Spine

SPINE Volume 38, Number 22S, pp S149-S160

Cervical Radiographical Alignment

Comprehensive Assessment Techniques and Potential Importance in Cervical Myelopathy

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Study Design. Narrative review.

Objective. To provide a comprehensive narrative review of cervical alignment parameters, the methods for quantifying cervical alignment, normal cervical alignment values, and how alignment is associated with cervical deformity and myelopathy with discussions of health-related quality of life.

Summary of Background Data. 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. In addition, classifications of cervical deformity have yet to be fully established and treatment options defined and clarified.

Methods. A survey of the cervical spine literature was conducted.

Results. New normative cervical alignment values from an asymptomatic volunteer population are introduced, updated methods for quantifying cervical alignment are discussed, and describing the relationship between cervical alignment, disability, and myelopathy are outlined. Specifically, methods used to quantify cervical alignment include cervical lordosis, cervical sagittal vertical axis, and horizontal gaze with the chin-brow vertical angle. Updated methods include T1 slope. Evidence from a few recent studies suggests correlations between radiographical parameters in the cervical spine and health-related quality of life. Analysis of the cervical regional alignment with respect to overall spinal pelvic alignment is emerging and critical. Cervical myelopthay and sagittal alignment of the cervical spine are closely related as cervical deformity can lead to spinal cord compression and tension.

Conclusion. Cervical deformity correction should take on a comprehensive approach in assessing global cervical-pelvic relationships and the radiographical parameters that effect health-related quality of life scores are not well-defined. Cervical alignment may be important in assessment and treatment of cervical myelopathy. Future work should concentrate on correlation of cervical alignment parameters to disability scores and myelopathy outcomes.

Summary Statements.

Statement 1: Cervical sagittal alignment (cervical SVA and kyphosis) is related to thoracolumbar spinal pelvic alignment and to T1 slope.

Statement 2: When significant deformity is clinically or radiographically suspected, regional cervical and relative global spinal alignment should be evaluated preoperatively via standing 3-foot scoliosis X-rays for appropriate operative planning.

Statement 3: Cervical sagittal alignment (C2-C7 SVA) is correlated to regional disability, general health scores and to myelopathy severity.

Statement 4: When performing decompressive surgery for CSM, consideration should be given to correction of cervical kyphosis and cervical sagittal imbalance (C2-C7 SVA) when present.

Key words: cervical spine alignment, cervical deformity, cervical myelopathy, T1 slope, cervical lordosis, cervical SVA, thoracic inlet angle, cervical HRQOL, chin-brow vertical angle.

Spine 2013;38:S149–S160

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Acknowledgment date: March 7, 2013. First revision date: June 8, 2013. Second revision date: July 15, 2013. Acceptance date: July 25, 2013.

The manuscript submitted does not contain information about medical device(s)/drug(s).

Supported by AOSpine North America, Inc. Analytic support for this work was provided by Spectrum Research, Inc., with funding from the AOSpine North America.

Relevant financial activities outside the submitted work: board membership, payment for lectures, consultancy, grants/grants pending, patents, royalties, support for travel, provision of writing assistance, medicines, equipment, or administrative support, expert testimony, grant, consulting fee or honorarium, travel/accommodations/meeting expenses, and stock/stock options.

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DOI: 10.1097/BRS.0b013e3182a7f449

The cervical spine is very complex as it allows the widest range of motion relative to the rest of the spine and also supports the mass of the head. This complex nature of the cervical region lends it self-susceptible to a variety of disorders and complications, many of which begin with, and inevitably lead to, alignment pathology that may warrant surgical consideration. Abnormalities of the cervical spine are usually very debilitating and induce adverse effects on the overall functioning and health-related quality of life (HRQOL) of the patient.

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. In addition, classifications of cervical deformity have yet to be fully established and treatment options defined and clarified. Furthermore, cervical myelopathy and its relationship to cervical alignment is a relatively new concept and currently being investigated. Cervical myelopathy has historically been viewed as a result of multilevel spondylosis, however recent studies suggest cervical alignment contributing to pathogenesis of cervical myelopathy. It has been shown in cadaver and animal models that an increase in sagittal malalignment leads to greater cord tension, flattening, and an increase in intramedullary pressure resulting in neurological compromise.[1–7] Shimizu *et al*[5] found a significant correlation between the degree of kyphosis and the amount of cord flattening leading to decreased vascular supply and ultimately demyelination with neuronal loss in small animals. Farley *et al*[7] found an increase in intramedullary pressure with kyphosis greater than 51° in cadavers. The effect of cervical alignment on myelopathy has also been demonstrated radiographically with flexion-extension magnetic resonance imaging (MRI) studies.[8–12] These studies show changes in T2 intensity and morphological changes of the cord consistent with myelopathy when the spine is in flexion or extension. Sagittal malalignment is a significant factor in contributing to cervical myelopathy, but with few reports investigating this subject.

Therefore, the purpose of this article is to provide a comprehensive narrative review of cervical alignment parameters, the methods for quantifying cervical alignment, normal cervical alignment values, and how alignment is associated with cervical deformity and myelopathy with discussions of HRQOL.

CERVICAL SPINE ALIGNMENT PARAMETERS AND METHODS

The 3 primary methods to assess cervical lordosis (CL) include Cobb angles, the Harrison posterior tangent method, and Jackson physiological stress lines.[13] The Cobb angle method measures the lordosis from either C1–C7 or C2–C7 and includes drawing 4 lines. The first line is drawn either parallel to the inferior endplate of C2 or extending from the anterior tubercle of C1 to the posterior margin of the spinous process and the second line drawn parallel to the inferior endplate of

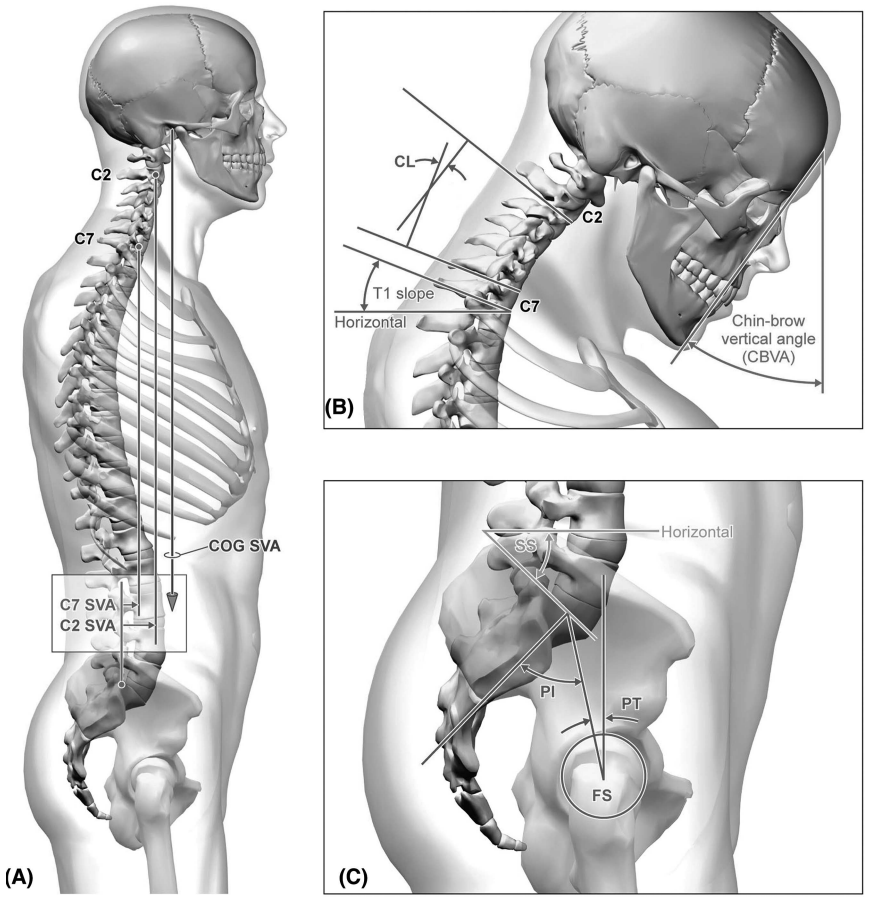

Figure 1. The spine functions as a global unit so that cervical alignment parameters influence and are influenced by parameters in the lower regions. Artist's illustration of the following spinal measurements (**A**) COG, and the C2 and C7 SVA, (**B**) CL and T1 slope, and (**C**) Sacral slope (SS), PI, and PT. CL indicates cervical lordosis; COG, center of gravity; FS, femoral shaft; PI, pelvic incidence; PT, pelvic tilt; SVA, sagittal vertical axis.

C7. Perpendicular lines are then drawn from each of the 2 lines noted in the earlier text, and the angle subtended between the crossing of the perpendicular lines is the cervical curvature angle (Figure 1B).[13] The Harrison posterior tangent method involves drawing parallel lines to the posterior surfaces of all cervical vertebral bodies from C2–C7 and then sums the segmental angles for an overall cervical curvature angle.[13] It has been suggested that the Cobb C1–C7 angle overestimates the CL, that the Cobb C2–C7 underestimates the CL, and that the Harrison method may provide the best estimate of lordosis.[13] Despite this finding, the Cobb method remains the clinical mainstay of CL measurement due to its ease of use, as well as its good intra- and inter-rater reliability.[14,15] Lastly, the Jackson physiological stress lines method requires drawing a parallel lines to the posterior surface of the C7 and C2 vertebral bodies and measuring the angle between them.[16]

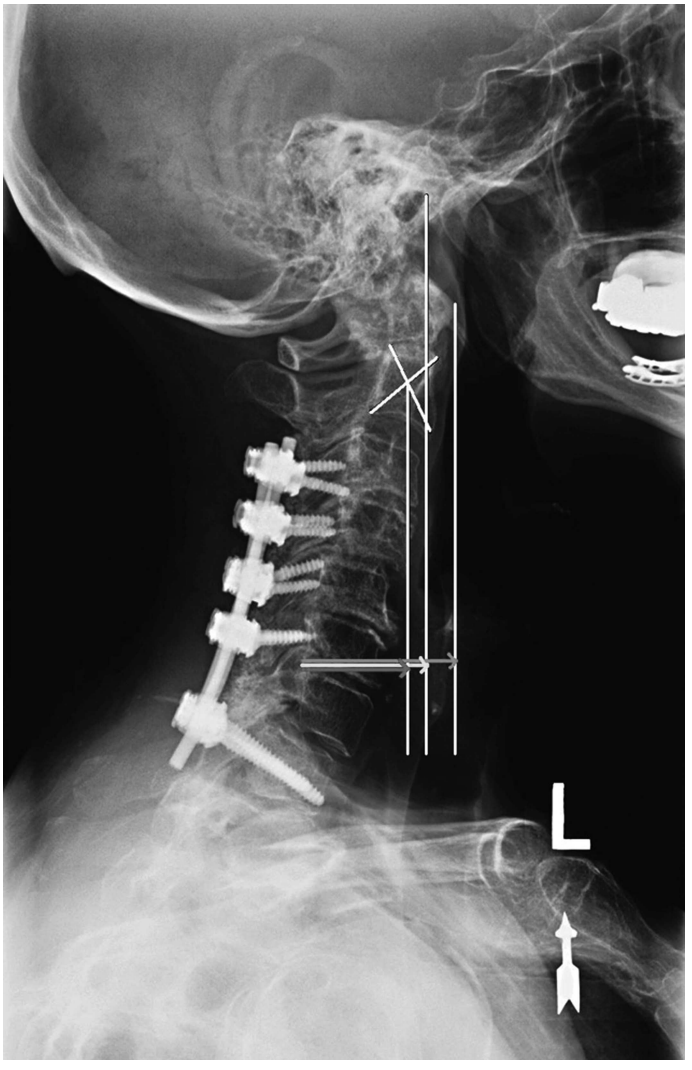

Figure 2. Visual representation of the technique used to measure cervical SVA. The longest arrow represents C1–C7 SVA (distance between plumb line dropped from anterior tubercle of C1 and posterior superior corner of C7), the shortest arrow represents C2–C7 SVA (distance between plumb line dropped from centroid of C2 and posterior superior corner of C7), and the middle arrow represents COG–C7 SVA (distance between plumb line dropped from anterior margin of external auditory canal and posterior superior corner of C7). SVA indicates sagittal vertical axis; COG, center of gravity.

Sagittal plane translation of the cervical spine is measured through the cervical sagittal vertical axis (SVA), for which there are a few different methods of measurements. Both C2 SVA and C7 SVA have been used to define global sagittal alignment by measuring the distance between the C2 and C7 plumb line, respectively, from the posterior superior corner of the sacrum. Cervical SVA (C2 SVA) can also be defined regionally using the distance between a plumb line dropped from the centroid of C2 (or odontoid) and the posterior superior aspect of C7 (C2–C7 SVA; Figure 1A, Figure 2). Another option that has been proposed for global SVA, in addition to the C7 SVA, is the gravity line. This is measured in the same way as the C7 SVA, however, the plumb line is drawn from the center of gravity (COG) of the head (COG SVA; Figure 1A, Figure 2).[17–23] On lateral radiographs, the COG of the head can be approximated by using the anterior portion of the external auditory canal as the initial point for the plumb line.[24] This method may also be applied regionally to C2 SVA instead of the C2 SVA (COG-C7 SVA) (Figure 1A). However, the C2 plumb line is especially clinically relevant as it has been directly correlated with HRQOL (specifically, Neck Disability Index and SF-36 PCS) in which larger C2 SVA relates to poorer HRQOL.[25]

When managing severe rigid cervical kyphotic deformities, measurement of horizontal gaze is especially useful as the loss of horizontal gaze has a significant impact on activities of daily living and quality of life.[26] The chin-brow vertical angle (CBVA) is the current method used when measuring horizontal gaze and is defined as the angle subtended between a line drawn from the patients chin to brow and a vertical line (Figure 1B).[26] The angle is measured on clinical photographs of the patient standing with hips and knees extended, while their neck is in a neutral or fixed position.[26] 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.[26–31]

Recent studies have investigated novel cervical parameters that have been found to be related to cervical alignment.[32] Lee *et al*[32] introduced the concepts of neck tilt and thoracic inlet angle (TIA). Neck tilt was defined as an angle between 2 lines both originating from the upper end of the sternum with one being a vertical line and the other connecting to the center of the T1 endplate. The TIA has been defined as the angle between a line originating from the center of the T1 endplate and perpendicular to the T1 endplate and a line from the center of the T1 endplate and the upper end of the sternum. A relationship exists such that TIA = T1 slope (angle between horizontal plane and T1 endplate [Figure 1B]) + NT. This is similar to the equation in the lumbar spine where pelvic incidence (PI) equals the sacral slope (SS) plus the pelvic tilt (PT) (PI = SS + PT; Figure 1C).

NORMAL CERVICAL ALIGNMENT

The cervical spine is the most mobile part of the spinal column, thus, a wide range of normal alignment has been described

TABLE 1. Normal Segmental Cervical Angles in Asymptomatic Adults From Literature*

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

Values presented as means ± SDs, and the negative sign indicates lordosis in the segmental values.
**Adapted from Hardacker et al.[35]*
SD indicates standard deviation.

TABLE 3. Normal CL Values for Males and Females in Different Age Groups in Asymptomatic Adults From Literature*

Age Group	Males (°)	Females (°)
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 presented as means ± SDs.
**Adapted from Gore et al.[34]*
CL indicates cervical lordosis; SD, standard deviation.

(Tables 1–4).[33–35] In asymptomatic normal volunteers, the mean total CL is approximately −40°, with, on average, the occiput-C1 segment being kyphotic.[35] Furthermore, the largest percentage of cervical standing lordosis (approximately, 75%–80%) is localized to C1–C2,[35,36] and relatively little lordosis exists in the lower cervical levels. Only 6° (15%) of lordosis occurs at the lowest 3 cervical levels (C4–C7).[35] The loss of subaxial lordosis has been reported in occiput-C2 fusions in which excessive hyperlordosis is created at occiput-C2.[37,38] This type of unfavorable reciprocal change is also seen in lumbar and thoracic osteotomy and has been reported by Lafage *et al*.[39] The majority of CL being localized to C1–C2 may be explained by the findings by Beier *et al*[24] that the COG of the head sits almost directly above the centers of the C1 and C2 vertebral bodies. Moreover, there is no difference between asymptomatic males and females in total CL, and there is a positive correlation with CL and increasing age.[34,35] Normal CBVA has not been characterized, but postoperative values of +10° to −10° have been well tolerated in patients.[26–31] The average odontoid-C7 plumb line distance ranges from 15 to 17 ± 11.2 mm.[35]

Cervical sagittal alignment may be dependent on the anatomy of the cervicothoracic junction. This is due to the shape and orientation of the thoracic inlet to maintain a balanced, upright posture and horizontal gaze, similar to the relationship between the PI and lumbar lordosis (LL; Figure 1C, Figure 3).[32] Lee *et al*[32] found significant correlations between the TIA and both the cranial offset and craniocervical alignment (Figure 4). The authors also found that a small TIA creates a small T1 slope and small CL angle to maintain the physiological neck tilting, and *vice versa*. The TIA and T1 slope may be used as parameters to evaluate sagittal balance, predict physiological alignment, and guide deformity correction of the cervical spine.[32] The T1 slope will determine the amount of subaxial lordosis required to maintain the COG of the head in a balanced position, and it will vary depending on global spinal alignment as measured by SVA and by inherent upper thoracic kyphosis (TK). In patients with scoliosis, the T1 slope has been shown to correlate directly with SVA measured from the C2 odontoid plumb line to provide a measure of overall sagittal alignment[40] (Figure 1A).

TABLE 2. Normal Cervical SVA Values in Asymptomatic Adults From Literature*

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

Values presented as means ± SDs.
**Adapted from Hardacker et al.[35]*
SVA indicates sagittal vertical axis; SD, standard deviation.

The authors of this review performed a retrospective radiographical analysis of all spinal parameters in an asymptomatic volunteer population of New York City (n = 55) with a mean age of 45 (range, 20–77) and without a history of chronic low back pain or prior spine surgery (normative values are presented in Table 4). The spinal regions (pelvis, lumbar, thoracic, and cervical) are not independent of one another, and multiple significant correlations were found between them. After an extensive analysis, the authors found that PI correlates with LL, LL correlates with TK, and TK correlates with CL (Figure 5). Thus, an increase in PI correlates with an increase in LL, which correlates with an increase in TK, which then correlates with an increase in CL. However, there was a lack of correlation found between PI and TK making the chain of correlation from the pelvis to the cervical spine more complicated. The current view is that LL is proportional to PI and TK because PI is a fixed parameter and TK has little flexibility. Subjects with a small PI or small TK had smaller LL than subjects with small PI and large TK. This demonstrates that TK is not a result of LL, but rather LL is a result of TK and PI. As mentioned in the earlier text, CL was correlated

TABLE 4. Mean Sagittal Parameters Among the Volunteers Stratified by Age Group

	20–39 yr		40–59 yr		>60 yr		*P*
	Mean	SD	Mean	SD	Mean	SD	
C2–C7 CL (°)	+9.4	9	+6.6	9	+22.2	9	<0.001
T4–T12 TK (°)	−38.1	11	−36	9	−45	14	NS
L1–S1 LL (°)	+61.5	12	+60.3	7	+55.7	13	NS
PT (°)	12.1	7	14.5	5	15.1	8	NS
PI (°)	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
T1 slope (°)	−22	7	−21.1	8	−31.6	9	0.001

P values refer to ANOVA comparison between groups.

NS indicates nonsignificant; ANOVA, analysis of variance; CL, cervical lordosis; SVA, sagittal vertical axis; TK, thoracic kyphosis; LL, lumbar lordosis; PT, pelvic tilt; PI, pelvic incidence.

with TK showing that as TK increases, CL also increases. However, this change in CL is not large enough to maintain the head over the pelvis, but it does provide adequate maintenance of horizontal gaze. In addition to the correlations between CL and TK, CL was also found to correlate with SVA, PT (Figure 6), and T1 slope. Subjects that had a positive SVA demonstrated an increase in CL, regardless of whether their SVA was within the normal range of values. This is a compensatory mechanism in which the cervical adaptation to the sagittal global alignment occurs to maintain a horizontal gaze as mentioned in the earlier text. Therefore, CL can be considered as an adaptive spinal segment to global alignment, similar to TK and LL. When TK and LL adapt to the patient's PI, the amount of CL will be proportional to the other curves.

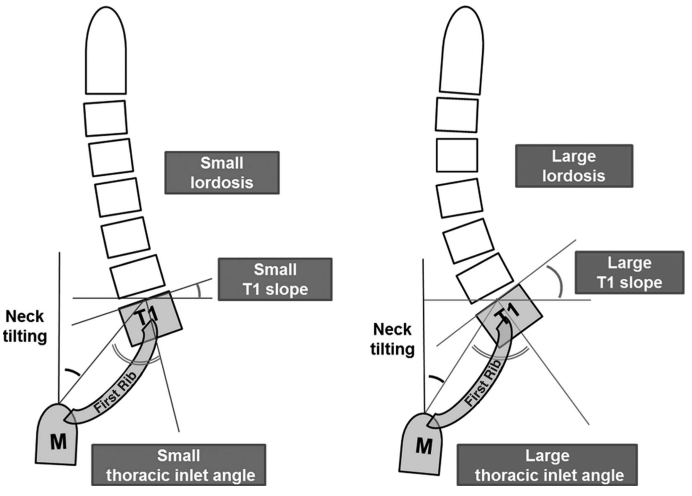

Figure 3. An illustration of the relationship between TIA, T1 slope, and CL. A small TIA yields a low T1 slope and therefore less CL is required to balance the head over the thoracic inlet and trunk. Conversely, a large TIA yields a greater T1 slope so that a greater magnitude of CL is required to balance the head over the thoracic inlet and trunk. CL indicates cervical lordosis; TIA, thoracic inlet angle.

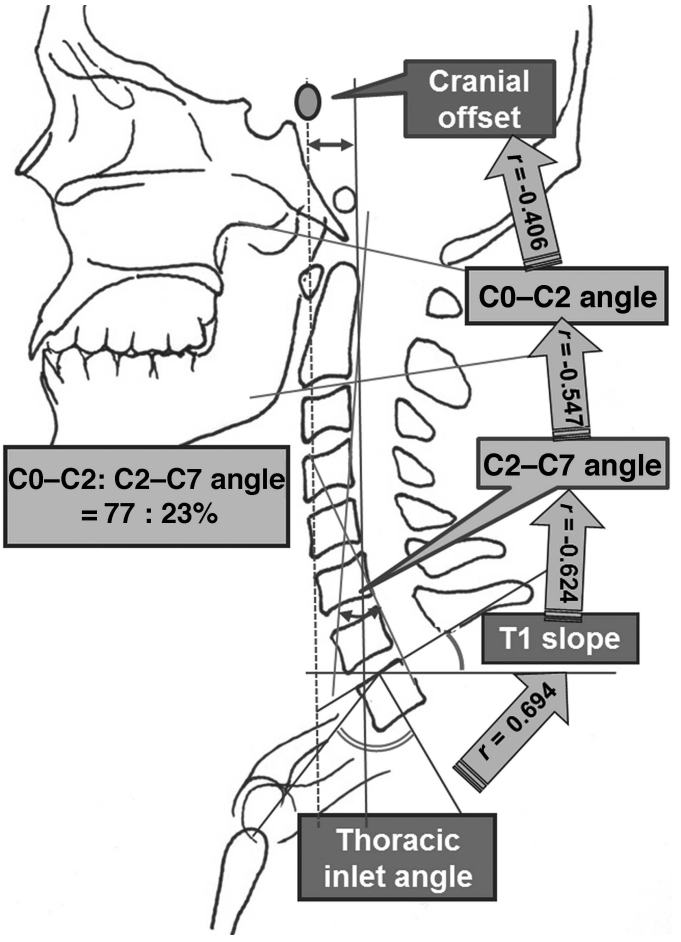

Figure 4. Schematic drawing illustrating the sequential linkage of significant correlation from the TIA to the cranial offset and craniocervical alignment. The *R* values within the arrows between each segment illustrate the Pearson correlation coefficient between the 2 segments. The sequential correlations between adjacent segments links the correlation between the TIA and the cranial offset. TIA indicates thoracic inlet angle.

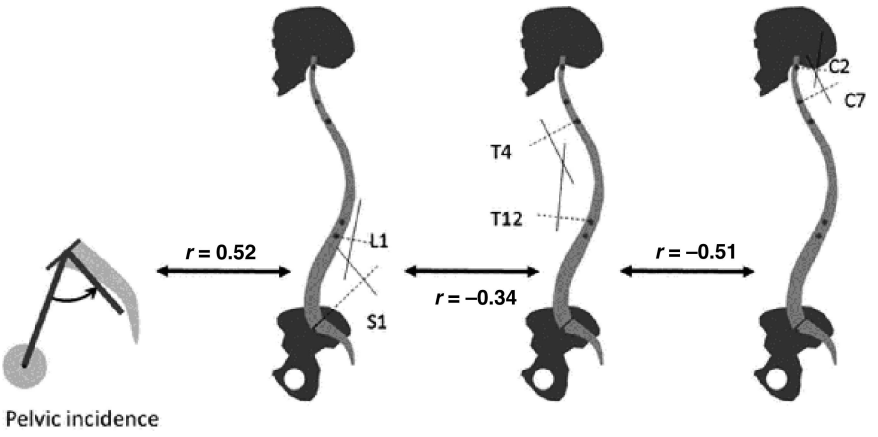

Figure 5. Chain of correlation between PI and regional sagittal parameters with the corresponding Pearson coefficient *r* values. A large PI requires a large LL. An increase of LL is correlated with an increased TK, which is correlated with an increased CL. PI indicates pelvic incidence; CL, cervical lordosis; TK, thoracic kyphosis; LL, lumbar lordosis.

However, when the patient has an anterior malalignment of the spine (from a reduction in LL and/or an increase in TK), an increase in CL is a compensatory mechanism. Conversely, if a primary cervical deformity exists, changes in the lumbar spine and pelvis will attempt to compensate.

The cervical alignment parameters discussed in the earlier text are critical during the evaluation and surgical planning for cervical deformity correction. Therefore, CBVA, T1 slope, C2 SVA and regional CL should all be considered in preoperative planning strategies, and consideration should be given to obtaining preoperative 3-ft standing radiographs that provide visualization from the external auditory canal (approximation of the center of mass of the head) to the femoral heads.

CERVICAL ALIGNMENT, DEFORMITY, AND HRQOL

Cervical kyphosis is the most prevalent cervical spinal deformity and may develop secondary to multilevel laminectomies, advanced degenerative disease, systemic arthritides, trauma, and neoplastic etiologies.[41–46] However, cervical sagittal alignment (*e.g.*, C2 SVA) is closely related to the cervical sagittal Cobb angle (*e.g.*, C2–C7 Cobb angle) as described in the earlier text; however, cervical sagittal alignment also takes into account the alignment of subjacent segments, including the thoracolumbar spine and pelvis (Figure 7A–C). Cervical spine deformities 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.[47–51]

The current literature reports changes in radiographical parameters of lordosis and kyphosis after surgical correction,[52–56] but there lacks a clear indication of an optimal amount postoperative CL to be achieved. It has become an accepted general rule to correct cervical kyphosis to be as close to neutral as possible.[43] Current research is adopting a trend toward defining cervical sagittal alignment parameters similar to the accepted C7 SVA (Figure 2)[57] traditionally used to measure sagittal alignment of the thoracolumbar spine. Specifically, as noted in the earlier text, the C2 plumb line and CBVA are increasingly being used.[25,26,35,58,59] To evaluate the effect of cervical alignment properly in relation to the overall sagittal alignment of the spine, standing 3-ft spine radiographs are needed.

Few studies, report the relationship between radiographical parameters in the cervical spine and HRQOL.[25] The effects of the cervical radiographical measurements on outcome scores

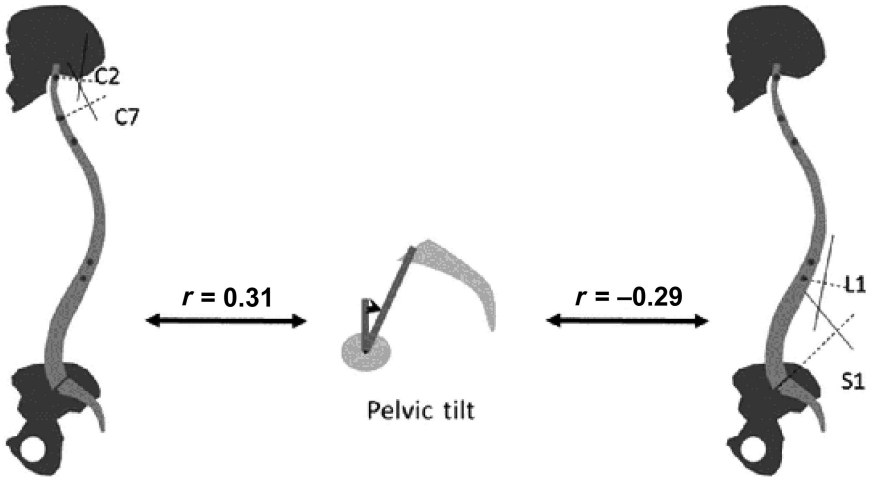

Figure 6. Correlation between PT and lumbar/CL. A loss of LL is correlated with a pelvic retroversion acting as compensatory mechanisms. Pelvic retroversion is also correlated with an increased CL. CL, cervical lordosis; LL, lumbar lordosis.

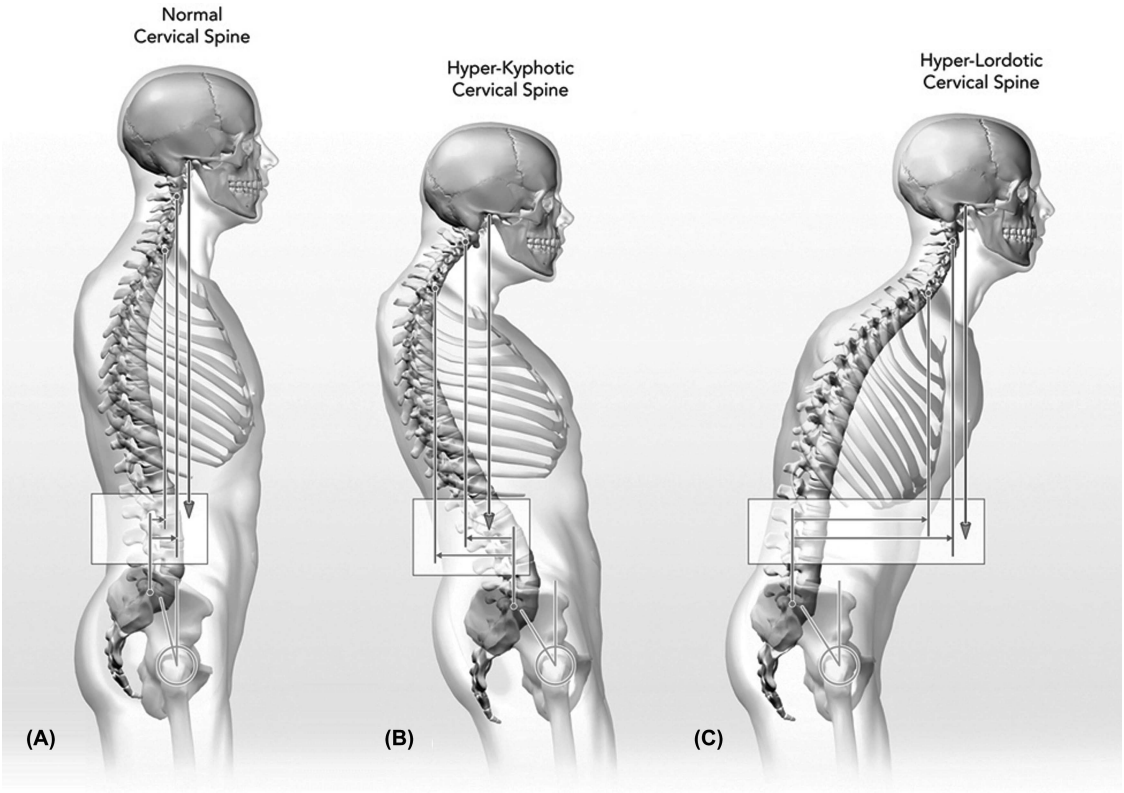

Figure 7. Proper sagittal alignment facilitates posture maintenance **A**, and poor alignment can lead to compensatory mechanisms that alter alignment parameters of the cervical spine **B** and **C**. An elevated PT is produced by either cervical kyphosis or global sagittal malalignment but PT due to cervical kyphosis is usually accompanied by lumbar hyperlordosis. PT indicates pelvic tilt.

are not nearly as well-defined as global and pelvic parameters are in thoracolumbar deformity.[60–63] The majority of the literature focuses on regional measurements of kyphosis. A common finding throughout the studies is the increase in neck pain in patients with greater kyphosis, whether after cervical spine trauma[64] or operative procedures such as anterior cervical spine fusion[65] or single-level anterior cervical discectomy and fusion.[66] Naderi *et al*[67] concluded that the presence of abnormal cervical curvature predicts less postoperative neurological improvement.

More recent studies of cervical alignment parameters, mostly lordosis between C2 and C7, in relation to postoperative clinical outcomes are weak in suggesting significant correlations. A double-blind, randomized controlled trial evaluating the relationship between lordotic alignment, both cervical and segmental, and clinical outcomes using normal and lordotically-shaped allografts for anterior cervical discectomy and fusion was conducted by Villavicencio *et al*.[68] 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 outcome scores. Guerin *et al*[69] also noted that only segmental sagittal alignment correlated with clinical outcomes after cervical disc arthroplasty, whereas overall cervical lordotic alignment did not. Jagannathan *et al*[70] found no significant relationship between the change in segmental kyphosis and postoperative functional status. CBVA is recognized to be the most objective measure of horizontal gaze; however, it had no significant correlation to overall clinical outcome (Modified Arthritis Impact Measurement Scale) in cervical kyphosis in patients with ankylosing spondylitis.[26] Despite this result, it has proven to be a very reliable and useful tool in assessing pre- and postoperative horizontal gaze, and correction of the CBVA does lead to positive postoperative outcomes regarding patient's satisfaction of horizontal gaze improvement.[26–31]

These studies have primarily focused on lordosis between C2 and C7 and not the aforementioned SVA parameters, with the exception of one study.[25] When assessing thoracolumbar deformity, SVA values are standard measurements. It is well known that both Glassman *et al*[71] and Mac-Thiong *et al*[21] concluded that positive sagittal malalignment, defined as a C7 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*[21] even extended this association to involve the global balance as defined by the gravity line. Currently, only one study has broadened these observations between SVA measurements and HRQOL scores (Neck Disability Index and SF-36 PCS) to include the cervical spine.[25] It suggests that increasing C2 SVA is a cause for clinical concern of cervical malalignment indicated by poor HRQOL scores and

TABLE 5. Correlations Between T1 Slope, C2–C7 SVA, C2–C7 Lordosis, and T1 Slope, C2–C7 Lordosis*

Radiographical Measure	Radiographical Measure	Pearson Coefficient	*P*
C2–C7 lordosis	T1 slope	0.38	<0.0001
C2–C7 SVA	T1 slope	0.44	<0.0001
C2–C7 SVA	T1 slope, C2–C7 lordosis	0.45	<0.0001

**Adapted from Tang et al.[25]*
SVA indicates sagittal vertical axis.

C2 SVA more than 40 mm is correlated to worse outcomes assessed by the NDI.[25] In addition, the authors found significant correlations between T1 slope and C2–C7 lordosis, T1 slope and C2–C7 SVA, as well as C2–C7 SVA and the difference between T1 slope and C2–C7 lordosis (T1 slope − C2–C7 lordosis); Table 5.

The T1 slope, as mentioned in the earlier text, has only been studied in a few select reports[32,40,72] and is being found to play an important role in cervical and global alignment. Knott *et al*[40] investigated multiple sagittal and coronal alignment parameters in an attempt to identify the ones that may influence global sagittal alignment. The T1 slope was the greatest predictor of C2–C7 SVA, and they recommended full standing radiographs when T slope is less than 13° or more than 25°.[40] They also recommended the use of C2 global SVA instead of the standard C7 SVA because the C2 SVA was found to be larger than the C7 SVA, and it takes into account the position of the head.[40] The most recent study involving T1 slope was by Kim *et al*[72] in which they investigated the relationship between preoperative T1 slope and postoperative cervical sagittal alignment in patients undergoing laminoplasty for cervical myelopathy. The patients were divided into 2 groups: high and low preoperative T1 slope based on the 50th percentile. They found that patients with high preoperative T1 slope were more likely to have postoperative kyphotic changes at 2-year follow-up.[72] This further highlights the importance of the T1 slope in cervical sagittal alignment and surgical planning.

Despite the progressive findings linking radiographical parameters and clinical outcomes, study limitations still exist because most are retrospective analyses. Furthermore, the contribution of the overall improvement in postoperative status that may be attributed to spinal cord decompression in many of these procedures is especially overlooked in many of these studies. 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 as well as evaluation of inter- and intrarater reliability for the cervical parameters.

CERVICAL ALIGNMENT AND MYELOPATHY

Cervical spondylotic myelopathy (CSM) has been reported as the most common cause of spinal cord dysfunction in patients older than 55 years.[73] Traditionally, the etiology of CSM has been described as a result of multilevel spondylosis in which osteophyte formation occurs as a result of degenerative changes in the discs.[74,75] However, less attention has been made to the fact that progressive cervical kyphosis has also been associated with myelopathy. The mechanism behind the development of the myelopathy is a result of the kyphosis forcing the spinal cord against the vertebral bodies inducing anterior cord pathology as well as increasing the longitudinal cord tension due to the cord being tethered by the dentate ligaments and cervical nerve roots[41,44] (Figure 8A–C). Over time, as the curve becomes more pronounced, the anterior and posterior margins of the cord compress and the lateral margins expand.[5] Cord tethering has been shown to cause an increase in intramedullary pressure leading to neuronal loss and demyelination.[1–3,5] Furthermore, the small feeder blood vessels on the cord become flattened, leading to reduced blood supply.[5] As the curve magnitude increases these pathological changes become more pronounced, especially on the anterior side that is directly exposed to the mechanical compression.[5] It has been shown in animal models that greater cord tension increases intramedullary cord pressure[1–4] and leads to neuronal apoptosis.[5] Shimizu *et al*[5] quantitatively analyzed that the severity of demyelination and neuronal loss

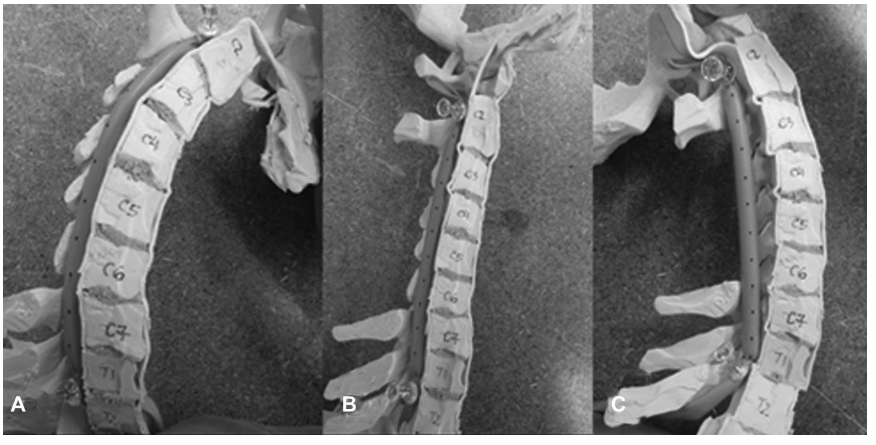

Figure 8. Sagittal cervical spine model demonstrating spinal cord tension and length changes in response to sagittal alignment. The distance between marks (black dots) on the cord were measured and were 1.2 cm for kyphosis (**A**), 1.1 cm for the neutral position (**B**), and 1.0 cm for the CL with C3–C5 laminectomy (**C**). CL indicates cervical lordosis.

in histological sections of spinal cords after induction of cervical kyphosis was small game fowls. They found a significant correlation between the degree of kyphosis and the amount of cord flattening.[5] Analysis with angiography demonstrated that the vascular supply to the anterior portion of the cords was decreased.[5] Furthermore, neuronal loss and atrophy of the anterior horn as well as demyelination of the anterior fasciculus was observed with the extent of demyelination progressing as the kyphosis became greater.[5] The pattern of demyelination began with the anterior fasciculus, but then progressed to the lateral and posterior fasciculi.[5] Thus, sagittal alignment of the cervical spine may play a large role in the development of cervical myelopathy.

Dynamic radiographical studies have found cervical cord changes upon flexion-extension, which may contribute to possible mechanisms of cervical myelopathy. Muhle *et al*[76] measured the sagittal cord diameter in 40 healthy subjects and found that, upon flexion, the cord diameter significantly reduces compared with the neutral position. Yanase *et al*[77] measured the cervical cord volume in healthy patients and found that the cord volume varies with sex, age, height, and body weight.[77] However, when calculating a volume ratio (foramen magnum to inferior C2 volume to foramen magnum to inferior C7), there were no variations noted.[77] When radiographically measuring cervical cord volumes in patients with cervical myelopathy as a result of cord atrophy, they recommend using the ratio, given it's free of individual variation. Yu *et al*[11] investigated the relationship of high intensity lesions on T2-weighted MR images and dynamic changes in the cervical spine for patients with CSM. On a T2-weighted MR image, they found that segmental hyperextension and range of motion were risk factors for high intensity lesions.[11] These results are similar to the results derived by Zhang *et al*,[12] in which they also investigated flexion-extension MRI in patients with spondylotic CSM. They showed that the cervical cord is significantly longer in flexion than in the neutral or extension positions.[12] The cord available space was found to be the greatest in the neutral position with it being the least in extension.[12] Furthermore, patients were more likely to have cord impingement on extension than flexion.[12] In patients with spondylotic cervical myelopathy, flexion may be a larger contributor to the etiology as cord impingement is exacerbated. However, in patients with primary cervical malalignment, in which flexion/kyphosis is the predominant position of the spine, the myelopathy may be due to cord lengthening, flattening, and vascular compromise. Further flexion-extension MRI studies in patients with primary cervical deformity are required to expand on this potential difference in etiology.

There exist a great deal of controversy surrounding the optimal surgical approach to correct cervical myelopathy.[73] Surgical considerations and options for cervical myelopathy must take into account the sagittal alignment of the cervical spine as it affects the approach as well as myelopathy etiology and progression. Decompression alone, even ventral decompression, which does not decrease cord tension induced by kyphosis may therefore not result in optimal outcomes.[5] Cervical myelopathy correction without sagittal malalignment may develop postlaminectomy kyphosis, the most common etiology of cervical spinal deformity,[41,44,78] and should be considered preoperatively. The posterior neural arch is responsible for the majority of the load transmission through the cervical spine as the natural biomechanics of the spine rely on a lordotic curve to distribute most of the load posteriorly. Removal of it causes a significant loss of stability. However, the spine may not become destabilized initially. Over time, the added instability with losing the posterior arch-facet complex tends to cause a shift in load bearing from the posterior column to the anterior column. This shift leads to cervical kyphosis as the discs and vertebral bodies become wedged with greater sagittal malalignment during the course of months to years. Cervical myelopathy may develop from the change in sagittal alignment to a kyphotic predominance and draping of the cord as discussed in the earlier text. In the end, the postlaminectomy kyphosis created a worsened myelopathy from a surgical treatment that was intended to treat myelopathy. With the recent work of Kim *et al*[72] specifically investigating postlaminoplasty, the preoperative T1 slope should be measured as the likelihood of developing kyphotic changes at 2 years increases with a higher preoperative T1 slope.

Posterior approaches alone may not be sufficient to correct cervical lordotic alignment in the subaxial spine above C7. Reconstruction using lordotic interbody spacers through an anterior approach may be needed to restore the natural lordotic curve of the cervical spine. If posterior decompression alone is undertaken or the cervical spine is fused in a kyphotic position, future myelopathy may develop because of the reasons discussed in the earlier text. Studies have shown that patients who underwent 1- or 2-level corpectomies for CSM had maintenance of CL and positive long-term HRQOL (modified Japanese Orthopaedic Association myelopathy scale) outcomes.[79]

CONCLUSION

The future direction of cervical deformity correction should take on a comprehensive approach in assessing global cervical-pelvic relationships. As discussed, because the T1 slope and the TIA relate to CL, they are important parameters to consider in optimizing cervical deformity correction as well as the potential to develop postlaminectomy kyphosis.[63,72] However, because these are regional relationships, they do not characterize the global relationships in the spine, and a thorough approach to describing cervical deformities entails understanding the relationship of the cervical spine to the pelvis. It is very important to remember that the spinal regions are not independent of one another, and CL depends on both TK and LL. CL can be considered an adaptive spinal segment in which it 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, CL increases as a compensatory mechanism. There are limitations to the normative data presented by the authors, which is because of the retrospective design and limited number of subjects included. Furthermore, the lack of inclusion of C1–C2 mobility is a limitation because it may also be an important

source of cervical adaptation. However, the reported normative data on cervical alignment and correlations between key parameters related to standing posture offer key reference values as well as a foundation for the analysis and treatment of spinal malalignment conditions. Cervical myelopathy is a serious manifestation of cervical spine disease and may be initiated or exacerbated in a patient with cervical sagittal malalignment. Therefore, preoperative T1 slope and postoperative sagittal alignment must be considered when correcting 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. 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 after cervical deformity correction. Future work should also include inter- and intrarater reliability testing of the cervical parameters among large patient populations. In addition, thresholds for decision making on alignment and deformity correction need to be established as well as what factors may have the largest impact on HRQOL.

Summary Statements.

Statement 1: Cervical sagittal alignment (C2 SVA and kyphosis) is related to thoracolumbar spinal pelvic alignment and to T1 slope.

Statement 2: When significant deformity is clinically or radiographically suspected, regional cervical and relative global spinal alignment should be evaluated preoperatively *via* standing 3-ft scoliosis radiographs for appropriate operative planning.

Statement 3: Cervical sagittal alignment (C2–C7 SVA) is correlated to regional disability, general health scores, and myelopathy severity.

Statement 4: When performing decompressive surgery for CSM, consideration should be given to correction of cervical kyphosis and cervical sagittal imbalance (C2–C7 SVA) when present.

➢ Key Points

- ❑ Recent cadaveric and animal studies suggest cervical alignment may be important in assessment and treatment of cervical myelopathy.
- ❑ The radiographical parameters that effect HRQOL scores are not well-defined in comparison with global/pelvic parameters in thoracolumbar deformity.
- ❑ CBVA, C2 SVA, and regional CL should 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.
- ❑ The T1 inclination will determine the amount of subaxial lordosis required to maintain the COG of the head in a balanced position and will vary depending on global spinal alignment as measured by the SVA and by inherent upper TK.
- ❑ The future direction of cervical deformity correction with regard to potential spinal cord tension issues in kyphosis should take on a comprehensive approach in assessing global cervical and spinal pelvic alignment.

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