Over the last decade, multiple publications have identified the important radiographic parameters in the thoracolumbar spine that have direct effects on HRQOL. Normative global and regional parameters have been defined and critical thresholds for sagittal realignment planning have been established. However, relatively few publications have defined these normative values for cervical alignment, and even fewer have directly evaluated the influence of segmental, regional, and global balance on outcomes in cervical surgery.

The cervical spine is a remarkably complex segment, Cervical spine alignment, sagittal deformity, and clinical implications

A review

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This paper is a narrative review of normal cervical alignment, methods for quantifying alignment, and how alignment is associated with cervical deformity, myelopathy, and adjacent-segment disease (ASD), with discussions of health-related quality of life (HRQOL). Popular methods currently used to quantify cervical alignment are discussed including cervical lordosis, sagittal vertical axis, and horizontal gaze with the chin-brow to vertical angle. Cervical deformity is examined in detail as deformities localized to the cervical spine affect, and are affected by, other parameters of the spine in preserving global sagittal alignment. An evolving trend is defining cervical sagittal alignment. Evidence from a few recent studies suggests correlations between radiographic parameters in the cervical spine and HRQOL. Analysis of the cervical regional alignment with respect to overall spinal pelvic alignment is critical. The article details mechanisms by which cervical kyphotic deformity potentially leads to ASD and discusses previous studies that suggest how postoperative sagittal malalignment may promote ASD. Further clinical studies are needed to explore the relationship of cervical malalignment and the development of ASD. Sagittal alignment of the cervical spine may play a substantial role in the development of cervical myelopathy as cervical deformity can lead to spinal cord compression and cord tension. Surgical correction of cervical myelopathy should always take into consideration cervical sagittal alignment, as decompression alone may not decrease cord tension induced by kyphosis. Awareness of the development of postlaminectomy kyphosis is critical as it relates to cervical myelopathy. The future direction of cervical deformity correction should include a comprehensive approach in assessing global cervical-pelvic relationships. Just as understanding pelvic incidence as it relates to lumbar lordosis was crucial in building our knowledge of thoracolumbar deformities, T-1 incidence and cervical sagittal balance can further our understanding of cervical deformities. Other important parameters that account for the cervical-pelvic relationship are surveyed in detail, and it is recognized that all such parameters need to be validated in studies that correlate HRQOL outcomes following cervical deformity correction.

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KEY WORDS • cervical spine alignment • cervical deformity • cervical myelopathy • cervical adjacent-segment disease • sagittal vertical axis • health-related quality of life

Abbreviations used in this paper: ACDF = anterior cervical discectomy and fusion; ASD = adjacent-segment disease; CBVA = chin-brow to vertical angle; CSM = cervical spondylotic myelopathy; CTJ = cervicothoracic junction; HRQOL = health-related quality of life; NDI = Neck Disability Index; SF-36 = 36-Item Short-Form Health Survey; SVA = sagittal vertical axis.
as it not only supports the mass of the head but also allows the widest range of motion relative to the rest of the spine. The intricacies of the cervical region make it susceptible to a variety of disorders and complications, many of which inevitably lead to, or even begin with, alignment pathology that may warrant surgical consideration. Abnormalities of this critical segment can be debilitating and induce adverse effects on the overall functioning and HRQOL of the patient. Furthermore, the cervical spine plays a pivotal role in influencing subjacent global spinal alignment and pelvic tilt as compensatory changes occur to maintain horizontal gaze.

In the past, research conducted on the relationship between spinal malalignment and HRQOL has largely focused on the thoracolumbar and pelvic regions, and comparatively little attention has been given to the cervical spine. Currently, indications for surgery to correct cervical alignment are not well defined and there is no set 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, the purpose of this article is to provide a comprehensive review of cervical alignment parameters and related outcome measures that may provide guidance for proper surgical treatment and highlight deficiencies in the current literature. Comparisons to established spinal pelvic parameters that predict disability in thoracolumbar surgery will be described. Other pathologies that are closely influenced by cervical deformity, including ASD and myelopathy, are also discussed.

**Cervical Spine Alignment Parameters**

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, and any deviations from the normal alignment of the mass of the head result in an increase in muscular energy expenditure. Cervical spine stability as it not only supports the mass of the head but also allows the widest range of motion relative to the rest of the spine. The intricate plexus.

In this classification, the anterior column consists of the posterior arch and the ligamentous complex, approximately 1 cm above and anterior to the external auditory canal, and any deviations from the normal alignment of the mass of the head result in an increase in muscular energy expenditure. Cervical spine stability. 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. This is in contrast to the lumbar spine, in which the anterior loads (67%–82%) have been reported as higher than the posterior loads (18%–33%). The natural curvature of the cervical spine maintains a lordotic shape as a result of the wedge-shaped cervical vertebrae and the need to compensate for the kyphotic curvature of the thoracic spine. 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 CTJ. Deviations from this curvature, such as a loss of lordosis or the development of cervical kyphosis, are associated with pain and disability.

The 3 primary methods to assess cervical lordosis include Cobb angles, Jackson physiological stress lines, and the Harrison posterior tangent method (Fig. 1), the most common of which are Cobb angles typically measured from C-1 to C-7 or C-2 to C-7. The 4-line method involves 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 2 lines noted above and the angle subtended between the crossing of the perpendicular lines is the cervical curvature angle. The Jackson physiological stress line method requires drawing 2 lines, both parallel to the posterior surface of the C-7 and C-2 vertebral bodies, and measuring the angle between them. Lastly, the Harrison posterior tangent method involves drawing lines parallel 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. It has been suggested that the Cobb C1–7 angle overestimates cervical lordosis, that the Cobb C2–7 angle underestimates cervical lordosis, and that the Harrison method may provide the best estimate of lordosis. Despite this finding, the Cobb method remains the clinical mainstay of cervical lordosis measurement due to its ease of use, as well as its good intrarater and interrater reliability.

Translation of the cervical spine in the sagittal plane is measured through the cervical SVA, for which there are different methods of measurement. Both C-2 SVA (Figs. 2 and 3 left) 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, respectively, from the posterior superior corner of the sacrum. Cervical SVA can also be defined regionally using the distance between a plumb line dropped from the centroid of C-2 (or dens) and the posterosuperior aspect of C-7 (C2–7 SVA; Figs. 2 and 3). The gravity line measured from the center of gravity of the head has been proposed as an additional method to the C-7 plumb line to assess global sagittal alignment (center of gravity SVA; Fig. 3 left).

This method may also be applied regionally to cervical SVA using a plumb line drawn from the center of gravity of the head instead of C-2 (center of gravity to C-7 SVA). On lateral radiographs,
the center of gravity of the head can be approximated by using the anterior portion of the external auditory canal as the initial point for the plumb line (Fig. 3 left). However, the C-2 plumb line is especially clinically relevant because it has been directly correlated with HRQOL, in which larger C-2 SVA relates to poorer HRQOL. The CBVA is an assessment of horizontal gaze. This measurement is especially useful in the management of severe, rigid, cervical kyphotic deformities, as the loss of horizontal gaze has a significant impact on activities of daily living and quality of life. The CBVA is defined as the angle subtended between a line drawn from the
The angle is measured on clinical photographs of the patient standing with hips and knees extended while the neck is in a neutral or fixed position. This parameter is gaining popularity, and deformity correction that has considered CBVA has been shown to be associated with positive postoperative outcomes such as improved gaze, ambulation, and activities of daily living. Lee et al. introduced the concepts of thoracic inlet angle, neck tilt, cervical tilt, and cranial tilt, which have all been found to be related to cervical alignment (discussed below). The thoracic inlet angle was defined as the angle between a line originating from the center of the T-1 endplate and perpendicular to the T-1 endplate and a line from the center of the T-1 endplate and the upper end of the sternum. Neck tilt was defined as an angle between 2 lines both originating from the upper end of the sternum, with 1 being a vertical line and the other connecting to the center of the T-1 endplate. A relationship exists such that thoracic inlet angle equals T-1 slope (angle between a horizontal plane and a line parallel to the superior T-1 endplate; Fig. 4) plus neck tilt. This is similar to the equation in the lumbar spine in which pelvic incidence equals the sacral slope plus the pelvic tilt. Cervical tilt was defined as the angle between 2 lines, both originating from the center of the T-1 upper endplate; one is perpendicular to the T-1 endplate and the other passes through the tip of the dens. Cranial tilt was defined as the angle between 2 lines, both originating from the center of the T-1 upper endplate, with 1 passing through the dens (same as the second line in cervical tilt) and the other being a vertical line.

Normal Cervical Alignment

Because the cervical spine is the most mobile part of the spinal column, a wide range of normal alignment has been described (Tables 1–4; Blondel B, Schwab F, and Ames CP, unpublished data, 2012). In asymptomatic normal volunteers a large percentage (approximately 75%–80%) of cervical standing lordosis is localized to C1–2 and relatively little lordosis exists in the lower cervical levels. Similarly, most lumbar lordosis occurs at

<table>
<thead>
<tr>
<th>Level</th>
<th>Angle (°)</th>
</tr>
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<tbody>
<tr>
<td>C0–1</td>
<td>2.1 ± 5.0</td>
</tr>
<tr>
<td>C1–2</td>
<td>−32.2 ± 7.0</td>
</tr>
<tr>
<td>C2–3</td>
<td>−1.9 ± 5.2</td>
</tr>
<tr>
<td>C3–4</td>
<td>−1.5 ± 5.0</td>
</tr>
<tr>
<td>C4–5</td>
<td>−0.6 ± 4.4</td>
</tr>
<tr>
<td>C5–6</td>
<td>−1.1 ± 5.1</td>
</tr>
<tr>
<td>C6–7</td>
<td>−4.5 ± 4.3</td>
</tr>
<tr>
<td>C2–7</td>
<td>−9.6</td>
</tr>
<tr>
<td>total (C1–7)</td>
<td>−41.8</td>
</tr>
</tbody>
</table>

* Values presented as mean ± SD; negative sign indicates lordosis in the segmental values. Data from Hardacker et al., 1997.
A review of cervical spine alignment

**TABLE 2: Normal cervical SVA values in asymptomatic adults***

<table>
<thead>
<tr>
<th>Odontoid Marker</th>
<th>Mean ± SD (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>at C-7</td>
<td>15.6 ± 11.2</td>
</tr>
<tr>
<td>at sacrum</td>
<td>13.2 ± 29.5</td>
</tr>
</tbody>
</table>

* Data from Hardacker et al., 1997.

The caudal end with L5–S1 having the largest segmental lordotic angle.

The preponderance of cervical lordosis is localized to C1–2 may be explained by the findings of Beier et al., who showed that the center of gravity of the head sits almost directly above the centers of the C-1 and C-2 vertebral bodies. The mean total cervical lordosis is approximately 40°, and on average the occiput-C1 segment is kyphotic. Only 6° (15%) of lordosis occurs at the lowest 3 cervical levels (C4–7). The loss of subaxial lordosis has been reported in occiput–C2 fusions in which excessive hyperlordosis is created at occiput–C2. This type of unfavorable reciprocal change is also observed in lumbar and thoracic osteotomy and has been reported by Lafage et al.

Cervical lordosis may be dependent on the anatomy of the CTJ, which typically involves the C-7 and T-1 vertebrae, the C1–7 discs, and the associated ligaments, and may extend to T-2 and T-3 in terms of osteotomy planning. The CTJ also includes the thoracic inlet, a fixed bony circle that is composed of the T-1 vertebral body, the first ribs on both sides, and the upper part of the sternum. Biomechanically, the CTJ is a region in which the highly mobile cervical spine, which supports the head, transitions into the fairly rigid thoracic spine whose mobility is significantly reduced by the rib cage. Furthermore, the CTJ is the site at which 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, both in the static and dynamic states.

The sagittal alignment of the cranial and cervical spine may be influenced by the shape and orientation of the thoracic inlet to maintain a balanced, upright posture.

**TABLE 3: Normal cervical lordosis values for men and women in different age groups in asymptomatic adults***

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Men (°)</th>
<th>Women (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–25</td>
<td>16 ± 16</td>
<td>15 ± 10</td>
</tr>
<tr>
<td>30–35</td>
<td>21 ± 14</td>
<td>16 ± 16</td>
</tr>
<tr>
<td>40–45</td>
<td>27 ± 14</td>
<td>23 ± 17</td>
</tr>
<tr>
<td>50–55</td>
<td>22 ± 15</td>
<td>25 ± 11</td>
</tr>
<tr>
<td>60–65</td>
<td>22 ± 13</td>
<td>25 ± 16</td>
</tr>
</tbody>
</table>

* Values presented as means ± SDs. Data from Gore et al., 1986.
Primary deformities are often congenital, while many spine can be categorized as either primary or secondary. Corrected appear to play a more critical role in achieving better clinical outcomes.

While deformity of the cervical spine occurs in both the sagittal and coronal planes, sagittal plane deformities not only arise more frequently but when surgically corrected appear to play a more critical role in achieving better clinical outcomes. Deformity of the cervical spine can be categorized as either primary or secondary. Primary deformities are often congenital, while many secondary cervical deformities in the sagittal plane arise from iatrogenic causes or ankylosing spondylitis, a condition characterized by the ossification of the joints and ligaments in the spine. Left untreated, primary deformities in one region of the spine can lead to secondary deformities in another because the entire spine functions as 1 global unit whose individual regions can have a significant effect on each other. For example, a primary congenital lumbar hemivertebra can induce secondary cervical scoliosis.

Cervical kyphosis is by far the most prevalent cervical spine deformity and commonly presents with iatrogenic origins, such as postlaminectomy kyphosis. Once the onset of cervical kyphosis begins, the deformity tends to perpetuate itself, with forward shifting of the head and neck inducing abnormal forces that lead to further progression of the deformity. The spinal cord may be compressed as it extends over the profile of the deformity, which may lead to a myriad of incapacitating symptoms, including myelopathy, loss of horizontal gaze, and dysphagia. The primary goals of surgery aim to correct and stabilize the deformity while decompressing neural elements and restoring sagittal alignment.

It is important to appreciate that cervical sagittal alignment (cervical SVA) is closely related to the cervical sagittal Cobb angle (the C2–7 Cobb angle) as described above; however, cervical sagittal alignment also takes into account the alignment of subjacent segments, including the thoracolumbar spine and pelvis. Deformities localized to the cervical spine affect, and are affected by, other parameters of the spine in preserving global sagittal alignment. Sagittal alignment factors into maintenance of posture, and patients with poor sagittal alignment often develop potentially painful compensatory mechanisms that affect the cervical spine, including hyperlordosis of subaxial segments (Fig. 11).

The main objectives of cervical deformity surgery include the maintenance/restoration of horizontal gaze, decompression of neural elements, and an overall effort to reestablish the normative alignment of the cervical spine. The most common radiographic parameters used in preoperative planning and postoperative assessment include regional measurements such as Cobb angles for kyphosis, C1–2 lordosis, and C2–7 lordosis.

| TABLE 4: Mean sagittal parameters among the volunteers stratified by age group* |
|------------------|------------------|------------------|------------------|
| Variable         | 20–39 yrs Mean  | 20–39 yrs SD    | 40–59 yrs Mean  | 40–59 yrs SD    | >60 yrs Mean   | >60 yrs SD     | p Value†       |
|                  |                  |                  |                  |                  |                  |                  |               |
| C2–7 cervical lordosis (°) | 9.4              | 9                | 6.6              | 9                | 22.2            | 9                | <0.001        |
| T4–12 thoracic kyphosis (°)  | -38.1            | 11               | -36              | 9                | -45             | 14               | NS            |
| L1–S1 lumbar lordosis (°)   | 61.5             | 12               | 60.3             | 7                | 55.7            | 13               | NS            |
| pelvic tilt (°)             | 12.1             | 7                | 14.5             | 5                | 15.1            | 8                | NS            |
| pelvic incidence (°)        | 52.1             | 10               | 54.3             | 8                | 53.5            | 10               | NS            |
| sacral slope (°)            | 40               | 9                | 39.9             | 7                | 36.5            | 10               | NS            |
| SVA (mm)                   | -28.5            | 28               | -18.2            | 39               | 22.4            | 40               | <0.001        |
| T-1 slope (°)              | -22              | 7                | -21.1            | 8                | -31.6           | 9                | 0.001         |

* Unpublished data, Blondel et al., 2012. NS = nonsignificant.
† p values refer to ANOVA comparison between groups.
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Although the current literature reports changes in radiographic parameters of lordosis and kyphosis, there is no clear indication of an optimal amount of cervical lordosis to be achieved postoperatively, and it has become an accepted general rule to correct cervical kyphosis to be as close to neutral as possible. Current research is adopting a trend toward defining cervical sagittal alignment parameters similar to the accepted C7

![Fig. 5. Illustrations demonstrating the concept of T-1 slope and its effect on cervical lordosis (left), and the relationship between thoracic inlet angle, T-1 slope, and cervical lordosis (right). Upper: The relationship between T-1 slope and cervical lordosis is similar to the relationship between pelvic incidence and lumbar lordosis. A greater T-1 slope yields a greater magnitude of cervical lordosis just as a greater pelvic incidence leads to greater lumbar lordosis. Lower: A small thoracic inlet angle yields a low T-1 slope and 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 T-1 slope so that a greater magnitude of cervical lordosis is required to balance the head over the thoracic inlet and trunk. M = manubrium. Reproduced with permission from Lee et al.: J Spinal Disord Tech 25:E41–E47, 2012.]

J Neurosurg: Spine / Volume 19 / August 2013
C0 = occiput. Adapted from Lee et al.: J Spinal Disord Tech 25: the correlation between the thoracic inlet angle and the cranial offset. Segments. The sequential correlations between adjacent segments link the Pearson correlation coefficient between the 2 craniocervical alignment. The r values within the arrows between the significant correlations from the thoracic inlet angle to the cranial offset and used.

The C-2 plumb line and CBVA are increasingly being used.

12,28,92,94 Lumbar deformity. HRQOL.104 

Tal boost. These cervical measurements are based on standing 3-foot spine radiographs. Few studies, however, report the relationship between radiographic parameters in the cervical spine and HRQOL.104 The effects of these cervical radiographic measurements on outcome scores are not nearly as well-defined as global and pelvic parameters are in thoracolumbar deformity.12,28,92,94 Furthermore, many of these studies neglect consideration of preoperative measurements that provide baseline values with which to compare postoperative status.

Of the few studies that explore associations between radiographs and clinical outcomes, there appears to be evidence suggesting that correlations between the 2 may be worth further investigation with larger sample sizes and more controlled prospective analyses. Among the outcome scores most frequently collected for the cervical spine are the NDI, SF-36 mental and physical component scores, and visual analog scale for neck pain as measures of clinical status, and Nurick grades, modified Japanese Orthopaedic Association scores, Odom scale scores, Frankel grades, and Ishihara indices as measures of functional status.

The majority of available reports provide assessment of regional measurements of kyphosis. A recurrent finding is the increase in complaints of neck pain in patients with greater kyphosis measurements, whether following cervical spine trauma28 or operative procedures such as anterior cervical spine fusion51 or single-level ACDF.69 Naderi et al.79 concluded that the presence of abnormal cervical curvature predicts less postoperative neurological improvement.

More recent works studying cervical alignment parameters (most represented as lordosis between C-2 and C-7) in relation to postoperative clinical outcomes are weak in suggesting significant correlations. Jaghannathan et al.43 found no significant relationship between the change in segmental kyphosis and postoperative functional status. Villavicencio et al.108 conducted a prospective, double-blind, randomized study evaluating the relationship between lordotic alignment (both cervical and segmental) and clinical outcomes using normal and lordotically shaped allografts for ACDF. They found that improved cervical Cobb angle alignment did not correlate significantly with clinical outcomes, but that maintaining or improving segmental sagittal alignment had significant implications for a higher degree of improvement in outcomes scores. Similarly, Guérin et al.52 also noted that only segmental sagittal alignment correlated with clinical outcomes after cervical disc arthroplasty, while overall cervical lordotic alignment did not. The CBVA, while recognized to be the most objective measure of horizontal gaze, had no significant correlation with overall clinical outcome (the Modified Arthritis Impact Measurement Scale) in cervical kyphosis with ankylosing spondylitis.102 However, it has proven to be a very reliable and useful tool in assessing preoperative and postoperative horizontal gaze, and correction of the CBVA does lead to positive postoperative outcomes regarding a patient’s satisfaction of horizontal gaze improvement.9,53,54,102,110

SVA traditionally used to measure sagittal alignment of the thoracolumbar spine.107 Specifically, as noted above, the C-2 plumb line and CBVA are increasingly being used.33,40,63,102,104 To evaluate the effect of cervical alignment in relation to the overall sagittal alignment of the spine, these measurements are based on standing 3-foot spine radiographs.

Interestingly, these studies investigating cervical alignment parameters primarily measure lordosis between C-2 and C-7 and not the aforementioned SVA parameters, with the exception of 1 study.104 Sagittal vertical axis values, however, are standard measurements taken to assess deformity in the thoracolumbar spine. In fact, both Glassman et al.27 and Mac-Thiong et al.69 concluded that positive sagittal malalignment, defined as a C-7 plumb line greater than 50 mm anterior to the posterior superior aspect of the sacrum, is associated with a deterioration of quality of life in patients with adult spinal deformity. Mac-Thiong et al.69 even extended this association to involve the global balance as defined by the gravity line. Currently, only 1 study has broadened these observations between SVA measurements and HRQOL scores to include the cervical spine. The study by Tang et al. suggests that increasing cervical SVA is a cause for clinical concern of cervical malalignment indicated by poor HRQOL.
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scores, and cervical SVA greater than 4 cm is correlated with worse outcomes assessed by the NDI (Fig. 12). In addition, the authors found significant correlations ($p < 0.0001$) between the T-1 slope and C2–7 lordosis ($r = 0.38$), T-1 slope and C2–7 SVA ($r = 0.44$), as well as C2–7 SVA and the difference between the T-1 slope and C2–7 lordosis (T-1 slope – C2–7 lordosis, $r = 0.45$).

Even with the progressive findings linking radiographic parameters and clinical outcomes, limitations still exist in the study designs, as most are retrospective analyses. Especially overlooked in many of these studies is the contribution of the overall improvement in postoperative status that may be attributed to spinal cord decompression in many of these procedures. There is a clear need for future prospective studies to further isolate the effect of cervical alignment on outcome measures and eliminate confounding variables. Analysis of the cervical regional alignment with respect to overall spinal pelvic alignment will be critical.

Cervical Deformity and ASD

Adjacent-segment disease of the cervical spine is among the most controversial topics in spine surgery. Adjacent-segment disease has been defined as the development of new radiculopathy or myelopathy of a motion segment adjacent to the site of a previous arthrodesis of the spine (either superior or inferior). However, studies have not demonstrated a clear correlation between the radiographic changes of adjacent segment degeneration and the clinical presentation of ASD. Nevertheless, the two terms are used interchangeably to describe the phenomenon. The most current data suggest the prevalence of ASD ranges from 9% to 17% with an annual incidence ranging from 1.5% to 4% of the patients undergoing ACDF.
There is overwhelming evidence for the existence of both clinical ASD and radiographic adjacent segment degeneration, but controversy remains about the origin of the ASD or degeneration.\textsuperscript{37,47,71,91,96,100} Investigations of whether ASD is the natural course of the spine or if adjacent spinal fusion contributes directly to ASD are still being conducted in hopes of finding a solid explanation. However, biomechanical studies have shown results of possible mechanisms of ASD. Despite the controversy over the origin of ASD, these studies all surround the idea that motion segments adjacent to cervical arthrodesis may result in increased loading and excessive motion.
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leading to disc degeneration. The increased mechanical stress has been shown to interfere with the nutritional supply of the disc contributing to disc degeneration. The discs rely on diffusion of nutrients into the disc due to the lack of blood supply, and an increased pressure within the disc may interfere with this diffusion process. Furthermore, increased mechanical loads on the disc are known to alter the extracellular matrix composition. These changes also occur with the normal aging process. The nutrition of the discs becomes impaired as calcification of the endplates and a reduction in peripheral arteries cause a lack of nutrition delivery as a person ages. There is also a loss of cells and extracellular matrix with normal aging. Usually elderly patients are undergoing cervical arthrodesis and the normal degeneration process may confound the effect of ASD from the fusion, leading to the current controversy.

A much less studied topic is the relationship between cervical deformity and ASD, but it deserves significant attention. As discussed above, the cervical spine maintains a natural lordotic curvature. This curve allows the cervical spine to distribute the load of the head through the posterior columns (articular processes and facet joints) withstanding about 64% of the load and 36% for the anterior columns. Therefore, it follows that kyphotic deformity of the cervical spine tends to shift the greater part of the load from the posterior columns to the anterior column. This could potentially increase adjacent segment mechanical load as discussed above and contribute to the development of ASD. There are a few studies that have examined this concept in the lumbar spine, with each one suggesting that postoperative sagittal malalignment of the lumbar spine and pelvis may promote ASD with a 4-fold increased incidence. An in vivo animal biomechanical study by Oda et al. demonstrated that postoperative lumbar kyphotic segments are forced into a hyperlordotic state creating a lordotic contracture, which leads to degenerative changes in the facet joints above and below the levels of fusion. Thus, correcting the sagittal alignment may reduce the development of ASD in the future. At the time of this review, there appears to be only 1 study investigating postoperative cervical kyphosis and ASD. Katsuura et al. performed a retrospective radiographic analysis of 42 patients who underwent ACDF with a minimum 5-year follow up. They found that postoperative kyphosis of the cervical spine may contribute to the development of ASD. Of the 42 patients, 21 (50%) had radiographic evidence of ASD. Of the normal group (without ASD), physiological cervical lordosis was preserved in 18 cases (85.7%). However, normal physiological lordosis was only present in 9 cases (42.8%) in the group with adjacent-level degeneration, which was significantly different compared with the normal group. Despite the small sample size of this study, the results suggest that cervical malalignment may contribute to ASD and this study lays the ground work for the initial investigation of this complicated topic. Further clinical studies with large sample sizes are needed to explore the relationship of cervical malalignment and the development of ASD.

Cervical Deformity and Myelopathy

Cervical spondylotic myelopathy is the most common cause of spinal cord dysfunction in patients more than 55 years old. The onset of CSM is generally insidious and involves a wide range of signs and symptoms depending on the cervical levels involved and the degree of neural compression. However, motor and sensory dysfunction are the most common complaints, with the legs often affected first. The origin of CSM has traditionally been described as a result of multilevel spondylotic changes in the discs lead to osteophyte formation. The osteophytes, along with ligamentous and facet hypertrophy, contribute to cervical spinal stenosis and eventually compress the spinal cord. Long-term stenosis and compression may cause demyelination and eventual necrosis of gray and white matter.

Progressive cervical kyphosis has also been associated with myelopathy. The deformity leads to draping of the spinal cord against the vertebral bodies and anterior pathology, increasing the longitudinal cord tension due to the cord being tethered by the dentate ligaments and cervical nerve roots. As the curve becomes more pronounced over time, the spinal cord becomes compressed and flattened. The anterior and posterior margins of the cord compress while the lateral margins expand. Tethering of the cord can produce increased intramedullary pressure. This compression leads to neuronal loss and demyelination of the cord. 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. As the kyphotic angle increases, these changes become greater, especially on the anterior side that is exposed directly to the mechanical compression. Greater cord tension increases intramedullary cord pressure and has been shown to lead to apoptosis in animal models. Shimizu et al. induced cervical kyphosis in small game fowls and quantitatively analyzed the severity of demyelination and neuronal loss in histological sections of the spinal cords. They 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. 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.

Thus, sagittal alignment of the cervical spine may play a substantial role in the development of cervical myelopathy, which is illustrated in Case 2 (Fig. 14).

The current literature is filled with controversy surrounding the best surgical approach to correct CSM. Surgical considerations and options for treating cervical myelopathy must take into account the sagittal alignment of the cervical spine as it affects the approach as well as myelopathy origin and progression. Decompression alone, even ventral decompression, which does not decrease cord tension induced by kyphosis, may therefore not result in optimal outcomes.

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. As mentioned above, 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 with losing the pos-

Fig. 10. The spine functions as a global unit so that cervical alignment parameters influence, and are influenced by, parameters in the lower regions. CL = cervical lordosis, COG = center of gravity, FS = femoral shaft, PI = pelvic incidence, PT = pelvic tilt. SS = sacral slope.
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The anterior 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 kyphosis can then lead to cervical myelopathy due to the curve of the spine as discussed above, thus creating worsened myelopathy from a surgical treatment that was intended to treat myelopathy. The kyphosis can then simultaneously contribute to the development of ASD due to 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 C-7 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 ASD due to the reasons discussed above. Recent data has shown that patients who underwent 1- or 2-level corpectomies for CSM had positive long-term outcomes in terms of HRQOL and maintenance of the regional cervical lordosis.

**Future Directions and Global Cervical-Pelvic Relationships**

Regional radiographic relationships have been well established in the literature regarding cervical deformities. As discussed, the T-1 slope and thoracic inlet angle, as they relate to cervical lordosis, are important parameters to consider in optimizing cervical deformity correction. However, inasmuch as these are regional relationships, they do not characterize the global relationships in the spine. A new chapter in describing cervical deformities entails understanding the relationship of the cervical spine to the pelvis.

Understanding pelvic incidence as it relates to lumbar lordosis was crucial in building our knowledge of thoracolumbar deformities. Similarly, a parameter such as the T-1 incidence can further our understanding of cervical deformities. A patient with cervical deformity can alter the T-1 slope through compensatory mechanisms such as retroverting the pelvis, thoracic hypokyphosis, and lumbar hyperlordosis (Fig. 7 lower). Patients who develop cervicothoracic deformities after thoracolumbar fusions (as in patients with proximal junctional kyphosis) cannot rely on thoracic and lumbar compensatory mechanisms, but they do rely on pelvic retroversion to improve their horizontal gaze. Unlike T-1 slope, the T-1 incidence is independent of pelvic version and thus it can be a better
predictor of the magnitude of cervical deformity correction necessary for optimal balance.

Another parameter that accounts for the cervical-pelvic relationship, the C-2 spino-pelvic inclination, may prove to be as important as the analogous T-1 spino-pelvic inclination (T-1 tilt) in correlating with HRQOL outcomes. The goal of cervical deformity correction is to align the center of mass of the head over the pelvis, and therefore, C-2 should be likewise aligned.

Many studies have established the importance of the CBVA in cervical deformity correction. Generally, determining the CBVA requires a clinical photograph of the patient standing with knees locked in extension. The CBVA is not usually apparent on most standing lateral cervical radiographs. A better measure that correlates with horizontal gaze and can be visualized and measured on a standard lateral cervical radiograph would be more useful; such a measure is the C-2 slope. The horizontal tilt of the C-2 endplate on a standing lateral radiograph will correlate with the ability of a patient to maintain a horizontal gaze. The normative values of occiput–C1 and C1–2 lordosis have been established in studies of asymptomatic individuals. From the occiput to C-2, on average, there is about 30° of lordosis in a comfortable standing posture. Therefore, the C-2 slope should be close to 15° for a comfortable horizontal gaze (a CBVA of 10° has been described as an optimal target). There can be a tremendous degree of compensation and hyperlordosis from the occiput to C-2 and as a result a C-2 slope as large as 50° could allow for a CBVA of 10° with maximal upper cervical compensation, but this degree of compensation may not be comfortable. All such parameters need to be validated in studies that correlate HRQOL outcomes following cervical deformity correction.

**Summary**

The cervical spine is complex and surgical management of cervical disease remains a significant challenge. An understanding of cervical biomechanics as well as the normative data for cervical alignment is necessary to manage complex cervical pathology. The cervical spine carries the load of the head and neck via a 3-column model consisting of an anterior and 2 posterior columns, which should not be confused with the 3-column model in the thoracolumbar spine consisting of anterior, middle, and posterior columns. Within the 3 columns of the cervical spine, the overall shape is lordotic, with the thoracic inlet angle playing a major role in the degree of lordotic curvature, similar to that of pelvic incidence and lumbar lordosis. The major parameters used to assess cervical spine alignment include Cobb angles, Jackson stress lines, and Harrison posterior tangent lines for sagittal curvature; gravity line (center of gravity of the head) or C-2 plumb line for SVA; and the CBVA for horizontal gaze.

**Fig. 12.** Lateral radiographs of 2 different patients demonstrate how increased cervical SVA relates to poor HRQOL measures. **Left:** Normal cervical SVA of 20.9 mm with an SF-36 physical component score of 55.1 and NDI of 3 (no disability). **Right:** Increased cervical SVA of 59.2 mm with an SF-36 physical component score of 28 and NDI of 37 (severe disability).

**Fig. 13.** 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 was measured and was 1.2 cm for kyphosis (A), 1.1 cm for the neutral position (B), and 1.0 cm for cervical lordosis with a C3–5 laminectomy (C).
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Newer parameters include thoracic inlet angle, cervical tilt, neck tilt, and cranial tilt. It has been shown that these parameters affect the alignment of the cervical spine. To maintain neck tilt at approximately 44° to reduce muscle energy expenditure, the thoracic inlet angle increases or decreases based on changes in T-1 slope and cervical lordosis. These relationships form a baseline foundation for future investigation as well as surgical planning of cervical fusions. Furthermore, it is very important to remember that the spinal regions are not independent of one another. Cervical lordosis depends on both thoracic kyphosis and lumbar lordosis. Cervical lordosis can be considered an adaptation by which the cervical spinal segment changes relative to the other spinal segments to attempt to maintain the head over the pelvis and maintain horizontal gaze. In a patient with global sagittal malalignment, cervical lordosis increases as a compensatory mechanism.

The most common type of cervical malalignment is cervical kyphosis, generally due to iatrogenic origins such as postlaminectomy kyphosis. The main objectives of cervical deformity surgery include the maintenance/restoration of horizontal gaze, decompression of neural elements, and an overall effort to reestablish the normative alignment of the cervical spine. Despite the current literature reporting positive outcomes with restoring cervical lordosis, a clear consensus on the optimal amount of cervical lordosis is still lacking. However, it has become a general rule to at least correct the cervical kyphosis to a neutral position. To completely evaluate cervical alignment in the context of the entire spine, full standing radiographs are needed. This is critical due to the cervical spine adapting to the rest of the spine as discussed above. In addition, the relationship between HRQOL and cervical alignment, particularly cervical SVA, has not been discussed in the literature. Of the studies that do exist, maintaining or improving segmental cervical sagittal alignment correlates more with postoperative clinical outcomes than overall cervical lordosis via Cobb angles.

Adjacent-segment disease continues to be very controversial as studies are still attempting to determine if ASD is the natural course of the spine or if adjacent spinal fusion contributes directly to ASD. Various biomechanical studies have proposed mechanisms for the lumbar spine that include increased loading and excessive motion of the intervertebral disc adjacent to the fusion site. The cervical spine is much less studied, with the only study investigating this topic concluding that postoperative cervical kyphosis may contribute to cervical ASD. Thus, maintaining or improving cervical lordosis is very important when correcting any kind of cervical deformity.

Cervical myelopathy is a serious manifestation of cervical spine disease and may be initiated or exacerbated in a patient with cervical sagittal malalignment. The deformity leads to a draping of the spinal cord against the vertebral bodies, leading to anterior spinal cord compression and increasing the longitudinal cord tension due to the cord being tethered by the dentate ligaments and cervical nerve roots. The compression and increased tension leads to an increase in medullary pressure and ultimately neuronal loss causing myelopathy. Therefore, postoperative sagittal alignment must be considered when correct-

![Fig. 14. Case 2. Images obtained in a 55-year-old man with progressive neck pain and myelopathy in the setting of solid fusion due to kyphosis-induced cord tension and sagittal imbalance.](image-url)
ing cervical deformities to prevent the onset or exacerbation of the cervical myelopathy symptoms. This is especially true when performing multilevel laminectomies in which the spine may not initially be destabilized. However, because the cervical spine relies on the posterior columns for weight bearing, resecting the posterior elements causes a shift in the load from posterior to anterior. Over time, the cervical spine becomes kyphotic due to the neck musculature constantly contracting and becoming fatigued. This may result in worsened myelopathy from a surgery originally intended to correct myelopathy.

Finally, the future directions of cervical deformity lie in assessing the spine as a whole, including the cervical-pelvic relationships. As discussed above, the T-1 slope plays a role in cervical lordosis. A patient can alter the T-1 slope through compensatory mechanisms such as retroverting the pelvis, thoracic hypokyphosis, and lumbar hyperlordosis. However, patients who develop cervico-thoracic deformities after thoracolumbar fusions (as in patients with proximal junctional kyphosis) cannot rely on thoracic and lumbar compensatory mechanisms, but they do rely on pelvic retroversion to improve their horizontal gaze. Unlike T-1 slope, the T-1 incidence is independent of pelvic tilt and thus it can be a better predictor of the magnitude of cervical deformity correction necessary for optimal balance. The C-2 spine-pelvic inclination may prove to be just as useful for the cervical spine as the T-1 spine-pelvic inclination is for HRQOL, because the goal of cervical deformity surgery is to align the center of mass of the head over the pelvis, and thus C-2 should be aligned as well. The CBVA has been one of the best measures of horizontal gaze, as mentioned above. However, this measure is not generally apparent on lateral cervical radiographs. If this is the case, the C-2 slope (horizontal tilt of the C-2 endplate) may be used to correlate the patient’s ability to maintain a horizontal gaze. These concepts are in the early stages and future studies correlating them with HRQOL will expand the current understanding of cervical alignment and deformity surgery. Likewise, further investigation of the cervical spine in other areas is much needed as well, especially the relationship between the various cervical alignment parameters and HRQOL, cervical deformity, and osteotomy classification, and more standardized indications for surgery.

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