shimizu and colleagues[46] induced cervical kyphosis is small game fowls, and quantitatively analyzed the severity of demyelination and neuronal degeneration in histologic sections of the spinal cords. These investigators found a significant correlation between the degree of kyphosis and the amount of cord flattening. Moreover, demyelination of the anterior fasciculus as well as neuronal loss and atrophy of the anterior horn was observed, with the extent of demyelination progressing as the kyphosis became greater.[46] The pattern of demyelination began with the anterior fasciculus but then progressed to the lateral and posterior fasciculi. Further analysis with angiography demonstrated that the vascular supply to the anterior portion of the cords was decreased.[46] Thus, sagittal alignment of the cervical spine may play a substantial role in the development of cervical myelopathy.

The current literature is filled with controversy surrounding the best surgical approach to correct cervical spondylotic myelopathy.[51] Surgical considerations and options for cervical myelopathy

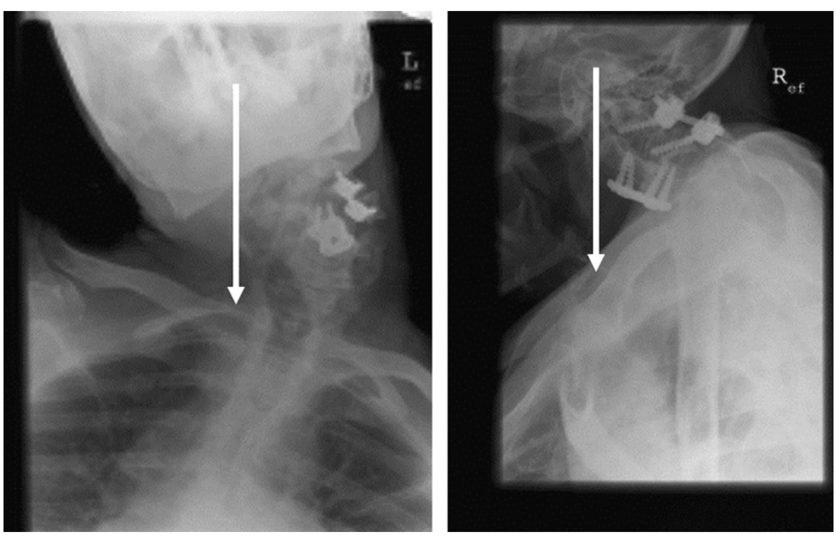

Fig. 9. (*Left*) Anterior-posterior radiograph showing coronal malalignment. (*Right*) Lateral radiograph showing sagittal malalignment.

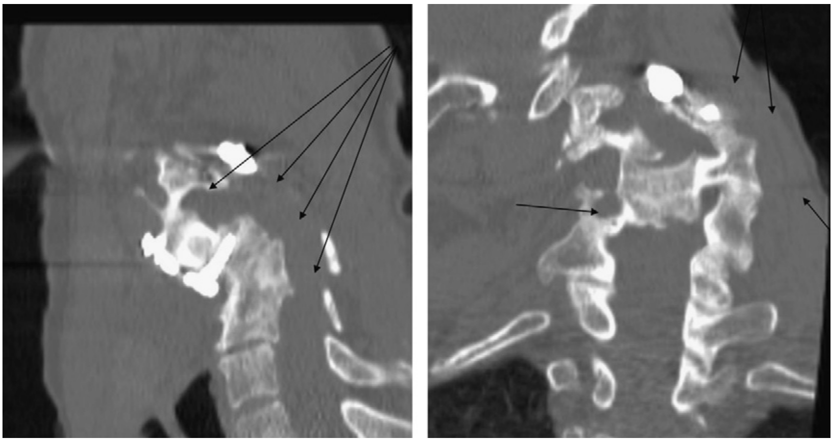

Fig. 10. (*Left*) Sagittal computed tomography (CT) image showing severe cervical sagittal malalignment (*arrows*). (*Right*) Anterior-posterior CT image showing severe coronal malalignment (*arrows*).

must take into account the sagittal alignment of the cervical spine, as it affects the approach to as well as the etiology and progression of myelopathy. Decompression alone, even ventral decompression, which does not decrease cord tension induced by kyphosis, may therefore not result in optimal outcomes.[46]

When correcting cervical myelopathy without sagittal malalignment, the surgeon should consider the possible future development of postlaminectomy kyphosis, which is the most common cause of cervical spine deformity.[35,45,52] As already mentioned, the natural biomechanics of the spine rely on a lordotic curve to distribute most of the load posteriorly. Thus, the posterior neural arch is responsible for most of the load transmission down the cervical spine, and removal of it causes a significant loss of stability. Initially, performing extensive multilevel laminectomies may not immediately destabilize an intact spine. However, the added instability on losing the posterior arch-facet complex tends to cause a shift in load bearing from the posterior column to the anterior column. Over time, this shift places added stress on the cervical musculature, requiring constant contraction to maintain an upright head posture, which results in fatigue and pain. Cervical kyphosis occurs as the load is shifted anteriorly and, as the discs and vertebral bodies become wedged, it progresses to greater sagittal malalignment. This

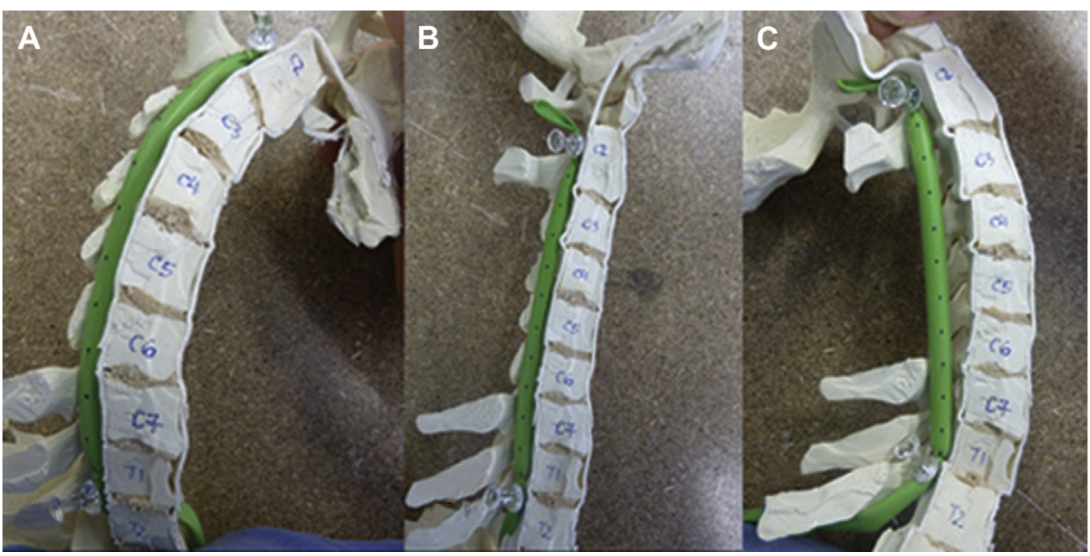

Fig. 11. Sagittal cervical spine model demonstrating spinal cord tension and length changes in response to sagittal alignment. The distance between marks (*black dots*) on the cord were measured and were 1.2 cm for kyphosis (*A*), 1.1 cm for the neutral position (*B*), and 1.0 cm for the cervical lordosis with C3-C5 laminectomy (*C*).

kyphosis can then lead to cervical myelopathy resulting from the curve of the spine as discussed earlier, thus creating worsened myelopathy from a surgical treatment that was intended to treat myelopathy. The kyphosis can then simultaneously contribute to the development of adult spinal deformity caused by the increased loads and pressure anteriorly, possibly adversely affecting the discs.

Furthermore, it is not always possible to correct cervical lordotic alignment in the subaxial spine above C7 through a posterior approach alone. An anterior approach with reconstruction using lordotic interbody spacers may be needed to restore the natural lordotic curve of the cervical spine. If the cervical spine is fused in the kyphotic position or posterior decompression alone is undertaken, this may lead to future myelopathy and/or adult spinal deformity attributable to the reasons discussed. Recent data have shown that patients who underwent 1- or 2-level corpectomies for cervical spondylotic myelopathy had positive long-term outcomes in terms of HRQoL and maintenance of their regional cervical lordosis.[53]

SURGICAL OSTEOTOMIES FOR CERVICAL DEFORMITY

Surgical intervention should be considered if the patient does not respond to a conservative treatment protocol or shows evidence of deteriorating myelopathy, radiculopathy, or functional impairment, such as inability to achieve horizontal gaze, swallowing dysfunction related to head position, tension/kyphosis-induced myelopathy, or neck pain due to head imbalance.[21,32,54–56] The spinal cord may be decompressed effectively by an anterior, posterior, or combined approach, but full decompression may require deformity correction as in cases of kyphosis. Supplemental posterior fixation minimizes the risk of anterior dislodgment of the graft even in the presence of solid anterior fixation.[57] Treatment of these complex cervical deformities is challenging and requires a clear understanding of the disease and the patient. Surgeons must be comfortable with remobilization of the spinal column anteriorly and posteriorly, vertebral artery anatomy, and methods of anterior and posterior correction.

Significant, irreducible deformity of the cervical spine may be sufficient to require corrective osteotomy. At the craniocervical junction, neurologic or functional impairment associated with the deformity may be best managed by osteotomy and fixation. Rigid deformities of the cervical spine below the craniocervical junction are more likely to require some kind of osteotomy to correct the deformity and restore horizontal gaze.

This section details the preoperative considerations and surgical procedures of 4 cervical osteotomies: (1) craniocervical junction osteotomy using sequential anterior-posterior approaches, (2) Smith-Petersen osteotomy, (3) CTJ PSO, and (4) cervical circumferential osteotomy.

Preoperative Considerations in Rigid Cervical Deformity

History

Patients may give a history of past trauma, sometimes associated with intercurrent illness of ankylosing spondylitis or rheumatoid arthritis as well as previous cervical spine surgery, degenerative disorders, and neoplastic disorders.

Signs and symptoms

Symptoms may include suboccipital headache and neck stiffness, occipital neuralgia, symptoms of myelopathy, or progressive deformity leading to functional impairment, such as difficulty with looking forward or with eating and drinking. Patients may complain of low back pain and standing fatigue caused by the use of compensatory muscles to elevate pelvic tilt in order to alter gaze angle.

Physical examination

It is critical to obtain 36-in radiographs and to examine patients while standing. Occasionally lumbar sagittal deformities will need to be corrected first. Correction of lumbar imbalance will alter head position substantially, especially in rigid deformities like ankylosing spondylitis. However, all corrective lumbar osteotomies will change the T1 slope angle to some extent, and therefore will change cervical alignment and often cervical C2 SVA. Signs of myelopathy may be evident in relation to past injury, compression, or cord tension due to stretch induced by kyphosis.

Imaging

The deformity should be evaluated by anterior/posterior and lateral cervical radiographs along with dynamic lateral flexion/extension views. The deformity is then accurately measured (ie, sagittal angle determination) and any other abnormalities noted (eg, subluxation and pseudarthrosis).[32,33,58] It is important to obtain full-length posteroanterior and lateral 36-in scoliosis radiographs to examine overall sagittal and coronal balance in these patients.[32,33,59] The authors assess cervical, thoracic, and lumbar sagittal alignment individually and lobally, and define the effect of regional imbalance on cervical balance and determine whether it is a primary, secondary, or compensatory cervical deformity. The degree of required correction depends on the angle of the cervical deformity (the CBVA), the C2 plumb line, and the desired final lordosis.[21,25,33,40,60] The goal of treatment is to obtain balance, horizontal gaze, and cord decompression, and to normalize cord tension. Dynamic (ie, flexion/extension) radiographs permit an assessment of the overall flexibility of the cervical spine, which is paramount when designing a treatment strategy. CT scans of the cervical spine are also useful in determining the presence of fusion or ankylosis of the facet joints and discs, and allow assessment of fixation points such as C2 and upper thoracic pedicles.

All patients should be evaluated with preoperative MRI or CT myelography. These imaging modalities permit the evaluation of compressive abnormality. If significant ventral compressive abnormality (disc, osteophyte) is present, a ventral decompressive procedure may first be performed before the correction of the deformity.

Decision for planning of osteotomy

It is important when planning deformity surgery for cervical kyphosis to consider whether the deformity is rigid or fixed and whether there are neurologic symptoms. **Fig. 12** depicts the surgical-decision making process in cervical deformity osteotomy. In the craniocervical junction, osteotomy is indicated when the deformity is irreducible and sufficient to result in severe pain, and functional or neurologic impairment that cannot be relieved with a surgical decompression and/or stabilization procedure alone. In the flexible subaxial deformity, a posterior stabilization (usually C2-T2) is advocated; when deformity is semirigid, Smith-Petersen osteotomy should be considered.

However, in the clinical setting of rigid cervical kyphosis (high to mid cervical kyphosis) with neurologic symptoms, the spinal cord is usually tethered over the subaxial kyphotic segment, leading to neurologic symptoms and myelopathy; therefore, segmental kyphosis correction (circumferential osteotomy) is mandatory to untether and decompress the spinal cord. In the setting of a rigid cervical kyphosis in mid to low cervical spine with cervical sagittal imbalance, a C7 or T1 PSO may be sufficient.

Craniocervical Junction Osteotomy

At the craniocervical junction it is unusual for an osteotomy to be required, and little has been published on the subject in the surgical literature.[61] However, cases exist, usually in the posttraumatic setting and in association with other conditions such as ankylosing spondylitis or end-stage rheumatoid arthritis with fixed atlantoaxial deformity, whereby the neurologic or functional impairment associated with the deformity may be best managed by osteotomy and fixation.

Indications and contraindications

Osteotomy is indicated when the deformity is irreducible (possibly following a trial of traction) and sufficient to result in severe pain and functional

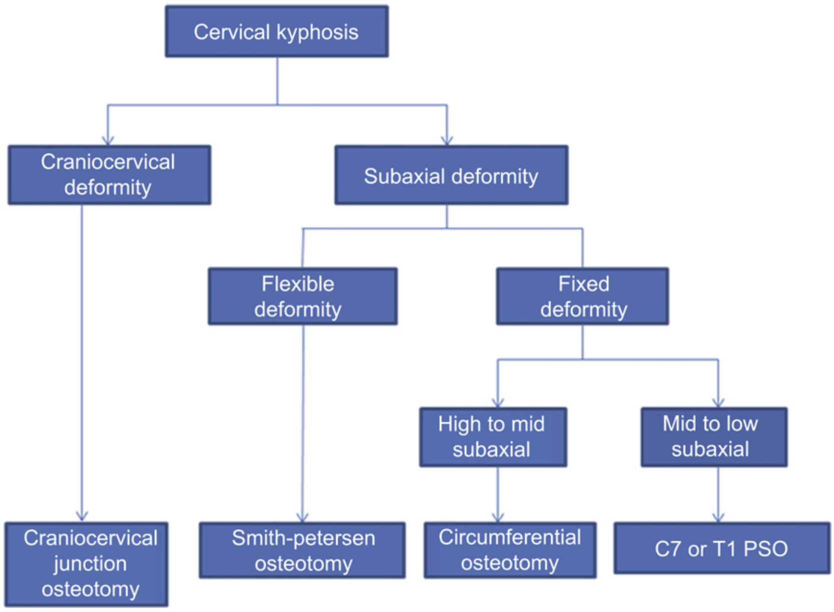

Fig. 12. The surgical decision-making process in cervical kyphosis.

or neurologic impairment that cannot be relieved with a surgical decompression and/or stabilization procedure alone. The procedure is contraindicated in the presence of significant osteoporosis or debilitating comorbidities.

Fig. 13 illustrates a case example of craniocervical junction osteotomy. Plain radiographs at the atlantoaxial level reveal substantial kyphotic deformity, possibly in the presence of an old odontoid fracture, with subluxation or dislocation of the C1/C2 joints (see **Fig. 13**). There may be bony union across the subluxed joints or involving other elements of the atlantoaxial complex.

Surgical technique

1. The ease of surgical access to the ventral aspect of C2 is an important consideration when choosing between an anterior/posterior or posterior-only approach. Grundy and Gill[61] have described a posterior-only approach in cases where the anticipated anterior access may be difficult. Preoperative planning of the intended osteotomy orientation is also important when considering the type of anterior approach. An osteotomy, which is oriented obliquely backward and upward from the base of C2 (**Fig. 14**A), will enable satisfactory exposure through a high anterior retropharyngeal approach. This approach is described here.
2. The patient will usually require awake endoscopic intubation and is positioned supine for the first (anterior) stage of the surgery. It is preferable to use an operating table such as the Jackson table (Mizuho OSI, Union City, CA), which will enable rotation of the patient to the prone position for the second surgical stage, and to secure the head in a Mayfield 3-point head-holder. Access for adjustment of the head and neck position should be maintained throughout the procedure. Intraoperative image-guided surgical navigation, such as with an O-Arm/Stealth (Medtronic, Dallas, TX), Iso-C (Siemens, Erlangen, Germany), or

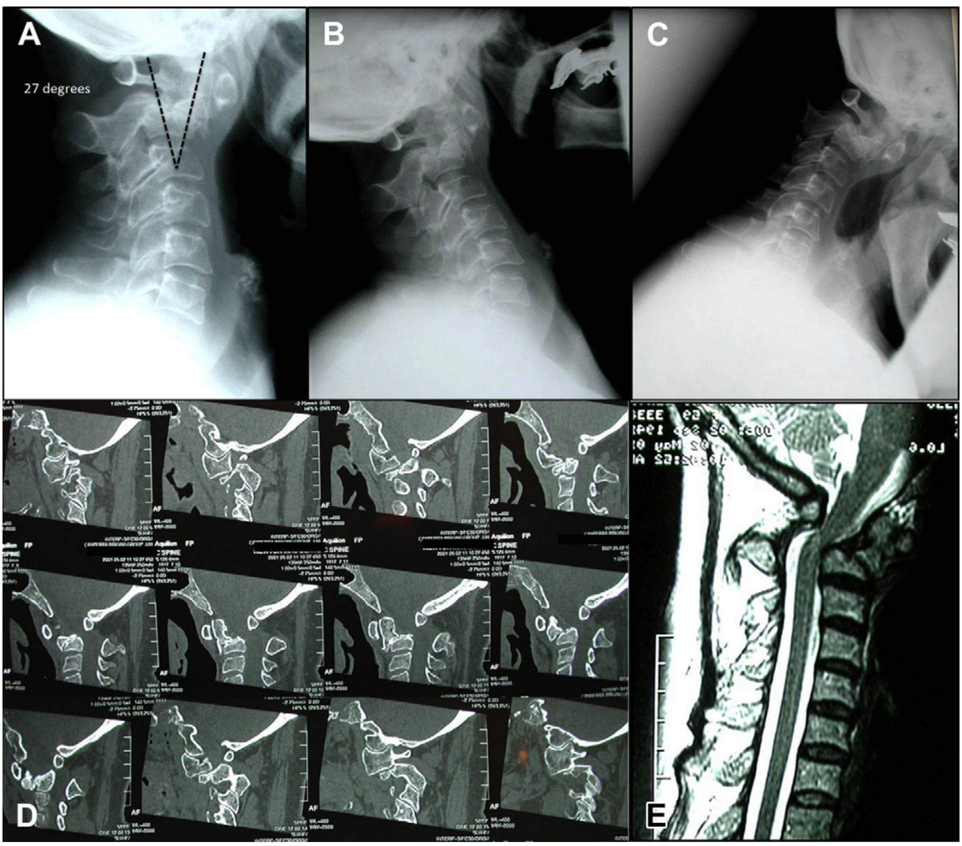

Fig. 13. (*A–E*) A 59 year-old woman with history of rheumatoid arthritis and severe suboccipital neck pain and early signs of myelopathy, 6 months following a motor vehicle accident resulting in type III odontoid fracture, managed conservatively in SOMI (sternal occipital mandibular immobilizer) brace. Plain radiographs, CT scans, and magnetic resonance imaging (MRI) show (*A–C*) development of fixed 27° kyphotic deformity, (*D*) bilateral facet joint dislocations, and (*E*) spinal cord compression.

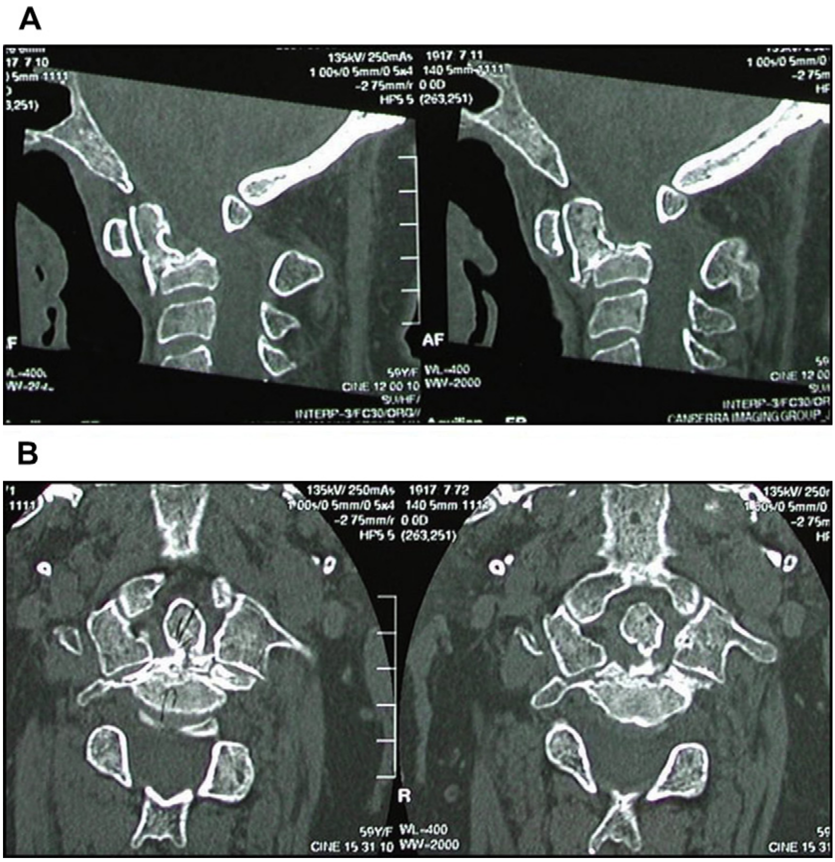

Fig. 14. CT scan of sagittal and coronal reconstructions showing (*A*) orientation of planned osteotomy and (*B*) bilateral extent of base of osteotomy.

similar system may facilitate surgeon orientation and placement of the osteotomy. Intraoperative neuromonitoring may be helpful during the deformity reduction.

3. A high, anterolateral skin incision is made for a retropharyngeal approach to the C2 vertebral body.
   a. Retropharyngeal approach to the ventral aspect of C2 vertebral body with fluoroscopic confirmation of position.
   b. Mobilization of longus coli muscles, bilaterally.
   c. Identify the old fracture line (when present). Define the bilateral extents of the fracture line and endeavor to dissect upwards to define the lateral aspects of the odontoid process, bilaterally (**Fig. 14**B); this is important to completely mobilize the odontoid with the osteotomy and to avoid injury to the vertebral arteries.
   d. Make the osteotomy through the old fracture line using a high-speed drill with a small cutting burr. Frequent position/orientation checks are made with fluoroscopic or image guidance. The osteotomy is extended through to back of the odontoid and bilaterally. Take care not to venture too widely, to avoid injury to the vertebral arteries. If necessary, navigation may be used.
   e. Depending on whether there is bony union of the posterior elements of the C1/C2 complex, an attempt may be made at this stage to open up the fracture line and correct the deformity using intervertebral spreaders.
   f. The anterior wound is then closed over a suction drain before turning the patient to the prone position.
   g. Through a midline suboccipital incision, a subperiosteal dissection of the posterior elements of C1-C3 is performed with identification of the C2 nerve roots.
   h. While controlling any hemorrhage from the venous plexus around the C2 nerve roots, the superior articular surfaces of C2 are exposed and the posterior edges of the C1 lateral masses, adjacent to the inferior joint surfaces, are defined on each side. If there

has been any bony union between the C1 and C2 joints, this is divided with the high-speed drill or osteotome (**Fig. 15**). Dissectors are then carefully inserted into the dislocated C1/C2 joints and used to gently lever back the C1 lateral masses onto C2, while the surgical assistant and anesthesiologist adjust the head position in the Mayfield head-holder.

i. It is helpful to remove the articular cartilage from the C2 joint surfaces before reducing the dislocation. Subsequently, the articular cartilage is removed with a small angled curette from the inferior surface of the C1 lateral masses. Cancellous bone graft is then placed into the C1/2 joint spaces.

j. Depending on surgeon preference and the vertebral artery anatomy, the C1/C2 segment is then stabilized using either transarticular screws (with additional posterior wiring) or a C1 lateral mass and C2 pars screw construct.[62–64]

k. Further bone graft is placed over the decorticated posterolateral elements before posterior wound closure, in layers, over a vacuum drain.

4. Depending on how the patient is tolerating the procedure and the time available, the patient may be repositioned supine immediately or later, as a delayed procedure, for placement of bone graft into the anterior osteotomy site. This site will have opened up into a wedge-shaped defect following the posterior deformity correction (**Fig. 16**A). Suitably fashioned allograft or iliac crest autograft is inserted into the wedge-shaped osteotomy site and secured with a small locking plate (**Fig. 16**B). Subsequent, standard postoperative care follows segmental atlantoaxial stabilization and fusion (**Fig. 17**).

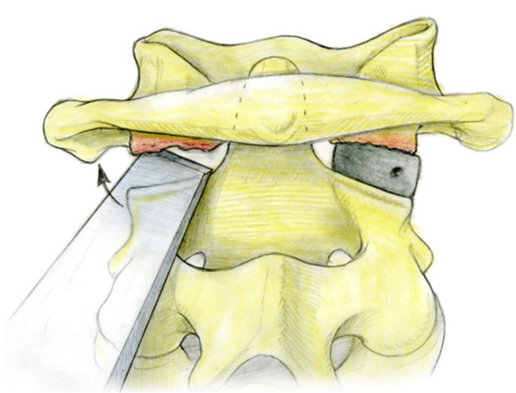

Fig. 15. An osteotome may be used to mobilize the C1-C2 joint space from the anterior or posterior approach in cases of fixed atlantoaxial deformity.

5. The patient is then returned, ventilated, to the intensive care unit.

Smith-Petersen Osteotomy

Semirigid deformity (eg, spondylitic joints and discs but no segmental bridging bone in a patient with good bone quality)

The Smith-Peterson extension osteotomy technique, described in 1945, has been used extensively and was previously considered the prototype procedure for reconstruction of sagittal imbalance in patients with deformity above the thoracolumbar junction.[65] Inspired by the lumbar osteotomy performed by Smith-Petersen, in 1958 Urist first reported his experience of cervical osteotomy on one patient with severe flexion deformity of ankylosing spondylitis.[66] It is important to distinguish between opening wedge osteotomy (the classic Smith-Peterson osteotomy used for ankylosing spondylitis patients at C7) and the procedure involving complete facet removal and posterior closure over a mobile disc space, which is more commonly used for semirigid cervical deformity and sometimes more appropriately called the cervical Ponte osteotomy.

If the deformity is partially correctable with traction or posture (ie, neck extension), a dorsal-only Smith-Petersen osteotomy/Ponte strategy may be used.[40,41,67] Traction may be used to reduce the deformity, and then may be continued in the operating room. Because this osteotomy uses some cantilever force on the pre-bent rod to achieve lordosis and segmental osteotomy closure, a stiffer cobalt-chrome rod is recommended in preference to a 3.5-mm titanium rod. Usually these cases involve fusion from C2-T2/T3 (see case example, **Figs. 18** and **19**).

Ankylosing spondylitis may produce an extreme fixed flexion deformity at the CTJ. This extreme deformity may place the chin in close proximity to the chest, which may interfere with eating and respiration. Some have advocated treating this deformity by Smith-Petersen osteotomy with anterior osteoclasis, with gentle extension of neck intraoperatively, resulting in the classic opening wedge.[40,41,60,67]

Ankylosing spondylitis (opening wedge osteotomy)

Indications and contraindications Severe flexion deformities of the cervical spine, whereby there is loss of horizontal gaze, difficulty with personal hygiene and function, and dysphagia, are corrected by traction or neck extension. Ankylosing spondylitis with fixed deformity is treated with Smith-Petersen osteotomy with anterior osteoclasis. Standing 36-in films are critical in

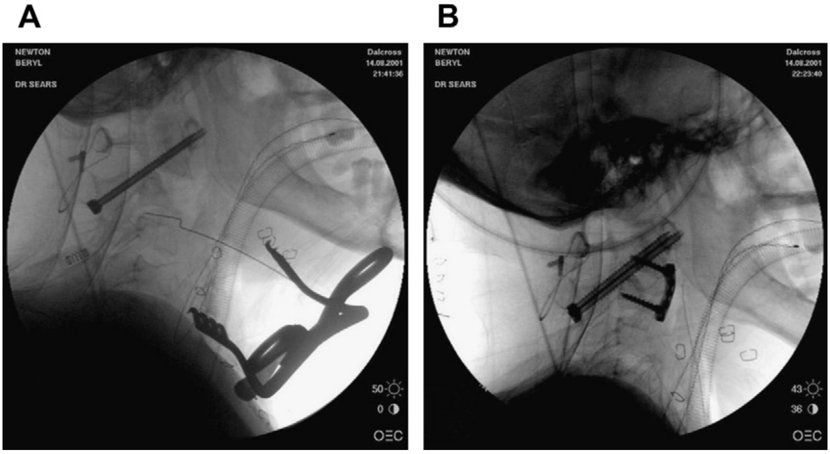

Fig. 16. Intraoperative fluoroscopic images showing (*A*) anterior wedge defect following posterior relocation of dislocated facet joints and transarticular screw fixation, and (*B*) following anterior bone grafting and plate fixation.

deterring whether lumbar or thoracic kyphosis also exists. If so, and global imbalance is present, the thoracolumbar deformity should be corrected first, as this by itself usually may restore horizontal gaze. If lumbar sagittal deformity is present and the cervical osteotomy is performed first, secondary lumbar correction may lead to an unacceptably high (gaze on the ceiling) issue and flexion osteotomy may then be needed.

Surgical technique The surgical technique for C7 Smith-Petersen osteotomy with anterior osteoclasis for fixed low cervical deformity in ankylosing spondylitis is as follows.

1. Classically the patient is positioned sitting. However, at their institution the authors position the patients prone in a halo ring. The kyphotic head position is accommodated by additional rolls and pads as needed to elevate the patient's thorax. Transcortical motor evoked potentials (MEP), somatosensory evoked potentials (SSEP), and electromyography (EMG) are used.
2. An incision is made posteriorly and the paraspinous muscles are dissected in a subperiosteal fashion, exposing the spinous processes, laminar facets, and lateral processes of C4-T2. If the bone is very soft, fixation is extended to bicortical C2 screws. Preoperative standing films will allow determination of the apex of the upper thoracic kyphosis, and the fixation is extended below this apex as needed.
3. After exposure, the osteotomy is performed. A complete C7 laminectomy and partial C6 and T1 laminectomies are performed. The resection is carried laterally to include the removal of the C7 pedicle with rongeurs. All resected bone is saved for reuse later to create the bone graft.
4. The residual portions of the C6 and T1 laminae need to be carefully beveled and undercut to avoid any impingement or kinking of the spinal

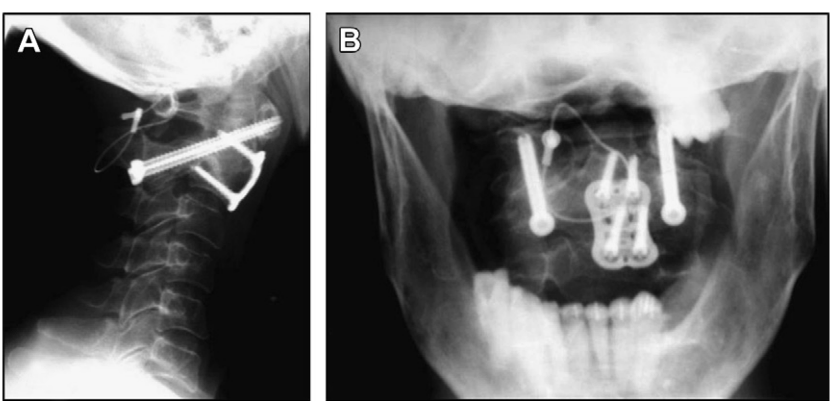

Fig. 17. Six-month postoperative lateral (*A*) and anterior-posterior (*B*) plain radiographs.

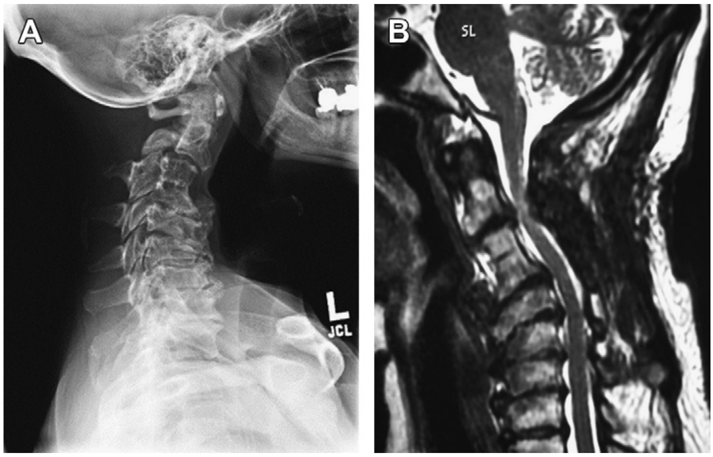

Fig. 18. Case example of semirigid deformity that was treated with Smith-Petersen osteotomy (SPO) and cobalt chromium rods. (*A*) Preoperative lateral radiograph showing cervical kyphosis. (*B*) Preoperative sagittal MRI showing spinal stenosis.

cord on closure of the osteotomy. Furthermore, the area near the C8 nerve root is curved to provide ample room for the nerve root on closure.

5. The surgeon grasps the halo and extends the neck gradually with closure of the osteotomy posteriorly as the osteoclasis across C7-T1 occurs anteriorly. An audible snap and sensation of the osteoclasis is usually heard (**Fig. 20**A). Also at this time, correction of rotation malalignment and lateral tilt is carried out.
6. The pre-bent rod is placed and locked down. The C8 foramen is inspected to make sure the nerve is free after complete closure. At the C7-T1 area, the posterior aspects of the spine may then be decorticated. The autologous bone graft from the resection is packed bilaterally onto the decorticated areas.

Cervicothoracic Junction PSO (Dorsal Approach)

For patients with fixed cervicothoracic kyphosis, a 360° release and fusion or an osteotomy typically is used to correct the kyphosis.[21] Such cervical osteotomies are performed at C7 or T1 because of the absence of the vertebral artery at this level. Preoperative CT angiography is performed to rule out an aberrant vertebral artery position at C7.

Several investigators have reported successful results for a single-level dorsal decancellation osteotomy, also known as the "eggshell" procedure

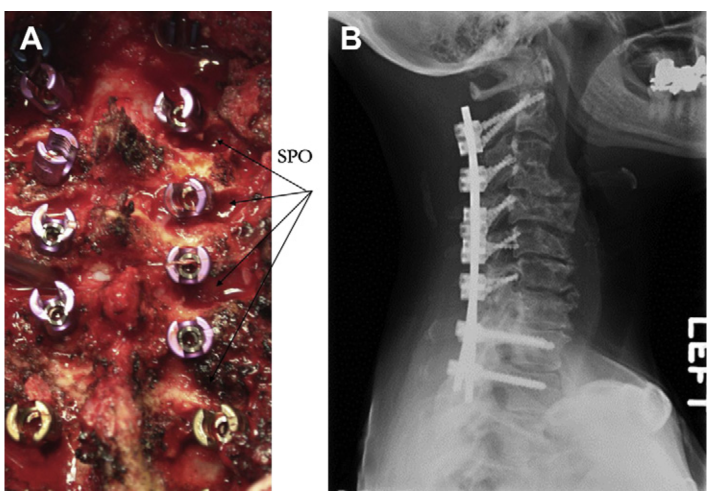

Fig. 19. Case example of semirigid deformity treated with SPO. (*A*) Intraoperative photograph showing the cervical kyphotic correction using multiple SPOs. (*B*) Postoperative lateral radiograph showing correction of the cervical kyphosis and use of a cobalt chromium rod.

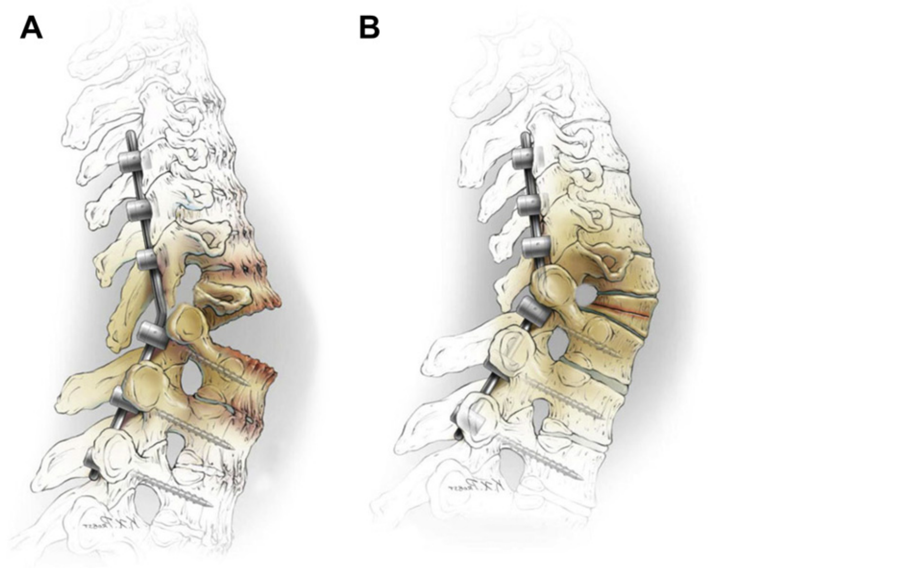

Fig. 20. Correction of kyphosis in Classic SPO. (*A*) Opening wedge for flexion deformity in ankylosing spondylitis. (*B*) Pedicle subtraction osteotomy (PSO). (*From* Scheer JK, Tang JA, Buckley JM, et al. Biomechanical analysis of osteotomy type and rod diameter for treatment of cervicothoracic kyphosis. Spine (Phila Pa 1976) 2011;36:E519–23; with permission.)

or PSO.[21,25,68,69] Once closed, there is bone contact in both columns and the spinal canal is effectively shortened (**Fig. 20**B). Thus the PSO procedure can provide excellent sagittal correction while simultaneously forming a stable construct and minimizing neural compression.

Indications

Indications are fixed sagittal malalignment of the cervical spine (mid to low subaxial cervical spine) affecting horizontal gaze, persistent pain related to cervical sagittal imbalance despite conservative treatment, high pelvic tilt causing low back pain driven by cervical deformity.

Surgical technique

The surgical technique for C7 PSO is as follows (**Fig. 21**).

1. The patient is positioned prone in a halo ring.
2. Transcortical MEP and SSEP as well as EMG neuromonitoring is used.
3. A standard posterior surgical approach is made to the cervical spine, creating an incision from C2 to T3/T5 depending on the location of the kyphotic apex.
4. A posterior incision is made from C2 to T3/T5, and is taken sharply through the skin and down to the fascia. The paraspinous muscles are dissected in a subperiosteal fashion, exposing the spinous processes, laminar facets, and lateral processes of the cervical spine, and transverse processes in the thoracic spine.
5. After exposure, the spine is instrumented accordingly (C2 bicortical pedicle screws, cervical lateral mass screws, and thoracic pedicle screws). It is preferable to extend the fixation to C2 to obtain bicortical screw placement for a stronger fixation point than at the lateral masses of the inferior vertebrae. Furthermore, it is preferable to have the caudal extent of the fusion terminate at either T3 or T5 depending on the extent of thoracic kyphosis to ensure the apex is within the fusion. Depending on surgeon preference, various types of fusion rods may be used such as stainless steel and titanium; however, cobalt-chrome rods are preferred.
6. The osteotomy begins with release and removal of the facets of C6-C7 as well as C7-T1 (**Fig. 21**I).The nerve roots at C7 and C8 are then identified and followed out of the foramen while carrying out the osteotomy, completely isolating the C7 pedicle (**Fig. 22**).
7. After the bilateral facetectomies and isolation of the C7 pedicle, the C7 pedicle is skeletonized and removed with Lempert rongeurs. Sequential lumbar or custom wedge-shaped spinal taps are used to decancellate the C7

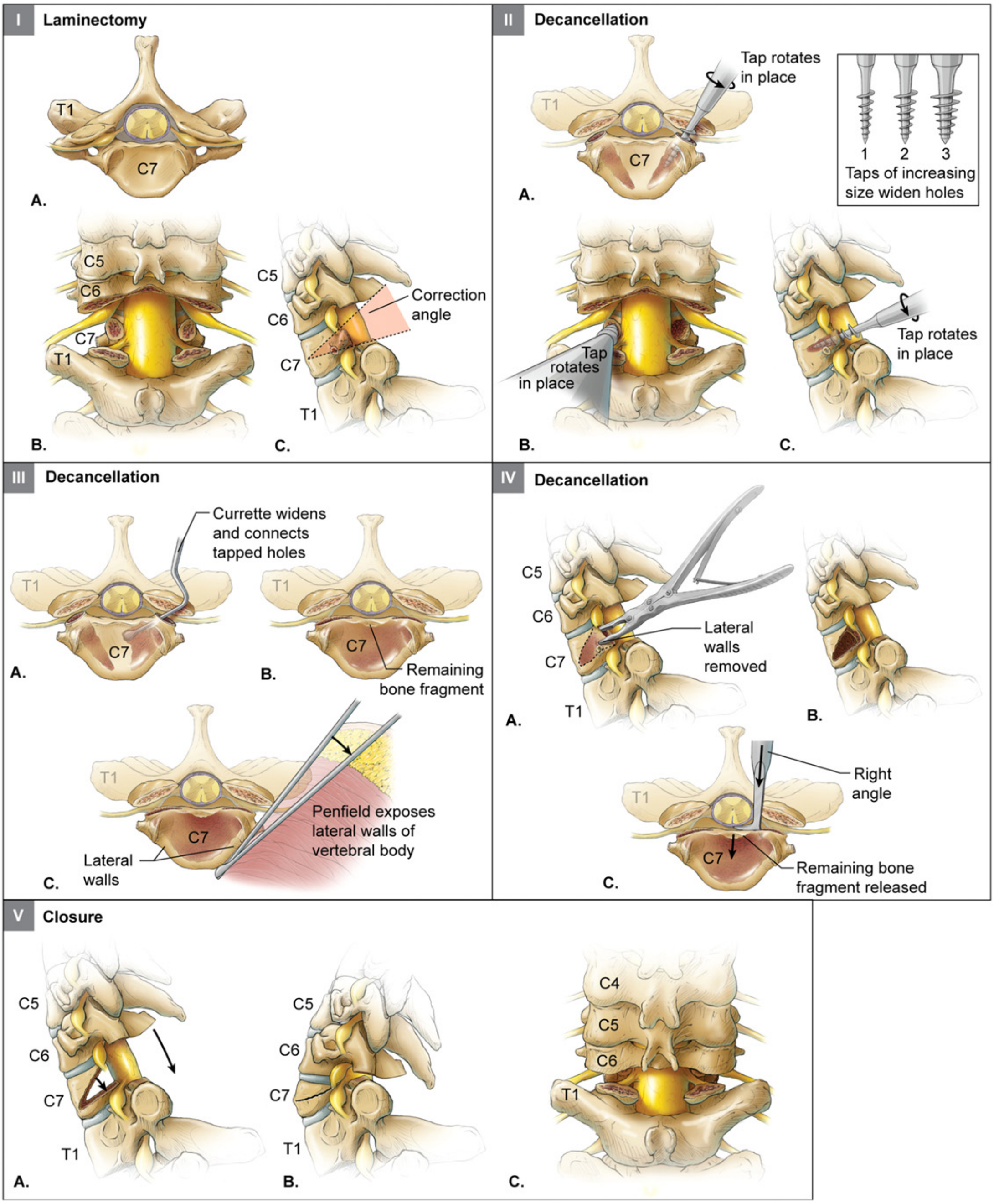

Fig. 21. C7 PSO technique. (*From* Deviren V, Scheer JK, Ames CP. Technique of cervicothoracic junction pedicle subtraction osteotomy for cervical sagittal imbalance: report of 11 cases. J Neurosurg Spine 2011;15:174–81; with permission.)

vertebral body (**Fig. 23**) combined with osteotomes and down-pushing curettes to attempt a 30° wedge (**Fig. 21**II and III).

8. The lateral wall of the C7 vertebral body is then dissected out with a Penfield 1 retractor and visualized (**Fig. 21**III, **Fig. 24**). The C7 lateral wall is removed with needle-nose rongeurs and osteotomes via the pedicle hole reamed out by the taps, followed by removal of the medial column (**Fig. 21**IV).
9. After completion of the osteotomy the head is loosened from the table, and the halo ring is used to extend the head and close the osteotomy (**Fig. 21**V, **Fig. 25**).
10. The wound is closed and the patient is taken to the surgical intensive care unit.

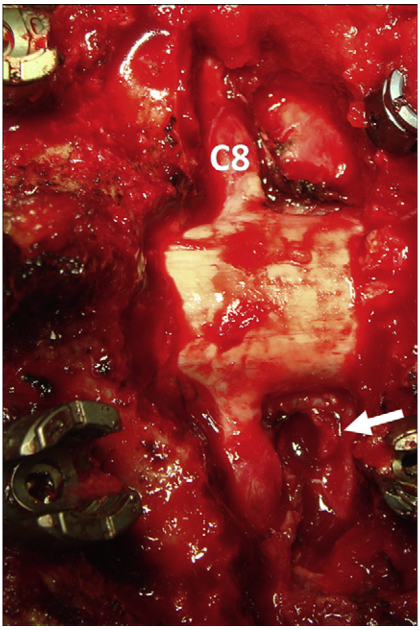

Fig. 22. Intraoperative photograph during C7 pedicle subtraction osteotomy showing isolation of the C7 pedicle and C8 nerve root.

Results

The PSO at the CTJ has 2 key benefits compared with the traditional Smith-Petersen osteotomy (see **Fig. 18**). First, The PSO results in greater biomechanical stability (producing a mechanically stiffer result) than that obtained with the Smith-Petersen osteotomy.[43,70] The Smith-Petersen osteotomy generally results in disc disruption or, in cases of ankylosing spondylitis, osteoclasis through a fused disc space or the anterior cortex of the vertebral body, causing a significant anterior gap in which the anterior longitudinal ligament is completely torn or the autofused anterior bridging osteophyte is fractured. The PSO leaves the anterior longitudinal ligament intact. In addition, the PSO has a wedge component that cleaves the vertebral body, creating a larger bone-on-bone load-bearing interface even when compared with a Smith-Petersen osteotomy that is fully closed posteriorly. This greater bone-on-bone contact significantly increases stiffness, especially in compression, and may provide better fusion rates in patients who do not have ankylosing spondylitis, as the PSO provides a substantial load-bearing surface area in the uniting of the anterior, middle, and posterior columns on closure.[43,70] No secondary anterior grafting is required. Second, The PSO results in a more controlled closure than does the Smith-Petersen osteotomy, because no sudden osteoclastic fracture is necessary.

In their surgical series of 11 patients who received cervicothoracic PSO, the authors found that this procedure results in excellent correction of cervical kyphosis and CBVA with a controlled closure, and improvement in HRQoL measures even at early time points.[21] The mean preoperative and immediate postoperative values ($\pm$standard deviation) for cervical sagittal imbalance were 7.9 $\pm$ 1.4 cm and 3.4 $\pm$ 1.7 cm. The mean overall correction was 4.5 $\pm$ 1.5 cm (42.8%), the mean PSO correction 19.0°, and the mean CBVA correction 36.7°. There was a significant decrease in both the Neck Disability Index (51.1–38.6, P = .03) and visual analog scale scores for neck pain (8.1–3.9, P = .0021). The SF-36 physical-component summary scores increased by 18.4% (30.2–35.8), without neurologic complications.

Complications

Because of the recent advances in surgical technique, anesthesia, and intraoperative neuromonitoring, CTJ PSO has been considered a safe, reproducible, and effective procedure for the management of cervicothoracic kyphotic deformities.[21] Cervicothoracic PSO has reported complications that include neurologic deficits, sudden subluxation, and even death.[40,59,67] Daubs and colleagues[71] found that increasing age was a

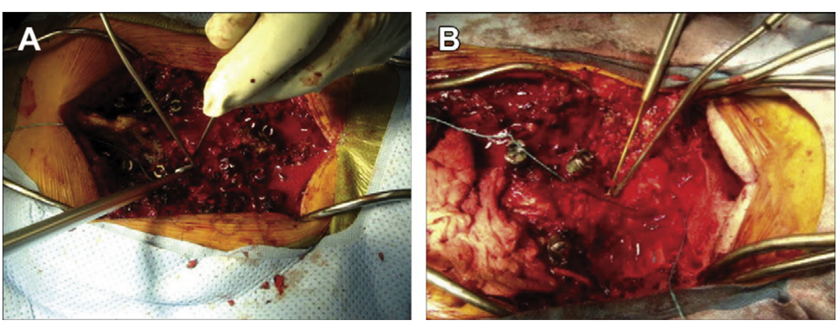

Fig. 23. Intraoperative photographs during C7 pedicle subtraction osteotomy showing 2 different views (*A* and *B*) of using lumbar taps to decancellate the C7 vertebral body.

Fig. 24. Intraoperative photograph during C7 pedicle subtraction osteotomy showing the use of a Penfield retractor to expose the lateral wall of C7.

significant factor in predicting a complication for patients older than 60 years; however, in the authors' series 8 of 11 patients were older than 60, among whom there were no perioperative neurologic deficits, with perioperative medical complications in only 2 of the 11 cases. The lower medical complication rate and decreased incidence of dysphagia may be due to the all-posterior nature of this technique. Posterior-only deformity corrections have also been associated with lower complication rates in thoracolumbar surgery in comparison with staged anterior-posterior procedures (**Table 2**).

Cervical Circumferential Osteotomy

In the clinical setting of rigid cervical kyphosis with neurologic symptoms, the spinal cord is usually tethered over the subaxial kyphotic segment, leading to neurologic symptoms and myelopathy. Therefore, segmental kyphosis correction is needed to untether and decompress the spinal cord in the mid subaxial region. This technique is in 3 stages: posterior, anterior, posterior (**Figs. 26–28**).

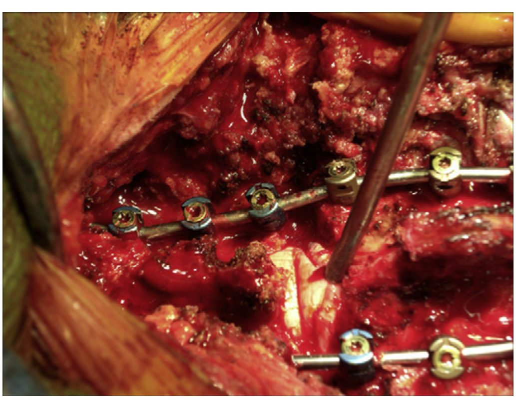

Fig. 25. Intraoperative photograph during C7 pedicle subtraction osteotomy showing closure of the osteotomy.

These stages can be carried out during a single anesthesia or in a delayed fashion according to the extension of the planned procedure and the condition of the patient. All stages are performed under general anesthesia with neuromonitoring using standard motor and sensory evoked potentials.

1. First stage (see **Fig. 26**): A standard posterior approach (laminectomy, facetectomy, and insertion of pedicle screw and lateral mass screw) to the cervical spine is performed for the predetermined levels.
2. Second stage (see **Fig. 27**): Anterior approach to the anterior cervical vertebrae for the decompression and remobilizing the cervical spine.
3. Third stage (see **Fig. 28**): The patient is again positioned prone and the previous posterior incision reopened. Final correction of deformity is gained.

Indications and contraindications

Fixed mid subaxial kyphotic deformity results from degenerative or inflammatory conditions or, often, from previous fixation in a kyphotic position (**Fig. 29**A). Cervical sagittal imbalance secondary to failed anterior procedures as a result of non-unions or graft subsidence is increasingly common. It is important to achieve enough correction of sagittal imbalance and regional lordosis to allow dorsal cord migration and decreased cord tension.

Surgical procedure

1. First stage
   a. After a standard posterior cervical approach, previous instrumentation can be removed and the fusion mass explored, searching for any sites of nonunion.
   b. Laminectomies can be done as needed, especially around the apex of the deformity to allow for free movement of the spinal cord after the correction of the deformity. Previous laminectomy scar is removed down to the dura.
   c. Through the same approach, the necessary foraminotomies are performed, dictated by the patient's preoperative clinical and radiographic status. Bilateral osteotomies, including the cephalad part of the superior facet and caudad aspect of the inferior facet, are performed at the apical levels of the kyphosis. Care must be taken to carry the resection lateral enough to release all the fusion mass or facets and generously

Table 2
Demographic data including patient age, cause of deformity, comorbidities, radiographic results, and complications

Case No.	Age (y), Sex	Diagnosis	Operation	Complications
1	70, M	Chin-on-chest deformity	C7 PSO	Pneumonia
2	56, M	Cervical kyphosis and cervical myelopathy	C7 PSO	
3	82, F	Chin-on-chest deformity	C7 PSO	
4	80, M	Chin-on-chest deformity	C7 PSO	Pneumonia
5	73, F	Fixed coronal and sagittal plane cervical deformity	C6 and C7 PSO	
6	69, M	Cervical kyphosis	C7 PSO	Dysphagia/PEG
7	59, F	Chin-on-chest deformity	C7 PSO	
8	75, M	Cervical kyphosis	C7 PSO	
9	94, F	Chin-on-chest deformity	T1 PSO	
10	63, M	Chin-on-chest deformity	C7 PSO	Rod fracture at 4 mo
11	52, M	Chin-on-chest deformity	C7 PSO	

Abbreviations: PEG, percutaneous endoscopic gastrostomy; PSO, pedicle subtraction osteotomy.

decompress the exiting nerve root (see **Fig. 26**).

d. Segmental instrumentation is placed in the form of lateral mass or pedicle screws, depending on the level and surgeon's preference.

e. The incision is closed in the standard fashion postoperatively; the patient can be mobilized with the use of a hard collar until the next stage.

2. Second stage
   a. The patient is turned to the supine position and an anterior cervical approach is taken

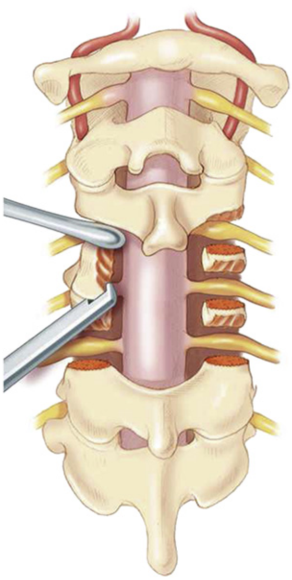

Fig. 26. First stage involving removal of previous instrumentation, central and foraminal decompressions, multiple posterior osteotomies, and posterior reinstrumentation (not depicted here). This procedure is known as the cervical Ponte osteotomy, which can be performed in a single stage to loosen semirigid deformities with mobile discs.

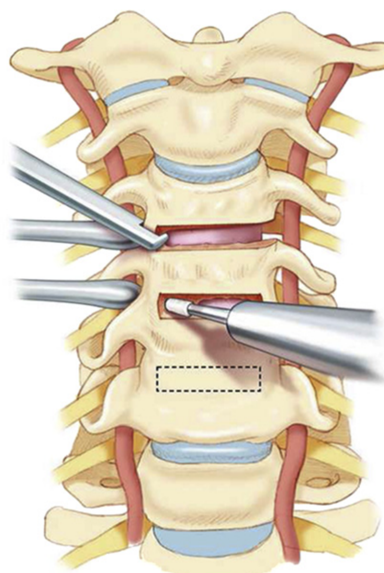

Fig. 27. Anterior second stage with multiple osteotomies/discectomies involving resection of the uncovertebral joints and protection of the vertebral artery. An anterior, overcontoured plate can also be used to produce anterior translation at the apex of the deformity (not depicted here).

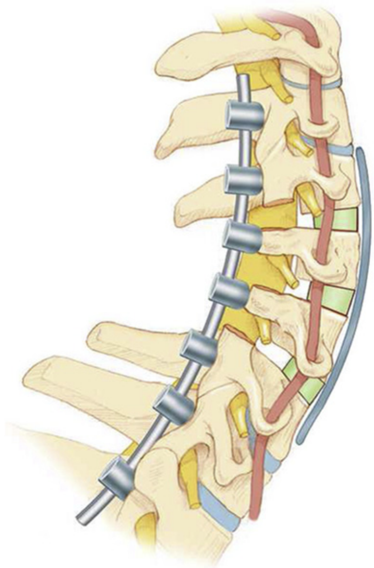

Fig. 28. Final correction after the third stage and rod placement.

through previously operated tissue planes. Any anterior instrumentation used in prior surgeries can be removed at this time.

b. Anteriorly based osteotomies are performed as needed depending on the presence of ankylosed/fused segments, the necessity of anterior decompression, and the overall deformity. For improved correction, the osteotomies must be performed lateral to the uncovertebral joints, protecting the vertebral artery from the burr with a Penfield #4 dissector[38] (see **Fig. 27**).

c. After complete release, lordosing distraction is applied at each osteotomy site with Caspar pins, and a laminar spreader is inserted in the disc space.
d. Interbody lordotic grafting (autograft, allograft, or cages as preferred) is performed.
e. A plate spanning the osteotomies is overcontoured (**Fig. 30**) and fixed initially at the apical level by parallel screws, conforming the apical segment into more lordosis as the screws are tightened and the spine is sequentially reduced to the plate.
f. The rest of the screws are placed and secured, and the incision is closed in the standard fashion.

3. Third stage
   a. The patient is again positioned prone and the previous posterior incision reopened.
   b. Bony surfaces are decorticated with bone grafting and rod placement (see **Figs. 28** and **29**B). Compression at the osteotomies may be performed if deemed necessary.
   c. Following closure, the patient is immobilized in a hard cervical collar. Placement of a feeding tube can be done at the end of the procedure if problems with swallowing are anticipated.
   d. The patient is kept intubated and nursed in a head-up position to reduce postoperative pharyngeal edema until it is considered safe to remove the endotracheal tube.

Results

A gradual and acceptable correction is achieved through the summation of correct positioning,

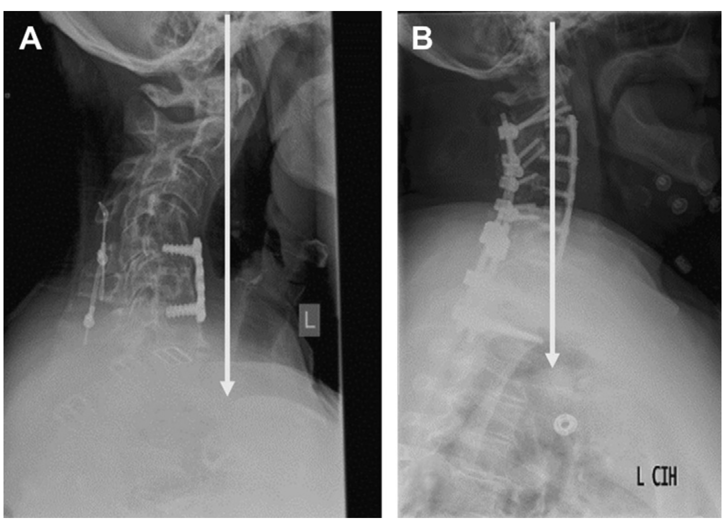

Fig. 29. Preoperative (*A*) and postoperative (*B*) lateral radiographs demonstrating a case example of a 540° circumferential procedure.

Fig. 30. An anterior cervical plate following 3-point bending resting on top of a model cervical spine for comparison of the curvature obtained from the bending.

multiple osteotomy sites, plated anterior segmental translation, and posterior instrumented compression.

In the authors' 14 cases of surgical experience, osteotomies were performed at 3.9 (range 3–6) levels anteriorly and 6.6 (range 3–18) levels posteriorly. The estimated blood loss was on average 1484 mL (range 400–4600 mL). The average stay in the hospital was 19 days (range 3–55 days) and stay in the intensive care unit 6.2 days (range 0–15 days). Days intubated averaged 3.8 (range 0–15 days).

The average C2-C7 angle changed from 12.4° of kyphosis (range 58° of kyphosis to 30.9° of lordosis) to an average of 14.9° of lordosis after surgery (range 9.4° of kyphosis to 35.1° of lordosis). The average angular correction was

Table 3
Major complications for the various osteotomies

Technique	No. of Patients	Overall Complication Rate	Mortality Rate	Neurologic Complication Rate	Complications
PSO: Deviren et al[21]	11	4/11	0	0	1 dysphagia/PEG, 1 rod fracture, 2 pneumonia
360°: Nottmeier et al[72]	41	2/41	0	2/41	1 quadriparesis, 1 C8 radiculopathy
540°: Acosta et al[44]	14	5/14	0	1/14	1 incidental durotomy, 1 persistent CSF leak, 1 superficial wound infection, 1 infection at iliac bone harvest site, 1 C5 palsy
Circumferential: Mummaneni et al[73]	30	11/30	2/30	0	2 wound infections, 1 fall with fracture of C6, 1 plate dislodgment, 1 transient dysphonia, 1 intraoperative CSF leak, 3 perioperative tracheostomy and gastrostomy, 2 deaths
OWO: Simmons et al[40]	131	55/131	4/131	21/131	2 intraoperative neurologic, 1 hemiparesis, 16 C8 radiculopathy, 2 C8 nerve root irritations, 6 pseudarthrosis, 5 pneumonia, 4 deep vein thrombosis with pulmonary embolism, 15 halo pin infections, 4 deaths
Anterior-posterior: O'Shaughnessy et al[74]	20	7/20	0	4/20	2 durotomy, 3 transient C5 palsy, 1 head-holder failure with resultant quadriplegia, 1 late progression of deformity at the caudal junctional end

Abbreviations: CSF, cerebrospinal fluid; OWO, opening wedge osteotomy; PEG, percutaneous endoscopic gastrostomy; PSO, pedicle subtraction osteotomy.

27.7° (range 1.9°–74.6°). The average preoperative C2-C7 translation improved from 46.9 mm (range 86–2 mm) to 26 mm (range 57 to −3 mm) for an average 20.8 mm of correction.

Complications

In the authors' surgical series, there was 1 case of incidental durotomy that was repaired during the same surgery. One patient had persistent cerebrospinal fluid leak postoperatively and was taken back to the operation room for repair. There was 1 superficial wound infection and 1 infection at the iliac crest bone harvest site. The former resolved with irrigation and debridement and oral antibiotics. The latter was managed with a wound vacuum system and oral antibiotics. Other complications not directly related to surgery were 1 acute subdural hematoma that required craniotomy and 1 pneumothorax secondary to line placement. Regarding neurologic complications, 1 patient had postoperative right C5 palsy interpreted to be secondary to root stretching after deformity correction. Complications from the literature regarding the osteotomies discussed are presented in **Table 3**.

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