Novel Angular Measures of Cervical Deformity Account for Upper Cervical Compensation and Sagittal Alignment

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Study Design: This is a retrospective review of a prospective multicenter database.

Objective: This study introduces 2 new cervical alignment measures accounting for both cervical deformity (CD) and upper cervical compensation.

Summary of Background Data: Current descriptions of CD like the C2–C7 sagittal vertical axis (cSVA) do not account for compensatory mechanisms such as C0–C2 lordosis and pelvic tilt, which makes surgical planning difficult. The craniocervical angle (CCA) combines the slope of McGregor's line and the inclination from C7 to the hard palate. The C2-pelvic tilt (CPT) combines C2 tilt and pelvic tilt. Like the T1 pelvic angle, CPT is less affected by lower extremity and pelvic compensation.

Methods: Novel and existing CD measures were correlated in 781 patients from a thoracolumbar deformity (TLD) database and 61 patients from a prospective CD database. CD patients were subanalyzed by region of deformity driver: cervical or cervico-thoracic junction. TLD patients were substratified according to whether or not they had CD as well, where CD was defined as cSVA > 4 cm or T1 slope minus cervical lordosis mismatch (TS-CL) > 20.

Results: TLD cohort: mean cSVA was 31.7 ± 17.8 mm. Subanalysis of TLD patients with CD versus no-CD demonstrated significant differences in CCA (56.2 vs. 60.6, $P < 0.001$) and CPT (32.6 vs. 19.3, $P < 0.001$). CCA and CPT correlated with cSVA ($r = -0.488/r = 0.418$, $P < 0.001$) and C0–C2 lordosis ($r = -0.630/r = 0.289, P < 0.001$). CD cohort: mean cSVA was 47.3 ± 32.2 mm. CCA and CPT correlated with cSVA ($r = -0.811/r = 0.657$, $P < 0.001$) and C0–C2 lordosis ($r = -0.656/r = 0.610$, $P < 0.001$). CD cohort subanalysis indicated that CT patients were significantly more deformed by cSVA (71.3 vs 24.0 mm, $P < 0.001$), CCA (47.1 vs 59.1 degrees, $P < 0.001$), and CPT (63.3 vs 43.8 degrees, $P = 0.002$). Using linear regression analysis, cSVA of 4 cm corresponded to CCA of 53.2 degrees ($r^2 = 0.5$) and CPT of 48.5 degrees ($r^2 = 0.4$).

Conclusions: CCA and CPT account for both cervical sagittal alignment and upper cervical compensation and can be utilized in assessment of cervical alignment.

Key Words: sagittal cervical deformity, upper cervical compensation, HRQOL

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Sagittal spinal deformity results in pain and disability and has a major health impact comparable to cancer diabetes and heart disease.[1–6] This has been well recognized in the thoracolumbar deformity literature.[1–6] Glassman et al[1] demonstrated that sagittal thoracolumbar deformity could be quantified with the use of the sagittal vertical axis (SVA) and greater degrees of sagittal malalignment were shown to correlate with worse disability. Other sagittal parameters have also been shown to be useful in the evaluation of thoracolumbar deformity, adding more nuance to the evaluation of sagittal deformity.[2–5]

More recently, the sagittal alignment of the cervical spine is gaining more attention.[7–10] However, our assessment of cervical alignment is rudimentary. Only the cervical (C2–C7) sagittal vertical axis (cSVA) has been shown to be relevant to health-related quality of life (HRQOL) measures in patients with cervical pathology.[7,8] The other cervical

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parameter frequently utilized to define cervical deformity (CD) is any amount of kyphosis from C2–C7 (CK).[9,10] But these may not be the best definitions of CD. For one, CK can be a physiological state of normal standing alignment particularly in patients who are sagittal neutral or sagittal backward in alignment.[10] Moreover, the cSVA has been shown to be affected by underlying thoracolumbar deformity and this increased cSVA reverses with correction of the underlying thoracolumbar deformity.[11]

As defined by these parameters, CD can be concurrent with thoracolumbar deformity (TLD) in 53% of adult spinal deformity patients.[12] To apply the concept of pelvic incidence (or rather sacral slope)—lumbar lordosis mismatch to the cervical spine, the T1 slope minus cervical lordosis mismatch (TS-CL) was studied in thoracolumbar deformity patients.[13] TS-CL was useful in defining CD and it predicted progression of CD after thoracolumbar deformity correction.[13]

However, these markers of cervical malalignment do not account for 2 important drivers of pathology and compensatory recruitment in CD patients. First, they do not take into account the spinopelvic complex. Second, current descriptions of cervical sagittal deformity do not account for both upper cervical compensation and subaxial sagittal malalignment; the cSVA only accounts for subaxial alignment from C2–C7.

This study assesses the utility 2 novel parameters of cervical sagittal alignment: the craniocervical angle (CCA) combines upper cervical compensation with a measure of cervical sagittal inclination (Figs. 1A, B) and second the C2-pelvic tilt (CPT) which combines the C2 tilt with the pelvic tilt (PT), incorporating the advantages of the TS-CL parameter while removing the effect of lower extremity and pelvic compensation (Fig. 2).

METHODS

This study was a retrospective review of 2 prospectively collected multicenter databases through the International Spine Study Group. Institutional Review Board approval was obtained at every site for each of the data set collections.

CD Cohort

The first was a primary cervical deformity database (Fig. 3). Inclusion criteria were adults (age older than 18 y) undergoing surgery for CD, defined by at least one of the following radiographic criteria: cSVA >4 cm, CK >10 degrees, TS-CL >20 degrees, cervical scoliosis >10 degrees or chin-brow-vertical-angle (CBVA) >25 degrees. Patients were categorized by an attending spine surgeon according to the primary driver of the deformity as either cervical (apex of the deformity between C3 and C7), cervicothoracic (apex between C7 and T2) or upper thoracic (apex between T2 and T7). Patients were also designated as having a secondary driver of deformity if they also had malalignment contributing to the cervical malalignment in the following areas: lower thoracic (apex between T7 and T10), thoracolumbar (apex between T10 and L2), lumbar (apex between L2 and S1). All patients included in the study had a primary driver of deformity in the cervical, cervicothoracic, or upper thoracic regions. For analysis cervicothoracic and upper thoracic groups were combined, denoted as the CT group. Inclusion criteria for the study included available baseline scoliosis films that include the cervical spine down to the pelvis. Demographic data collected included age and gender, as well as the following HRQOLs: Neck Disability Index (NDI), modified Japanese Orthopaedic Association (mJOA), EuroQual (EQ5D), and EQ5D visual analog scale.

Thoracolumbar Deformity Cohort

The second database included adult patients from a multicenter prospective thoracolumbar deformity database. Inclusion criteria were age older than 18 and presence of thoracolumbar deformity as defined by satisfying at least one of the following SRS-Schwab classification sagittal modifiers: PT > 20 degrees, SVA > 50 mm, or pelvic incidence minus lumbar lordosis mismatch (PI-LL) >10 degrees. Exclusion criteria included inability to stand, or sagittal radiographs lacking femoral heads. The database contained operative and nonoperative patients who satisfied these criteria. The following HRQOL data were collected: Oswestry Disability Index (ODI), Physical

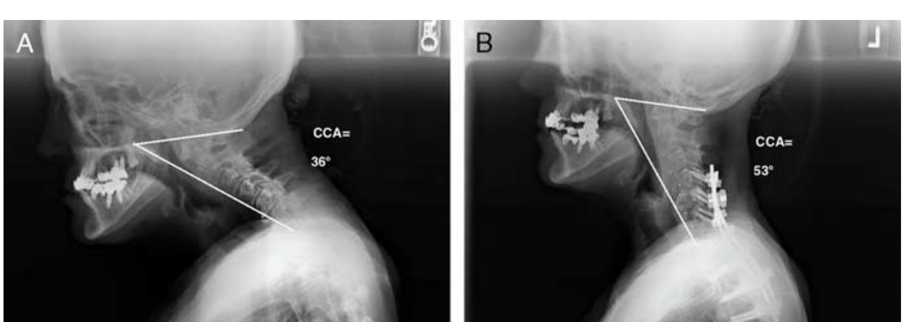

FIGURE 1. Cervical radiograph depicting the craniocervical angle (CCA) on preoperative (A) and postoperative (B) radiographs after deformity correction. CCA accounts for both cervical sagittal inclination and upper cervical compensation and is defined as the angle of the line from the center of C7 to the posterior corner of the hard palate and McGregor's line (the line from the posterior corner of the hard palate to the most caudal point of the occiput).

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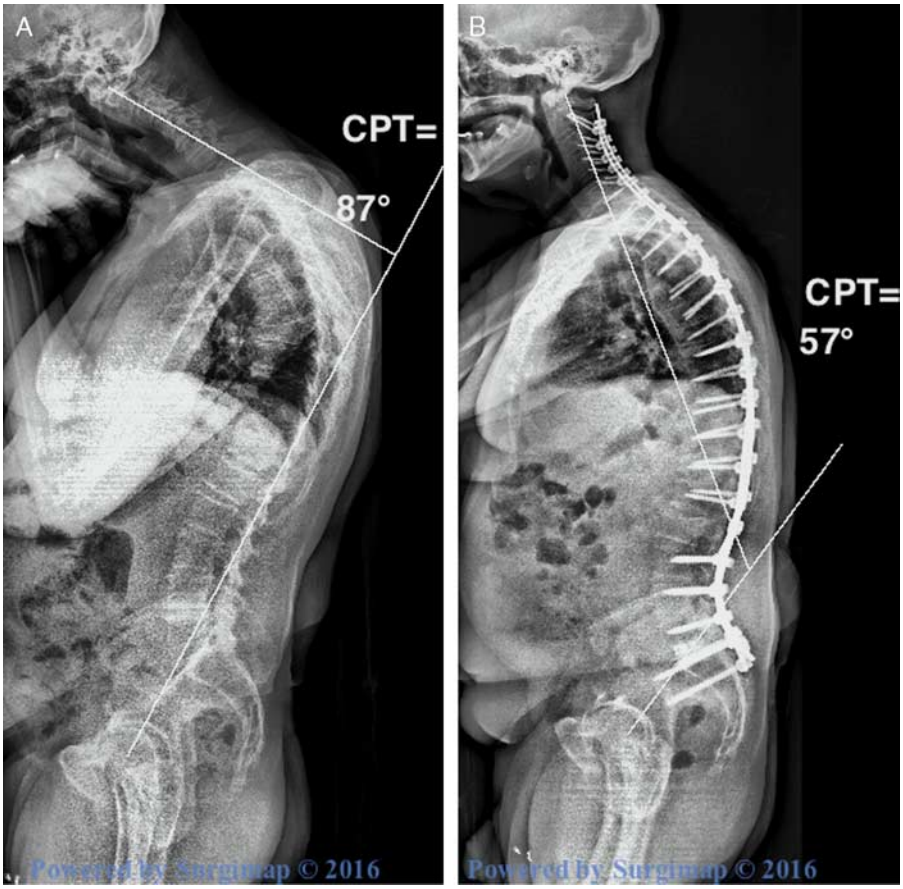

FIGURE 2. Full spine radiographs in a cervical deformity patient depicting preoperative (A) and postoperative (B) the C2 pelvic tilt (CPT) angle. A larger CPT angle corresponds to worse deformity.

Component Score, and Scoliosis Research Society (SRS)-22 scores. Demographic information was obtained including age, body mass index, and sex.

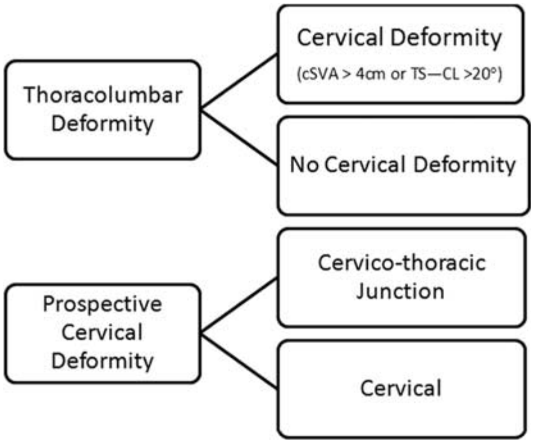

FIGURE 3. Stratification of the thoracolumbar deformity and prospective cervical deformity cohorts. cSVA indicates cervical (C2–C7) sagittal vertical axis; TS-CL, T1 slope minus cervical lordosis mismatch.

Radiographic Analysis

All subjects had radiographic imaging of the spinal axis (including pelvis) using 36-inch full-length films. Patients were instructed to assume a freestanding posture, with elbows flexed at approximately 45 degrees and fingertips on the clavicles. This position allows for consistent technique and comparative analysis.[14,15] Radiographic landmarks were marked using SpineView, a validated spine measurement software (ENSAM ParisTech, Paris, France),[16] and the radiographic markers were analyzed with Matlab (The MathWorks Inc., Natick, MA). The borders of the superior and inferior endplates were identified. For C2–T1, the posterior tangent line was also identified. Digitalization of each endplate from superior endplate of S1 to inferior endplate of C2, including femoral head, permitted calculation of standard spinopelvic, and regional cervical parameters.

The following novel cervical parameters were measured: CCA (the angle between the slope of McGregor's line and a line between the center of C7 to the hard palate, Fig. 1), and CPT (the angle between a line along the posterior C2 vertebra and a line from the center of the femoral head axis through the midpoint of the sacral plate, Fig. 2). The following traditional cranio-cervical parameters were measured: McGregor's line (McGS—a line between the posterior aspect of the hard palate and the posterior occipital condyle), cSVA [horizontal offset of the C2 plumbline (vertical line dropped from the center of the C2 vertebra) from the posterior superior corner of C7], cervical (C2–C7) lordosis (CL—the angle between the lower endplate of C2 and the lower endplate of C7), T1 slope (T1S—angle between a horizontal line and superior endplate of T1), TS-CL, C0–C2 lordosis (C0–2A—the angle between the occipital condyles and the lower endplate of C2), C2 slope (C2S—angle between the horizontal line and the lower endplate of C2), and C2–T1 pelvic angle (CTPA—angle between a line from the center of C2 to the center of the femoral heads and a line from the center of T1 to the center of the femoral heads). The following thoracolumbar and pelvic parameters were measured: PT (the angle between a line drawn from the center of the femoral head axis to the midpoint of the sacral plate, and the vertical), pelvic incidence (PI—the angle between a line drawn from the center of the femoral head axis to the midpoint of the sacral plate, and the perpendicular to the sacral plate), and T1 pelvic angle (TPA—the angle between a line from T1 to the center of the femoral heads and a line from the center of S1 endplate to center of femoral heads).

Statistical Methods

Correlation analysis was performed using Pearson correlation coefficient (r) between radiographic parameters. Specifically, CD parameters and global parameters were correlated with the new cervical parameters CCA and CPT. Subsequently, the cohort was stratified by presence of CD, defined by cSVA > 40 mm or TS-CL > 20 degrees. Linear regressions for CCA and CPT (dependent variables) and cSVA and TS-CL (independent variables) were performed in order to determine thresholds for CD. The coefficient of determination (r^2) was computed for each model. The cohorts were categorized by the presence of CD and they were matched with respect to PI-LL and TPA. Spinopelvic and cervical parameters were compared using unpaired t test.

RESULTS

CD Cohort

A total of 61 patients were included (mean age: 60.8 ± 10.0 y, 59% female). The cohort had cervical malalignment (cSVA: 47.3 mm and TS-CL: 34.9 degrees) but not global malalignment (SVA: 7.4 mm, PI-LL: 2.7 degrees) (Table 1). The HRQOL mean, SDs, and minimum and maximum values for this cohort are shown in Table 2.

The novel craniocervical parameters correlated with the spinopelvic and cervical parameters (Table 3). Specifically, CCA and CPT were correlated with PI, PT, T1S, cSVA, CTPA, and C0–C2 lordosis. CPT was correlated with TPA and TS-CL.

TABLE 1. For the Cervical Deformity (PCD) Cohort, Mean Spinopelvic and Cervical Parameters

PCD Cohort	Mean	SD	Minimum	Maximum
Spinopelvic				
Pelvic incidence (deg.)	55.5	11.8	55.0	79.3
Pelvic tilt (deg.)	20.6	11.9	−13.0	53.3
Pelvic incidence − lumbar lordosis (deg.)	2.7	19.1	−74.2	65.2
C7–S1 sagittal vertical axis (mm)	7.4	71.1	−127.8	171.2
T1 pelvic angle (deg.)	15.2	12.6	−27.0	56.4
Cervical				
C2–C7 lordosis (deg.)	−3.7	28.9	−74.2	152.2
C2–C7 sagittal vertical axis (deg.)	47.3	32.2	−33.7	103.5
T1 slope (deg.)	30.5	17.7	−10.6	81.2
T1 slope − cervical lordosis (deg.)	34.9	25.9	−102.3	77.1
C2–T1 pelvic angle (deg.)	4.9	2.9	−1.5	11.0

PCD indicates primary cervical deformity.

Linear regression analysis revealed significant relationship between CCA and cSVA, CPT and cSVA, and CPT and TS-CL. No relationship between CCA and TS-CL was identified.

Equation	r^2	Deformity Threshold Based On cSVA = 40 mm
CCA = 62.861 − 0.241 × cSVA	r^2 = 0.505	53.2 degrees
CPT = 29.626 + 0.471 × cSVA	r^2 = 0.431	48.5 degrees

To define thresholds of cervical disability for the new parameters based on established cSVA and TS-CL definitions, the following computations were performed. For regression with cSVA, the computed CCA and CPT based on a cSVA of 40 mm was 53.2 and 48.5 degrees, respectively.

The new cervical parameters did not correlate with HRQOLs (Table 4). Only TPA correlated with EQ5D (r = 0.340, P = 0.004). For individual questions, CCA correlated with EQ5D pain (r = −0.327, P = 0.020) and mJOA motor score upper (r = −0.462, P = 0.001). CPT correlated with mJOA lower (r = −0.286, P = 0.023). The other individual questions were not correlated with CCA or CPT.

Significant relationships were identified between the CCA and CPT with cSVA, C0–C2 lordosis, CTPA, T1S, C2 slope, and C2 tilt (Table 5).

TABLE 2. HRQOL Outcomes for the Primary Cervical Deformity (PCD) Cohort

PCD Cohort	Mean	SD	Minimum	Maximum
NDI	48.3	17.8	13.3	92
mJOA	13.5	2.4	7	18
EQ5D score	9.9	2.2	6	18
EQ5D VAS	60.5	23.7	0	95

EQ5D indicates EuroQual; HRQOL, health-related quality of life; NDI, Neck disability index; mJOA, modified Japanese Orthopaedic Association; VAS, visual analog scale.

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TABLE 3. For the Cervical Deformity (PCD) Cohort, Craniocervical (CCA) and C2 Pelvic Tilt (CPT) Correlations With Spinopelvic and Cervical Parameters

	CCA		CPT	
PCD Cohort	***r***	***P***	***r***	***P***
Spinopelvic				
Pelvic incidence (deg.)	−0.376	0.008	0.386	0.002
Pelvic tilt (deg.)	−0.298	0.04	0.484	< 0.001
Pelvic incidence − lumbar lordosis (deg.)	−0.097	0.513	0.213	0.088
C7–S1 sagittal vertical axis (mm)	−0.005	0.971	0.018	0.888
T1 pelvic angle (deg.)	−0.211	0.15	0.347	0.005
Cervical				
C2–C7 lordosis (deg.)	−0.328	0.032	−0.031	0.822
T1 slope (deg.)	−0.612	< 0.001	0.392	0.001
T1 slope − cervical lordosis (deg.)	−0.062	0.695	0.302	0.024
C2–C7 sagittal vertical axis (mm)	−0.811	< 0.001	0.657	< 0.001
C2 T1 pelvic angle (deg.)	−0.705	< 0.001	0.697	< 0.001
C0–C2 lordosis (deg.)	−0.656	< 0.001	0.610	< 0.001

PCD indicates primary cervical deformity.

Stratification by Driver of Deformity

A total of 28 cervical (C) patients (mean age: 61.1 y, 60.6% female) and 26 cervicothoracic (CT) patients (mean age: 61.8 y, 58.6% female) were included in the primary cervical deformity subanalysis. There were no differences in age or sex. The C subgroup had a lower cSVA, higher CCA, and lower CPT than the CT subgroup (Table 6). HRQOL comparison between the subgroups failed to reveal significant differences. For the C group, CPT ($r = 0.394$, $P = 0.034$), TS-CL ($r = 0.399$, $P = 0.043$), and C0–C2 lordosis ($r = 0.409$, $P = 0.028$) were correlated with mJOA sensation and cSVA was correlated with NDI lifting ($r = 0.386$, $P = 0.043$) and NDI pain intensity ($r = -0.449$, $P = 0.021$). For the CT group, CCA was correlated with EQ5D activity score ($r = -0.484$, $P = 0.030$).

Thoracolumbar Deformity Cohort

A total of 781 patients were included (mean age: 54.5 ± 16.4 y, 82% female, mean body mass index: 26.9). The cohort had global sagittal malalignment (mean SVA: 45.1 mm, mean TPA: 19.2 degrees) along with a mean cSVA of 31.7 degrees, T1S of 26.0 degrees, TS-CL of 17.4 degrees, and CTPA of 2.8 degrees (Table 7).

Correlation analysis between the novel craniocervical parameters and spinopelvic and cervical parameters yielded significant correlations. Specifically, CCA was negatively correlated with spinopelvic parameters and cervical parameters except for PI-LL and TS-CL where no significant correlation was identified. CCA negatively correlated with cSVA ($r = -0.488$) and C0–C2 lordosis ($r = -0.630$). CPT correlated with all spinopelvic and cervical parameters (Table 8).

Linear regression analysis revealed significant relationship between CCA and cSVA, CPT and cSVA, and CPT and TS-CL. No relationship between CCA and TS-CL was identified.

Equation	r^2	**Deformity Threshold Based On cSVA = 40 mm**
CCA = 64.608 − 0.213 × cSVA	$r^2 = 0.239$	56.1 degrees
CPT = 15.631 + 0.353 × cSVA	$r^2 = 0.175$	29.8 degrees

To define thresholds of cervical disability for the new parameters based on established cSVA and TS-CL definitions, the following computations were performed. For regression with cSVA, the computed CCA and CPT based on a cSVA of 40 mm was 56.1 and 29.8 degrees, respectively.

HRQOL analysis revealed significant albeit weak correlations between ODI, SRS activity, SRS pain, and SRS total with both CCA and CPT (Table 9). SRS appearance and Physical Component Score was correlated with CPT but not CCA.

Subanalysis of the TLD cohort by presence of CD and matching by PI-LL and TPA resulted in inclusion of 77 patients with CD and 72 patients without CD. Comparison of new cervical and spinopelvic parameters is shown in Table 10. The CD patients had lower CCA (56.2 vs. 60.6 degrees) and higher CPT (32.6 vs. 19.3 degrees) with no differences in PI-LL and TPA by design.

DISCUSSION

This study introduces novel angular measures of CD. They have advantages over existing definitions of CD in that they correlate more strongly with upper cervical compensation while still accounting for global

TABLE 4. For the Cervical Deformity (PCD) Cohort, Pearson Correlation Coefficient Analysis of Radiographic Parameters and HRQOL Total Scores

	CCA		CPT		CL		cSVA		TS-CL		TPA	
PCD Cohort	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***	***r***	***P***
NDI	0.034	0.814	0.050	0.692	−0.119	0.358	0.077	0.553	0.168	0.200	0.144	0.231
mJOA	−0.251	0.105	−0.075	0.579	0.134	0.329	0.166	0.234	−0.059	0.673	−0.136	0.293
EQ5D	−0.038	0.791	0.189	0.503	−0.087	0.175	0.175	0.177	0.164	0.211	0.340	0.004
EQ5D VAS	0.004	0.979	0.052	0.686	−0.088	0.501	0.046	0.730	0.066	0.618	0.043	0.728

CCA indicates craniocervical; CPT, C2 pelvic tilt; CL, cervical lordosis; cSVA, cervical (C2–C7) sagittal vertical axis; EQ5D, EuroQual; HRQOL, health-related quality of life; NDI, Neck disability index; mJOA, modified Japanese Orthopaedic Association; PCD, primary cervical deformity; TPA, T1 pelvic angle; TS-CL, T1 slope minus cervical lordosis mismatch; VAS, visual analog scale.

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TABLE 5. For the Cervical Deformity (PCD) Cohort, Pearson Correlation Coefficient Analysis of Novel and Established Radiographic Parameters

	CCA		CPT	
PCD Cohort	*r*	*P*	*r*	*P*
Craniocervical angle (deg.)			− 0.421	0.003
C2 pelvic tilt (deg.)	− 0.421	0.003		
C2–C7 lordosis (deg.)	− 0.328	0.032	− 0.031	0.822
C2–C7 sagittal vertical axis (mm)	− 0.711	< 0.001	0.657	< 0.001
T1S − cervical lordosis (deg.)	− 0.062	0.695	0.302	0.024
T1 pelvic angle (deg.)	− 0.211	0.15	0.347	0.005
C2–T1 pelvic angle (deg.)	− 0.705	< 0.001	0.697	< 0.001
T1 slope (deg.)	− 0.612	< 0.001	0.392	0.001
C2 slope (deg.)	− 0.413	0.006	0.852	< 0.001
C2 tilt (deg.)	− 0.302	0.033	0.865	< 0.001
C0–C2 lordosis (deg.)	− 0.656	< 0.001	0.610	< 0.001

CCA indicates craniocervical; CPT, C2 pelvic tilt; PCD, primary cervical deformity database.

sagittal deformity. The CCA (Fig. 1) combines a measure of cervical sagittal inclination, the line from C7 to the posterior corner of the hard palate with a surrogate measure of horizontal gaze, the slope of McGregor's line. The slope of McGregor's line has been shown to correlate strongly with the CBVA and it was more readily visible on cervical and full spine radiographs than the CBVA.[17] Thus, the CCA accounts for both cervicothoracic sagittal deformity and upper cervical compensation with a smaller angle defining greater CD. In patients from the prospective CD database, CCA correlated well with the cSVA ($r = 0.81$ $P < 0.001$) and the C0–C2 lordosis ($r = 0.66$, $P < 0.001$) (Table 3).

Likewise, the CPT angle correlated with the cSVA ($r = 0.66$, $P < 0.001$) and the C0–C2 angle ($r = 0.61$, $P < 0.001$). The correlation of the cSVA with C0–C2 angle was weaker than both the CCA and CPT. The strong correlation of the CPT angle with upper cervical compensation derives from the incorporation of C2 tilt in the measure. Increased C2 tilt determines the amount of C0–C2 lordosis necessary to maintain horizontal gaze. Another advantage of utilizing the C2 slope is that the C2 slope approximates the TS-CL. The TS-CL is a relatively new measure of CD that can identify cervical malalignment when it is concurrent with thoracolumbar deformity. A major advance of the assessment of thoracolumbar deformity was the recognition that the goal lumbar lordosis to achieve in corrective surgery is patient specific. The PI-LL relationship enabled surgeons to customize and plan corrections relative to the specifics of a patient's spinopelvic morphology. Similarly, a patient's cervical lordosis can be planned from the T1 slope assuming no thoracolumbar deformity. When TS-CL exceeds 20, then CD is present and there will be an imbalance in cervical alignment.[13]

When the TS-CL is dissected further, TS-CL = T1 slope minus (C7 slope minus C2 slope), where T1 slope approximates C7 slope in most cases, therefore, TS-CL ≈ C2 slope ≈ C2 tilt. Therefore a new parameter that includes C2 tilt as an equivalent to TS-CL will include all its advantages and the CPT correlated with TS-CL ($r = 0.30$ $P < 0.05$). But C2 tilt alone may be modified by knee flexion or pelvic retroversion. The T1 pelvic angle is a global thoracolumbar parameter that combines spinal inclination and pelvic retroversion, thus it is less affected by lower extremity and pelvic compensation; a new parameter that combines C2 tilt and PT would have a similar advantage.[2] In fact, the CPT measure correlated with TPA: in the thoracolumbar deformity cohort $r = 0.55$, $P = 0.005$ and in the CD cohort $r = 0.35$, $P = 0.005$.

Moreover, the CPT angle incorporates thoracolumbar alignment into the measure by including the PT. A complex relationship exists between the cervical and thoracolumbar segments in the context of spinal deformity. While thoracolumbar deformity patients can concomitantly have CD, a large thoracolumbar deformity can radiographically manifest with a high cSVA even in a patient without "true" CD. This latter phenomenon is best visualized after thoracolumbar correction in which the cervical curvature spontaneously resumes a normal alignment per radiographic definitions.[18–20] Indeed, Smith et al[11] demonstrated that patients with thoracolumbar deformity had increased cSVA and this CD improved with correction of the underlying thoracolumbar deformity.[13] Conversely, a patient undergoing CD correction who also has concurrent thoracolumbar deformity may never fully correct their cervical sagittal alignment as long as there is residual thoracolumbar deformity; the capacity of the cervical curvature to compensate may be exhausted in some patients. Realizing these intricate and not yet fully understood pathophysiological mechanisms, the CPT measure attempts to take

TABLE 6. For the Cervical Deformity (PCD) Cohort, Mean and SD for Cervical Deformity Parameters for the Subgroups Stratified by the Driver of Deformity: Cervical Versus Cervicothoracic

	Cervical			Cervicothoracic			
PCD Cohort	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	***P***
Craniocervical angle (deg.)	59.1	9.8	41.2, 76.1	47.1	9.8	32.4, 69.8	< 0.001
C2 pelvic tilt (deg.)	43.8	22.7	13.3, 100.9	63.3	22.6	28.7, 110.6	0.002
C2–C7 sagittal vertical axis (mm)	24.0	27.7	− 33.7, 65.8	71.3	19.2	23.5, 103.5	< 0.001
T1 slope − cervical lordosis (deg.)	32.0	18.2	5.0, 72.2	40.0	33.2	− 102.3, 77.1	0.287
C0–C2 lordosis (deg.)	38.1	11.8	20.6, 68.3	42.6	11.0	27.6, 62.5	0.150

PCD indicates primary cervical deformity database.

TABLE 7. For the Thoracolumbar Deformity (TLD) Cohort, Mean Global, and Cervical Parameters With SDs

TLD Cohort	Mean	SD	Minimum	Maximum
Spinopelvic				
Pelvic incidence (deg.)	54.6	13.0	7.7	110.6
Pelvic tilt (deg.)	21.6	11.1	−12.7	68.1
Pelvic incidence − lumbar lordosis (deg.)	10.8	20.6	−46.8	83.9
C7–S1 sagittal vertical axis (mm)	45.1	71.6	−120.3	326.5
T1 pelvic angle (deg.)	19.2	13.5	−9.3	72.7
Cervical				
C2–C7 lordosis (deg.)	8.6	16.1	−29.8	178.8
C2–C7 sagittal vertical axis (deg.)	31.7	17.9	−35.3	92.4
T1 slope (deg.)	26.0	13.2	−3.9	85.5
T1 slope − cervical lordosis (deg.)	17.4	11.2	−93.3	59.7
C2–T1 pelvic angle (deg.)	2.8	1.5	−2.5	10.3

a first step in providing a better radiographic understanding of the drivers of deformity by accounting for both regional deformities in one measure. In addition, measurement of the CPT does not require a full-spine 36 inch radiograph; the C2 tilt can be measured from a lateral cervical x-ray obtained with the patient standing and then the PT can be measured from a separate lateral pelvic x-ray with the patient maintaining the standing position. The CCA can be obtained from a standard cervical radiograph.

To quantify the thresholds of CD for these parameters, thoracolumbar deformity patients with and without CD were compared. The CCA was lower (56.2 vs. 60.6) and CPT was higher (32.6 vs. 19.3) in thoracolumbar deformity patients with concomitant CD (Table 10). Furthermore, using linear regression analysis on the primary CD cohort, the CCA and CPT corresponding to a cSVA of 40 mm was found to be 53.2 and 48.5 degrees, respectively. For regression with TS-CL, the CPT based on a TS-CL of 20 was 47.6 degrees. These values can serve as initial benchmarks for defining CD.

TABLE 8. For the Thoracolumbar Deformity (TLD) Cohort, Pearson Correlation Coefficient Analysis Between the Novel Cervical Parameters, the Craniocervical Angle (CCA) and C2 Pelvic Tilt (CPT) Angle, and Established Global and Cervical Radiographic Parameters

	CCA		CPT	
TLD Cohort	*r*	*P*	*r*	*P*
Spinopelvic				
Pelvic incidence (deg.)	−0.185	0.013	0.329	< 0.001
Pelvic tilt (deg.)	−0.160	0.033	0.587	< 0.001
Pelvic incidence − lumbar lordosis (deg.)	−0.088	0.243	0.465	< 0.001
C7–S1 sagittal vertical axis (mm)	−0.152	0.043	0.348	< 0.001
T1 pelvic angle (deg.)	−0.177	0.018	0.55	< 0.001
Cervical				
C2–C7 lordosis (deg.)	−0.176	0.019	−0.147	0.003
T1 slope (deg.)	−0.268	< 0.001	0.215	< 0.001
T1 slope − cervical lordosis (deg.)	−0.074	0.328	0.435	< 0.001
Cervical sagittal vertical axis (mm)	−0.488	< 0.001	0.418	< 0.001
C2–T1 pelvic angle (deg.)	−0.430	< 0.001	0.399	< 0.001
C0–C2 lordosis (deg.)	−0.630	< 0.001	0.289	< 0.001

TABLE 9. For the Thoracolumbar Deformity (TLD) Cohort, HRQOL Correlation Analysis Against the Craniocervical Angle (CCA) and the C2 Pelvic Tilt (CPT)

	CCA		CPT	
TLD Cohort	*r*	*P*	*r*	*P*
ODI	−0.189	0.012	0.177	< 0.001
PCS	0.098	0.219	−0.207	< 0.001
SRS activity	0.179	0.018	−0.190	< 0.001
SRS pain	0.150	0.049	−0.171	0.001
SRS appearance	0.131	0.086	−0.133	0.008
SRS satisfaction	0.032	0.681	−0.010	0.842
SRS total	0.159	0.037	−0.152	0.002

HRQOL indicates health-related quality of life; ODI, Oswestry Disability Index; PCS, Physical Component Score; SRS, Scoliosis Research Society.

The clinical relevance of these novel measures and of CD in general needs to be investigated further. None of the measures of the cervical sagittal alignment including the cSVA, cervical kyphosis, TS-CL, CCA and the CPT correlated with existing cervical HRQOL measures among the patients from the CD database. Tang and colleagues previously demonstrated that in postoperative patients, a cSVA > 4 cm corresponded to worse disability by the NDI and SF-36. However, the lack of any correlation in this series of patients may be explained by the relatively small cohort of patients. Nevertheless, this prospective database of CD patients represents the largest to date in the literature. The mean NDI and EQ5D for the patients in this database were 48.3 and 9.9, respectively, which represent a moderate-to-severe degree of disability.[21,22] One reason for the lack of a correlation that multiple pathologic entities are included. Patients with regional cervical kyphosis are likely to have severe degenerative disk disease of the cervical spine driving a greater NDI disability measurement. Conversely, patients with a severe chin on chest deformity may not necessarily have a higher NDI score. This brings into question the applicability of the NDI in assessing the disability specific

TABLE 10. For the Thoracolumbar Deformity (TLD) Cohort, Comparison of Mean Craniocervical and Spinopelvic Parameters for Patients With and Without Cervical Deformity

	Cervical Deformity		No Cervical Deformity		
TLD Cohort	Mean	SD	Mean	SD	*P*
Craniocervical angle (deg.)	56.2	7.1	60.6	7.1	< 0.001
C2 pelvic tilt (deg.)	32.6	16.1	19.3	11.4	< 0.001
Pelvic tilt (deg.)	20.3	10.4	21.5	11.0	0.159
Pelvic incidence (deg.)	54.9	12.7	54.2	12.6	0.463
T1 pelvic angle (deg.)	18.0	12.9	18.4	13.0	0.652
PI-LL (deg.)	8.9	20.5	9.7	20.2	0.655

PI-LL indicates pelvic incidence minus lumbar lordosis.

to CD. In fact correlations were found with various SRS-22 and ODI domains among patients with CD from the thoracolumbar deformity database. This database included more patients (n = 781), with greater statistical power and different HRQOL measures utilized (SRS-22, ODI, and SF-36). Specific domains of the SRS-22 and the ODI may be more relevant to CD such as appearance, activity, satisfaction, walking and standing, assessments that are not captured by the NDI questionnaire. ODI walking and standing may be more relevant to patients who cannot maintain horizontal gaze; these questions have been substituted in the NDI by questions about reading and concentration. The development of a CD specific disability measure is warranted.

For the thoracolumbar deformity cohort, CCA and CPT were correlated with ODI, SRS activity, SRS pain, and SRS total, demonstrating the clinical relevance of these parameters to capture pain and disability in a large database of patients. As the CCA decreases, disability increases with higher ODI scores and lower SRS-22 scores. Conversely, as CPT increases, ODI increases and SRS-22 scores decrease. With future study, the results in this study can serve as the basis for evaluating these parameters in a realignment planning context. Understanding the compensatory mechanisms recruited by patients, quantified by CCA, may lead to a better appreciation of the magnitude of correction needed in order to achieve a postoperative alignment that results in minimal energy expenditure.

We appreciate several limitations. Although our investigation is based on prospectively collected data, the primary limitation of the present study is the retrospective design. Further prospective studies with long-term follow-up should be undertaken to analyze the new parameters in the setting of postoperative deformity correction and HRQOL improvement. Second, the primary CD cohort was relatively small in number relative to the thoracolumbar deformity cohort, which may account for the lack of correlations between the novel alignment parameters and the HRQOL. Moreover, further studies with longer term follow-up may unveil the true relationship between CCA and C2PT and patient pain and disability along with further delineating the temporal value of these parameters. Third, by combining sources of deformity, only examining the CPT parameter will not provide the exact source of the deformity. For example, a chin on chest CD and a large thoracolumbar deformity may both present with a very similar CPT parameter. Truly, the proposed parameters are only useful when taken together with the traditionally utilized regional and global parameters that are used in deformity planning surgery. With future study, it is possible that the new parameters are especially useful in patients with bi-regional deformity.

Case Example

The patient is a 70-year-old male who presented with dropped head syndrome and kyphotic deformity along with lower back pain radiating to bilateral thighs. He was noted to have CD based on CPT of 87 degrees (Fig. 2A) and C2 tilt of 57 degrees (Fig. 4) along with a PT of 30 degrees (Fig. 5). He initially underwent posterior spinal fusion from C2–L2. However, the patient continued to have lower back pain and difficulty with activities of daily living. The CPT after his first surgery (Fig. 6) demonstrates high CPT that accounts for his thoracolumbar deformity with marked pelvic compensation. Subsequent revision fusion from L2 to pelvis resulted in both clinical improvement and adequate correction of sagittal alignment which is accounted by lower CPT (Fig. 2B).

FIGURE 4. Cervical deformity as demonstrated by high C2 tilt. The C2 pelvic tilt combines the C2 tilt and pelvic tilt.

CONCLUSIONS

The CCA combines the slope of McGregor's line and the inclination from C7 to the hard palate. The CPT combines C2 tilt and PT. Like the T1 pelvic angle, it is less affected by lower extremity and pelvic compensation. CCA and CPT account for both cervical sagittal alignment and upper cervical compensation. These novel parameters can be utilized in preoperative and postoperative assessments of cervical sagittal alignment.

FIGURE 5. Pelvic tilt of a patient with substantial spinopelvic deformity along with cervical deformity.

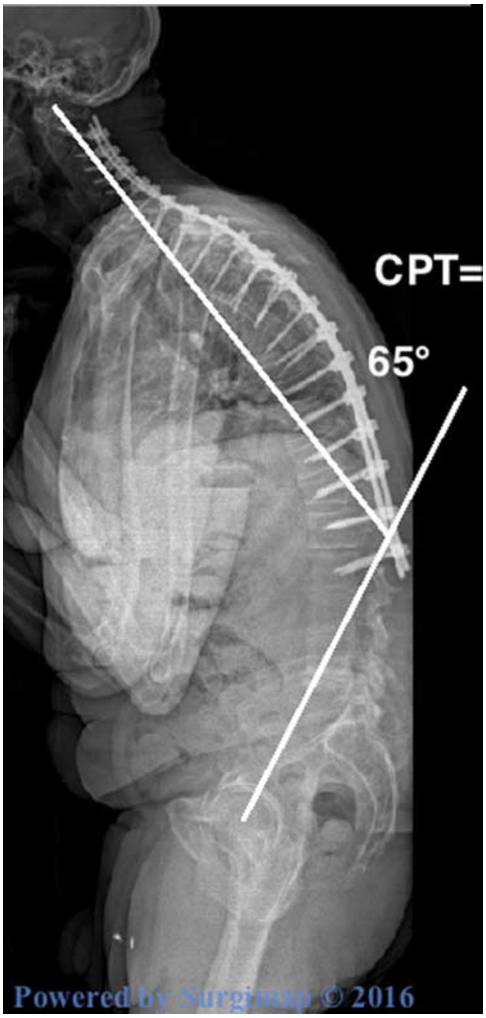

FIGURE 6. Index surgery postoperative radiographs demonstrating substantial residual cervical deformity and spinopelvic deformity that is simultaneously captured by C2 pelvic tilt (CPT).

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