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Primary Drivers of Adult Cervical Deformity: Prevalence, Variations in Presentation, and Effect of Surgical Treatment Strategies on Early Postoperative Alignment

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BACKGROUND: Primary drivers (PDs) of adult cervical deformity (ACD) have not been described in relation to pre- and early postoperative alignment or degree of correction.

OBJECTIVE: To define the PDs of ACD to understand the impact of driver region on global postoperative compensatory mechanisms.

METHODS: Primary cervical deformity driver/vertebral apex level were determined: CS = cervical; CTJ = cervicothoracic junction; TH = thoracic; SP = spinopelvic. Patients were evaluated if surgery included PD apex, based on the lowest instrumented vertebra (LIV): CS: LIV $\leq$ C7, CTJ: LIV $\leq$ T3, TH: LIV $\leq$ T12. Cervical and thoracolumbar alignment was measured preoperatively and 3 mo (3M) postoperatively. PD groups were compared with analysis of variance/Pearson χ^2, paired *t*-tests.

RESULTS: Eighty-four ACD patients met inclusion criteria. Thoracic drivers (n = 26) showed greatest preoperative cervical and global malalignment against other PD: higher thoracic kyphosis, pelvic incidence-lumbar lordosis (PI-LL), T1 slope C2-T3 sagittal vertical axis (SVA), and C0-2 angle ($P < .05$). Differences in baseline-3M alignment changes were observed between surgical PD groups, in PI-LL, LL, T1 slope minus cervical lordosis (TS-CL), cervical SVA, C2-T3 SVA ($P < .05$). Main changes were between TH and CS driver groups: TH patients had greater PI-LL (4.47° vs −0.87°, $P = .049$), TS-CL (−19.12° vs −4.30, $P = .050$), C2-C7 SVA (−18.12 vs −4.30 mm, $P = .007$), and C2-T3 SVA (−24.76 vs 8.50 mm, $P = .002$) baseline-3M correction. CTJ drivers trended toward greater LL correction compared to CS drivers (−6.00° vs 0.88°, $P = .050$). Patients operated at CS driver level had a difference in the prevalence of 3M TS-CL modifier grades (0 = 35.7%, 1 = 0.0%, 2 = 13.3%, $P = .030$). There was a significant difference in 3M chin-brow vertical angle modifier grade distribution in TH drivers (0 = 0.0%, 1 = 35.9%, 2 = 14.3%, $P = .049$).

CONCLUSION: Characterizing ACD patients by PD type reveals differences in pre- and postoperative alignment. Evaluating surgical alignment outcomes based on PD inclusion is important in understanding alignment goals for ACD correction.

KEY WORDS: Adult cervical deformity, Primary driver, Surgical correction, Postoperative alignment, Cervical spine, Cervicothoracic junction, Compensatory mechanisms

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The chain of correlation existing between positional parameters of upright posture and pelvic alignment is well defined and aids in the conservation of minimal energy expenditure in standing position and horizontal gaze preservation. Inclusion of the cervical spine

ABBREVIATIONS: ACD, adult cervical deformity; **CBVA,** chin-brow vertical angle; **CL,** cervical lordosis; **CS,** cervical; **cSVA,** cervical sagittal vertical axis; **CTJ,** cervicothoracic junction; **EQ-5D,** EuroQol 5D; **HRQL,** health-related quality of life; **LIV,** lowest instrumented vertebra; **mJOA,** modified Japanese Orthopaedic Association; **NDI,** Neck Disability Index; **NRS,** Numeric Rating Scale; **PD,** primary driver; **PI-LL,** pelvic incidence-lumbar lordosis; **SVA,** sagittal vertical axis; **TK,** thoracic kyphosis; **TS-CL,** T1 slope minus cervical lordosis; **3M,** 3 mo

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in this chain has been recently proposed by Ames et al[1] who noted significant correlations between T1 slope, cervical lordosis (CL), and thoracic kyphosis (TK). The ability of the cervical spine to compensate for deviations in the sagittal plane reinforces the interdependent and reciprocal reliance between cervical alignment, as assessed by both cervical sagittal Cobb angle (C2-C7 lordosis) and translation (C2-C7 sagittal vertical axis [SVA]), and the subjacent regional parameters of the thoracolumbar spine and pelvis.[1-5]

As the literature surrounding adult spinal deformity has progressed in recent years, the drivers of thoracolumbar deformity have become well understood: progressive loss of lumbar lordosis (LL) resulting in spinopelvic mismatch is often at the root of multiple spinal deformities, typically transferring compensatory burden to the thoracic spine and lower limbs.[6-8] Surgical management of adult spinal deformity has consequently evolved such that correction is aimed to address the deformity driver, which figures heavily into preoperative planning methods.

Similar etiological developments remain relatively unexplored for adult cervical spine deformity. Drivers of certain prevalent types of adult cervical deformity (ACD), notably cervical kyphosis, have been reported in smaller series and include multilevel laminectomy, degenerative conditions, trauma, and neoplastic etiologies.[9-11] The highly heterogeneous clinical and radiographic presentation of ACD has prompted its designation as a distinct clinical entity, culminating in development of the Ames Cervical Spine Deformity classification.[12] This classification seeks to refine care of ACD with respect to clinical evaluation, radiographic analysis, operative planning, and outcomes assessment.[2,4,13-15] However, it is currently unknown how different types of cervical deformity, recently outlined by the Ames classification, are driven by different structural modifications in alignment dependent on spinal region.

Formerly, surgical correction for cervical deformity focused on successful realignment dependent on the isolated deformity type.[16] Observation of spontaneous changes in adjacent spinal alignment however, predominantly in cervical hyperlordosis, following deformity correction has further highlighted the interdependence of cervical and thoracolumbar curves.[2,5] These findings have underscored the importance of global spinal sagittal harmony as a pre-eminent surgical goal of ACD correction. This may be achieved through complete assessment of ACD extending beyond the cervical spine to incorporate lower regional driving deformities.

Preoperative evaluation of ACD patients with concurrent proximal or distal sagittal malalignment driving cervical deformity has not yet been undertaken, with respect to radiographic alignment, surgical treatment, or clinical impact. As such, the goal of this study was to characterize the primary sagittal drivers of cervical deformity from a prospective, multicenter series of ACD patients, and to evaluate early postoperative radiographic discrepancies and surgical outcomes across driver groups.

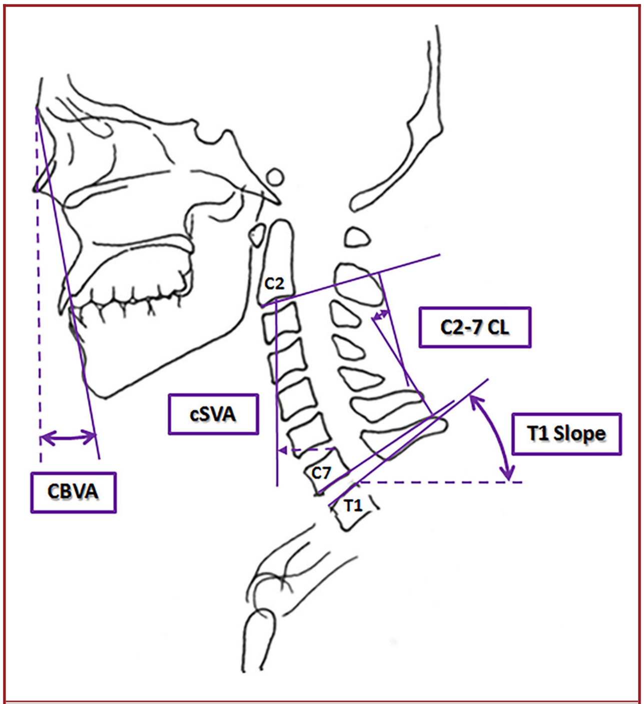

FIGURE 1. *Illustration of the measurement of radiographic cervical alignment parameters used to diagnose ACD for study inclusion. CBVA = chin-brow vertical angle; cSVA = cervical sagittal vertical axis; CL = cervical lordosis.*

METHODS

Study Design

Thirteen spine centers around the United States prospectively enrolled consecutive ACD patients from 2012 to 2015. Internal Review Board approval was obtained at all participating centers prior to study initiation and data collection protocols and appropriate patient consent was obtained for each patient at enrollment. Inclusion criteria for database enrollment were patient's age ≥ 18 yr, presence of cervical deformity, and plan for surgical deformity correction. For the purposes of this prospective database, ACD was defined radiographically as the presence of at least one of the following on preoperative imaging: cervical kyphosis (C2-C7 Cobb angle $>10^\circ$), cervical scoliosis (C2-C7 coronal Cobb angle $<10^\circ$), C2-C7 sagittal vertical axis (cSVA) $>$ 4 cm, or chin-brow vertical angle (CBVA) $>$ 25° (Figure 1). Patients with active tumors or infections were excluded. For the present study, all included patients had available neutral cervical anterior–posterior and lateral radiographs, as well as standing long-cassette images, at preoperative and 3-mo (3M) postoperative visit.

Data Collection and Radiographic Assessment

A retrospective review of the prospectively collected cervical deformity database was performed. Data collection at baseline included demographic, clinical, surgical, and radiographic information, as well as standardized health-related quality of life (HRQL) questionnaire assessment. Demographic and clinical data included patient age, sex, body mass index, Charlson Comorbidity Index, and comorbidity status.[17] Operative data included surgical approach, osteotomy

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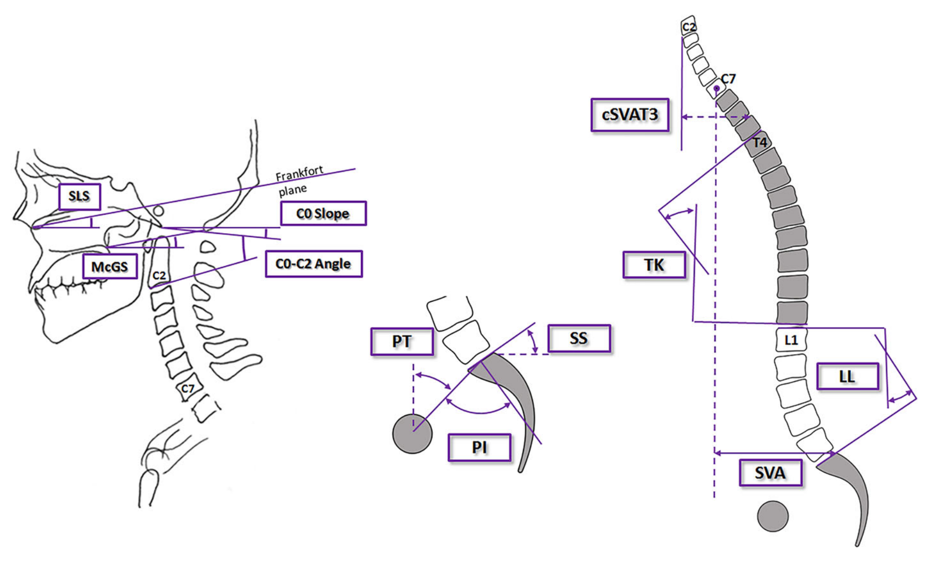

FIGURE 2. *Illustration of upper cervical and cranial (left), pelvic (middle), and global thoracolumbar (right) radiographic parameters measured for analysis. SLS = slope of line of sight; McGS = McGregor's slope; PT = pelvic tilt; SS = sacral slope; PI = pelvic incidence; SVA = sagittal vertical axis; TK = thoracic kyphosis; LL = lumbar lordosis.*

utilization, estimated blood loss, operative duration, number of levels fused, and length of hospital stay. HRQL tools included the Neck Disability Index (NDI), modified Japanese Orthopaedic Association (mJOA) score, Numeric Rating Scale for Neck/Back pain, and the EuroQol 5D (EQ-5D).

All patients received cervical and long-standing anterior-posterior and lateral imaging. Radiographic measurements (Figures 1 and 2) were analyzed using validated software (SpineView; ENSAM Laboratory of Biomechanics, Paris, France) and established techniques at a central location.[18,19] Cervical, cranial, and global spinopelvic sagittal parameters were measured before and after ACD correction.

Obtained cervical and cranial parameters included CL (angle between the lower endplates of C2 and C7), cervical sagittal vertical axis (cSVA: C2 plumbline offset from the posterosuperior corner of C7), cSVA from C2-T3, T1 slope minus CL (TS-CL: mismatch between T1 slope and cervical curvature), CBVA (angle between a line between the brow to the chin and the vertical), McGregor's slope (angle between the line from the posterosuperior aspect of the hard palate to the caudal portion of the opisthion and the horizontal), slope of line of sight (angle between the Frankfort plane and the horizontal), upper cervical curvature (C0-C2 angle: angle between McGregor line and lower C2 endplate), T1 slope, C0 Slope.

The global sagittal plane was described with the L1-S1 LL (angle between lower L1 and upper S1 endplates), T4-T12 TK (angle between the upper T4 endplate and lower T12 endplate), the SVA (horizontal offset between the plumbline dropped from C7 body to the posterosuperior S1 corner). Spinopelvic alignment was assessed with pelvic tilt (angle between the vertical and the line through the sacral plate midpoint to the femoral head axis), pelvic incidence (PI: angle between the line drawn from bicoxofemoral head axis center to the midpoint of the sacral plate and the perpendicular to the sacral plate), and the mismatch between PI and LL (PI-LL).

Primary Deformity Drivers Grouping

Based on spinal region involved, the following primary driver (PD) groups were generated: CS = cervical origin, CTJ = cervicothoracic junction origin, TH = thoracic origin, LP = lumbo-pelvic origin. Patients were also evaluated for whether or not the surgery included the PD apex level, based on lowest instrumented vertebra (LIV): CS: LIV ≤ C7, CTJ: LIV ≤ T3, TH: LIV ≤ T12, LP: LIV ≤ L5. All preoperative radiographs of included ACD patients were quantitatively assessed by the group of enrolling surgeons to identify the PDs of the cervical deformity in either the cervical, thoracic, or lumbar spine. The apex vertebral level of the PD for each patient was also determined.

Patients were also classified according to the Ames Adult Cervical Deformity (Ames-ACD) classification in order to compare our method for classifying sagittal drivers of cervical deformity that was consistent with this validated classification (Figure 3).[12] The Ames-ACD classification system incorporates a sagittal deformity descriptor (C = Cervical; CT = Cervico-thoracic, T = Thoracic; S = Coronal Deformity; CVJ = Cranio-Vertebral Junction), as well as modifiers for alignment (cSVA, CBVA, TS-CL) and disability (mJOA).

Statistical Analysis

All statistical tests were performed with SPSS software (version 21.0, Armonk, New York). Frequency distributions and descriptive analyses were determined for all demographic, clinical, surgical, and radiographic parameters. Following PD classification, patients were compared for preoperative cervical, cranial, global, and spinopelvic sagittal alignment using analysis of variance (ANOVA) tests with post hoc comparisons. Perioperative changes in alignment and patient-reported outcomes within and across PD groups were assessed with paired *t*-tests and ANOVA as appropriate. Statistical significance was set at $P < .05$, and analyses were 2-sided.

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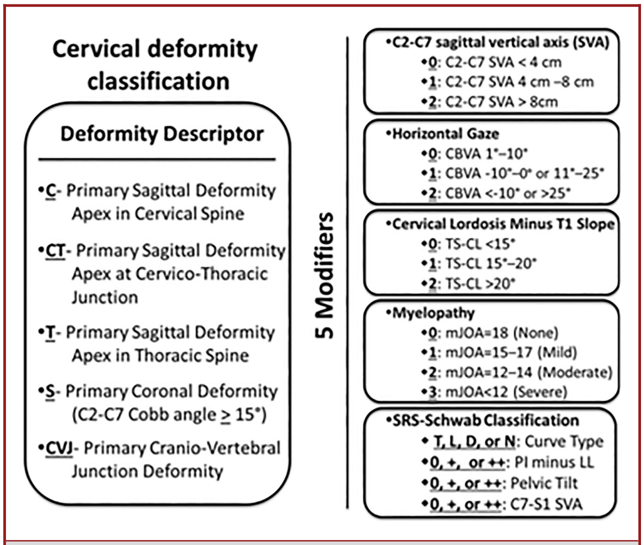

Cervical deformity classification

Deformity Descriptor

- **C**- Primary Sagittal Deformity Apex in Cervical Spine
- **CT**- Primary Sagittal Deformity Apex at Cervico-Thoracic Junction
- **T**- Primary Sagittal Deformity Apex in Thoracic Spine
- **S**- Primary Coronal Deformity (C2-C7 Cobb angle ≥ 15°)
- **CVJ**- Primary Cranio-Vertebral Junction Deformity

5 Modifiers

- **C2-C7 sagittal vertical axis (SVA)**
  - **0**: C2-C7 SVA < 4 cm
  - **1**: C2-C7 SVA 4 cm –8 cm
  - **2**: C2-C7 SVA > 8cm
- **Horizontal Gaze**
  - **0**: CBVA 1°–10°
  - **1**: CBVA -10°–0° or 11°–25°
  - **2**: CBVA <-10° or >25°
- **Cervical Lordosis Minus T1 Slope**
  - **0**: TS-CL <15°
  - **1**: TS-CL 15°–20°
  - **2**: TS-CL >20°
- **Myelopathy**
  - **0**: mJOA=18 (None)
  - **1**: mJOA=15–17 (Mild)
  - **2**: mJOA=12–14 (Moderate)
  - **3**: mJOA<12 (Severe)
- **SRS-Schwab Classification**
  - **T, L, D, or N**: Curve Type
  - **0, +, or ++**: PI minus LL
  - **0, +, or ++**: Pelvic Tilt
  - **0, +, or ++**: C7-S1 SVA

FIGURE 3. *Description of the Ames-ACD classification system.*

PDs Overview

A total of 84 patients with cervical deformity were identified as meeting study inclusion criteria. The mean age was 63.2 ± 10.5 (range: 32-83 yr), and comprised 61.9% females. The indication for surgery was the cervical deformity that can be seen through the baseline HRQL scores: Numeric Rating Scale Back = 5.64 ± 2.97, Numeric Rating Scale Neck = 6.75 ± 2.40, NDI = 48.68 ± 17.82, mJOA = 13.53 ± 2.71, and EQ-5D = 9.85 ± 2.04. The distribution of PD among all included ACD patients was as follows: cervical = 33 (40.2%), cervicothoracic junction = 12 (14.6%), thoracic = 26 (31.7%), lumbo-pelvic = 11 (13.4%). Radiographic examples of each PD type with corresponding apexes are provided in Figure 4. The most frequent driver apex for each PD was C5 (32.3%) for cervical, C7-T1 (36.4%) for cervicothoracic junction, and T3 (11.5%) for thoracic. PD groups were similar with regard to baseline demographics and comorbidity burden (Table 1), though lumbo-pelvic patients had a trend toward greater baseline body mass index than cervical patients (35.09 vs 28.23 kg/m^2, $P = .076$).

Analysis of PD distributions revealed significantly variability of cervical deformity type among included ACD patients. Figure 5 displays a summary of the Ames-ACD classification of deformity descriptors according to PD region. The prevalence of the cervical PD type significantly decreased with increasing Ames-ACD cSVA modifier grade (0: 56.0%, 1: 21.9%, 2: 18.2%, $P = .013$). There were no other significant associations noted between PD type and Ames-ACD alignment modifiers ($P > .05$ all cases).

Surgical Summary

The operative profile for PD groups is presented in Table 2. Almost all patients in each PD group underwent posterior fusions, though a high percentage also had concomitant anterior procedures. The mean number of levels fused differed significantly across PD groups, with thoracic patients experiencing the longest fusion segments (mean 11.3

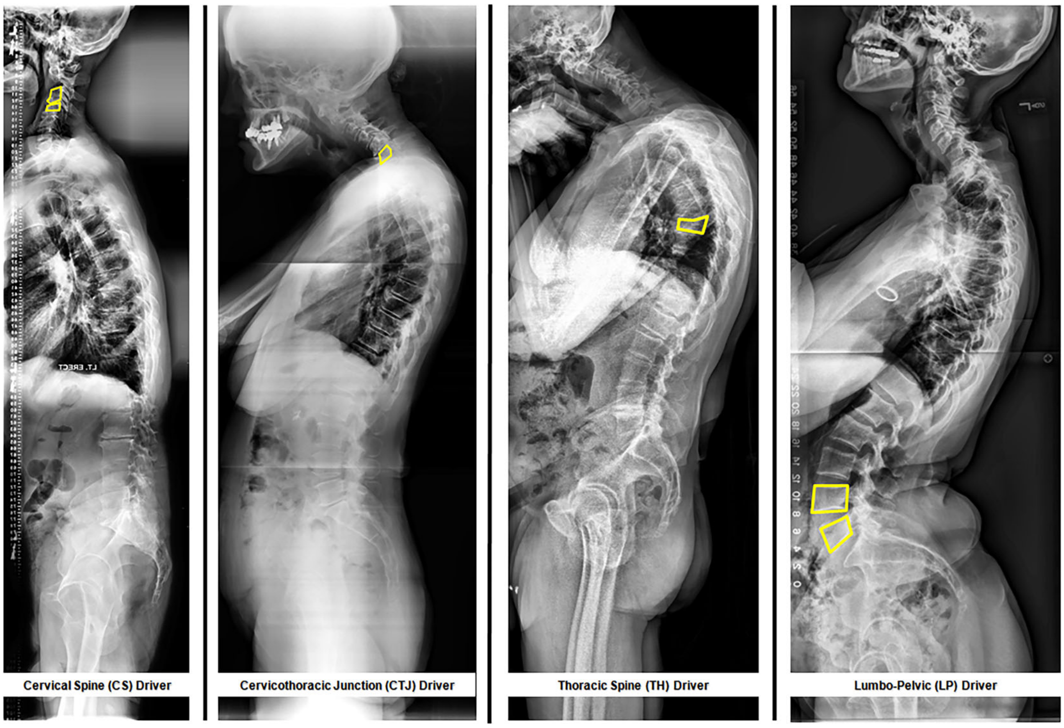

FIGURE 4. *Lateral full-body radiographic examples for each PD groups for patients with ACD. Vertebra outlined in yellow indicates the apex level(s) for the specific PD and patient.*

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TABLE 1. **Baseline Demographic Information for Included ACD Patients by Primary Driver (PD) Region**

	PD groups				*P*
	CS	CTJ	TH	LP	
Age (yr)	62.8 ± 11.5	61.4 ± 6.3	64.5 ± 10.8	60.0 ± 9.2	.644
Sex (% F)	58.1%	75.0%	65.4%	72.7%	.688
BMI (kg/m^2)	28.3 ± 7.9	27.6 ± 6.5	29.1 ± 7.6	35.1 ± 9.9	.088
Prior cervical Sx (%)	48.4%	75.0%	42.3%	45.5%	.291
Smoking history (%)	19.4%	0.0%	3.8%	10.0%	.146
Depression (%)	19.4%	33.3%	30.8%	45.5%	.390
Diabetes (%)	12.9%	8.3%	11.5%	9.1%	.971
Osteoporosis (%)	12.9%	8.3%	15.4%	18.2%	.906
CCI	0.9 ± 1.3	0.4 ± 0.7	0.9 ± 1.1	0.8 ± 1.2	.718

CS = cervical spine; CTJ = cervicothoracic junction; TH = thoracic; LP = lumbo-pelvic; BMI = body mass index; CCI = Charlson Comorbidity Index.

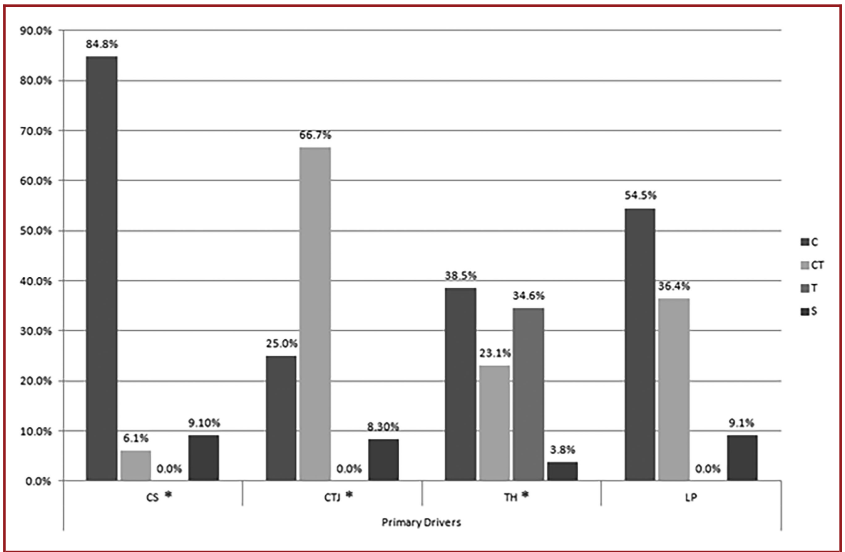

FIGURE 5. *Distribution of Ames Cervical Spine Deformity classification primary deformity descriptors (C = cervical; CT = cervicothoracic; T = thoracic; S = coronal cervical) according to PD type: CS = cervical spine; CTJ = cervicothoracic junction; TH = thoracic; LP = lumbo-pelvic. '*' represents statistical significance across groups to P < .05.*

TABLE 2. **Surgical Summary of Included Patients Based on Primary Driver (PD) Type**

	PD groups				*P*
	CS	CTJ	TH	LP	
Anterior approach (%)	51.5%	33.3%	40.0%	36.4%	.633
Posterior approach (%)	87.9%	100.0%	88.5%	81.8%	.549
Nb levels fused	7.9 ± 2.7	9.8 ± 5.4	11.3 ± 5.5	8.8 ± 1.9	**.040**∗
Partial facet (%)	15.2%	8.3%	15.4%	9.1%	.893
Complete facet (%)	30.3%	41.7%	23.1%	18.2%	.565
VCR (%)	0.0%	16.7%	23.1%	9.1%	**.038**∗
EBL (cc)	811.6 ± 697.8	904.2 ± 548.3	1389.1 ± 1282.5	871.1 ± 806.9	.147
Operative time (min)	315.8 ± 147.0	286.5 ± 137.4	385.9 ± 202.4	311.8 ± 112.7	.282

CS = cervical spine; CTJ = cervicothoracic junction; TH = thoracic; LP = lumbo-pelvic; VCR = vertebral column resection; EBL = estimated blood loss.
∗Bolded values represent statistical significance to *P* < .05.

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operated vertebral levels). There was a significant difference in frequency of vertebral column osteotomy utilization across PD groups ($P = .038$), and these osteotomies were most frequently performed at the T2, T3, or T4 vertebral levels. The PD groups were similar with regard to the remaining surgical variables assessed, including estimated blood loss, operative time, and recombinant human bone morphogenetic protein-2 utilization ($P > .05$ all).

Global Radiographic Analysis

Patients across the PD groups differed significantly on the basis of preoperative and acute perioperative spinal sagittal deformity (Table 3). Differences were predominantly noted between the cervical and thoracic drivers; specifically, thoracic patients displayed significantly greater sagittal plane deformity extending to the upper cervical alignment: thoracic drivers had greater TK compared to all driver groups (TH: 53.08° vs CS: 38.39°, CTJ: 35.33°, SP: 24.91°, $P < .001$). Thoracic drivers also had higher LL (60.48° vs 48.73°, $P = .050$), T1 slope (42.50° vs 26.31°, $P = .003$), C2-T3 SVA (104.21 vs 64.92 mm, $P = .005$), and C0-2 angle (45.42° vs 36.10°, $P = .021$) compared to cervical drivers. Lumbo-pelvic patients also had significantly lower T1 slope compared to thoracic (25.00° vs 42.50°, $P = .002$). Despite correction of alignment, differences in 3M postoperative sagittal alignment persisted across the PD groups. Thoracic driver patients retained the highest TK, T1 slope, and C2-C7 CL, and showed the greatest correction in SVA (Δ 41.44 mm) compared to cervical driver patients (Δ 6.03 mm). Though the lumbo-pelvic group had significantly greater reduction of TK (Δ −5.82) than the thoracic driver (Δ −1.28) cohort ($P < .05$ all cases).

TABLE 3. Preoperative (BL) and 3-month (3M) Postoperative Sagittal Plane Deformity Radiographic Parameters by Primary Driver (PD) Patient Groups

		PD Groups				*P*
		CS	CTJ	TH	LP	
PT (°)	BL	20.4 ± 11.2	17.9 ± 8.4	22.2 ± 14.1	19.5 ± 16.7	.797
	3M	22.5 ± 13.8	18.9 ± 9.2	21.6 ± 12.9	19.8 ± 14.3	.845
PI (°)	BL	54.6 ± 12.8	55.3 ± 11.0	57.2 ± 14.2	55.4 ± 9.9	.892
	3M	55.3 ± 13.5	56.0 ± 12.1	57.0 ± 13.5	54.9 ± 9.7	.951
PI-LL (°)	BL	5.7 ± 16.8	− 1.3 ± 10.3	− 4.0 ± 20.7	8.1 ± 30.4	.201
	3M	5.7 ± 20.3	3.7 ± 11.3	1.0 ± 21.8	8.5 ± 28.6	.761
LL (°)	BL	48.7 ± 16.0	56.6 ± 14.6	60.5 ± 15.2	47.3 ± 25.0	**.041***
	3M	49.0 ± 17.1	52.3 ± 18.2	55.4 ± 17.3	46.8 ± 22.2	.466
TK (°)	BL	38.4 ± 12.3	35.3 ± 14.8	53.1 ± 16.7	24.9 ± 13.6	**<.001***
	3M	42.1 ± 14.7	37.8 ± 9.6	50.5 ± 15.8	30.8 ± 19.2	**.003***
SVA (mm)	BL	15.94 ± 57.7	− 21.8 ± 56.5	− 1.9 ± 60.3	22.2 ± 130.4	.365
	3M	23.6 ± 52.3	25.6 ± 59.7	39.9 ± 81.6	39.6 ± 116.7	.840
T1 slope (°)	BL	26.3 ± 13.0	37.2 ± 13.4	42.5 ± 21.9	25.0 ± 17.9	**.002***
	3M	30.7 ± 9.2	35.8 ± 11.3	43.2 ± 20.4	24.7 ± 13.3	**.002***
TS-CL (°)	BL	33.3 ± 19.0	41.7 ± 13.8	45.2 ± 17.7	31.8 ± 21.6	.089
	3M	25.1 ± 14.4	34.3 ± 16.7	26.3 ± 11.7	25.6 ± 216.1	.392
C2-C7 CL (°)	BL	6.2 ± 13.7	5.5 ± 18.5	0.3 ± 27.3	6.9 ± 28.8	.781
	3M	6.0 ± 11.4	2.1 ± 11.9	15.7 ± 22.2	− 0.9 ± 13.4	**.023***
cSVA (mm)	BL	37.5 ± 24.3	55.5 ± 12.7	57.5 ± 28.4	47.0 ± 23.6	**.038***
	3M	34.2 ± 17.8	44.9 ± 10.8	42.2 ± 20.4	37.0 ± 22.5	.333
C2-T3 CL (°)	BL	9.0 ± 17.7	26.7 ± 19.5	18.1 ± 25.2	19.2 ± 27.5	.182
	3M	3.2 ± 11.2	− 11.4 ± 9.0	4.5 ± 18.2	− 5.6 ± 19.1	**.025***
C2-T3 SVA (mm)	BL	64.9 ± 35.9	92.7 ± 20.7	104.2 ± 46.0	73.7 ± 43.6	**.007***
	3M	66.4 ± 34.7	82.0 ± 16.9	86.3 ± 24.9	65.7 ± 32.2	.063
C2 slope (°)	BL	52.9 ± 90.5	36.4 ± 91.3	55.7 ± 99.7	30.1 ± 75.5	.830
	3M	22.3 ± 14.1	32.8 ± 15.9	26.0 ± 12.5	25.2 ± 17.2	.302
C1 slope (°)	BL	− 19.8 ± 113.2	14.4 ± 110.0	− 1.5 ± 124.6	36.9 ± 97.5	.523
	3M	11.6 ± 61.3	− 55.0 ± 72.1	5.4 ± 69.8	9.7 ± 63.0	**.036***
C0 slope (°)	BL	− 9.8 ± 116.7	− 13.1 ± 112.7	− 25.9 ± 126.3	41.6 ± 97.9	.466
	3M	12.8 ± 62.0	− 22.8 ± 89.2	4.4 ± 71.4	8.4 ± 57.2	.531
C0-C2 angle (°)	BL	36.1 ± 11.8	40.2 ± 10.4	45.4 ± 11.7	44.2 ± 11.5	**.025***
	3M	33.9 ± 13.1	35.0 ± 9.2	37.4 ± 7.6	39.1 ± 12.0	.501
McGS (°)	BL	10.9 ± 106.4	37.4 ± 115.8	39.6 ± 123.7	24.6 ± 97.0	.835
	3M	− 0.9 ± 69.3	− 38.5 ± 73.3	5.7 ± 39.8	19.6 ± 62.8	.191

CS = cervical spine; CTJ = cervicothoracic junction; TH = thoracic; LP = lumbo-pelvic, PT = pelvic tilt; PI = pelvic incidence; LL = lumbar lordosis; TK = thoracic kyphosis; CL = cervical lordosis; SVA = sagittal vertical axis; McGS = McGregor's slope.

*Bolded values represent statistical significance to $P < .05$.

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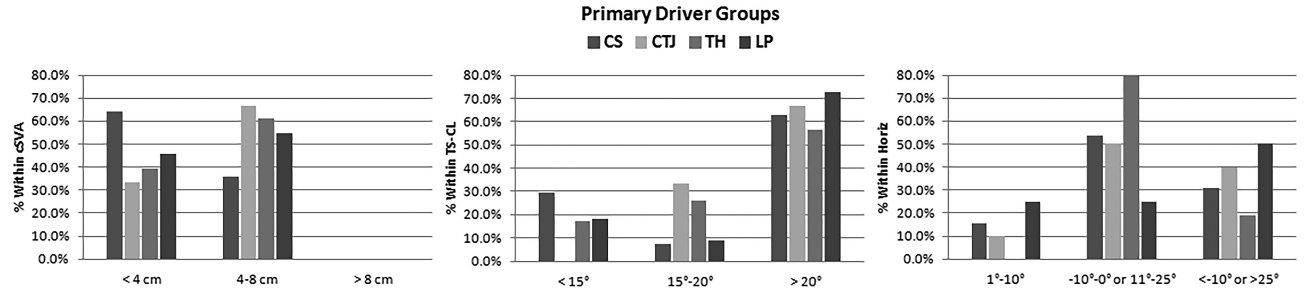

FIGURE 6. *Percentage of patients of each PD type (CS = cervical spine; CTJ = cervicothoracic junction; TH = thoracic; LP = lumbo-pelvic) within given thresholds of Ames Cervical Spine Deformity classification alignment modifiers.*

TABLE 4. Health-Related Quality of Life Scores at Baseline (BL) and 3 mo (3M) Postoperative Based on Primary Driver (PD) Type

		PD groups				*P*
		CS	CTJ	TH	LP	
NRS back	BL	5.6 ± 3.1	6.2 ± 2.8	5.1 ± 2.9	7.1 ± 2.4	.281
	3M	4.5 ± 3.3	5.7 ± 2.5	4.8 ± 3.5	7.2 ± 2.0	.098
	Δ	1.3 ± 3.1	0.7 ± 3.6	0.5 ± 2.4	0.1 ± 2.1	.608
NRS neck	BL	7.1 ± 2.1	6.6 ± 2.6	6.9 ± 2.5	6.0 ± 2.2	.596
	3M	4.5 ± 3.4	4.5 ± 2.9	5.3 ± 2.9	4.6 ± 2.4	.761
	Δ	2.8 ± 2.4	2.1 ± 3.3	1.6 ± 3.0	1.5 ± 3.1	.456
NDI	BL	48.9 ± 17.8	51.6 ± 16.2	47.5 ± 19.2	51.5 ± 17.5	.892
	3M	44.5 ± 21.8	42.3 ± 20.7	47.7 ± 19.9	46.3 ± 17.9	.873
	Δ	3.4 ± 16.9	9.3 ± 14.4	0.0 ± 15.5	6.1 ± 13.7	.377
mJOA	BL	12.8 ± 3.0	13.9 ± 2.2	13.8 ± 2.7	14.1 ± 2.3	.437
	3M	13.6 ± 3.0	13.6 ± 2.6	14.3 ± 2.5	15.1 ± 2.6	.430
	Δ	– 0.7 ± 2.7	0.1 ± 2.1	–0.1 ± 2.0	–0.9 ± 2.7	.702
EQ-5D	BL	10.0 ± 2.3	9.9 ± 1.9	9.5 ± 2.0	10.4 ± 1.7	.706
	3M	9.1 ± 2.0	9.4 ± 1.8	9.0 ± 1.9	9.5 ± 2.1	.744
	Δ	0.7 ± 1.9	0.6 ± 1.8	0.5 ± 1.7	0.9 ± 1.5	.954

CS = cervical spine; CTJ = cervicothoracic junction; TH = thoracic; LP = lumbo-pelvic; NRS = Numeric Rating Scale; NDI = Neck Disability Index; mJOA = modified Japanese Orthopaedic Association; EQ-5D = EuroQol 5D.

According to postoperative alignment goals set by Ames-ACD modifier groups (Figure 6), patients with the cervical PD had significantly lower rates of abnormal postoperative cSVA grades (0: 64.3% vs 1: 35.7%, $P = .044$) and TS-CL grades (0 = 35.7%, 1 = 0.0%, 2 = 13.3%, $P = .030$). Thoracic driver patients also showed lower horizontal gaze modifier = at 3M postoperative (0: 0.0%, 1: 81.0%, 2: 19.0%, $P = .025$).

Radiographic Analysis Based on PD Inclusion in Surgery

Patients operated at cervical driver level concomitantly increased in postoperative TK (38.93° vs 46.29°, $P = .004$) and T1 slope (20.23° vs 27.15°, $P = .022$) vs patients whose cervical drivers were not included in the surgery. Those whose surgeries involved the cervicothoracic junction driver showed a relaxation in LL (60.43° vs 54.43°, $P = .014$). Patients with surgeries involving thoracic driver level had a PI-LL mismatch increase (−5.42° vs −1.11, $P = .018$) with associated LL decrease (63.35° vs 58.50°, $P = .017$). This group also improved in C0-C2 slope at 3M (46.72° vs 37.28°, $P = .003$).

Patient-Reported Disability Analysis

HRQL measures were evaluated for all patients in each PD groups (Table 4). There were no differences noted in patient-reported outcomes at either baseline or 3M postoperative follow-up; differences in scores were also similar across the PD patient groups ($P > .05$ all cases).

DISCUSSION

ACD is a broad category encompassing multiple spinal alignment patterns that often originate, though are not isolated to, the cervical spine. There has been a growing appreciation of compensatory changes in adjacent alignment when significant sagittal deformity is present. Given the cervical spine's

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heightened flexibility, multiple reports have shown the corresponding influence of thoracolumbar deformity on reciprocal cervical alignment.[2,4,5] In distinction to the study of global spinal deformities, the evaluation and subsequent treatment of primary cervical deformities more often requires an understanding of the influence of additional regional deformity triggering the chain of events, which have been termed "primary drivers." This study provides a radiographic overview of ACD PDs and assesses the immediate effects of correction targeting the driver on radiographic alignment at presentation and during the early postoperative period.

In our study of 84 consecutive ACD patients, drivers of cervical deformity were identified in each spinal region with the 2 most prevalent categories being cervical (40.2%) and thoracic (31.7%). It was hypothesized that ACD patients would display differences in preoperative sagittal alignment, reflecting selective regional compensation depending on the driver. Based on radiographic assessment, significant differences in compensation based on driver type were indeed identified. Notably, ACD patients with a thoracic driver showed a higher preoperative TK and LL, which resulted in elevated T1 slope, cervical sagittal malalignment, and upper cervical hyperlordosis. These findings mirror those of Ames et al,[1] who performed a retrospective review of the sagittal alignment of 55 asymptomatic subjects. These authors noted significant associations between LL and TK ($r = -0.34$), and TK and CL ($r = -0.51$). The chain of correlation, traditionally referenced in the context of progressive spinopelvic deformity benefits henceforth from the inclusion of cervical alignment, and the application of the PD principal serves to show how differing regional drivers might influence cervical deformity.

Determining PDs in ACD patients also served to refine the type of cervical deformities described in this patient population. Implementation of the new Ames Cervical Spine Deformity classification system for cervical deformity in conjunction with the PD analysis produced significant results. Patients with cervical, cervicothoracic junction, and thoracic drivers each showed a different distribution in Ames deformity descriptor. As expected, patients with PDs in the cervical and cervicothoracic junction regions had the apex of the deformity in the same respective segments; however, patients with thoracic drivers had the apex of the deformity in the cervical region. This finding is reflected in our analysis of discrete radiographic alignment parameters, wherein patients with thoracic drivers had the higher positive cSVA. Indeed, the distribution of driver type also significantly differed with increasing Ames cSVA modifier grade.

Previous studies have evaluated sagittal drivers of cervical deformity both within and outside the cervical spine. These investigations however have chiefly evaluated cervical malalignment as only secondary to thoracolumbar deformity, and not vice versa. Notably, Hilibrand et al[20] looked at the impact of thoracic hyperkyphosis (>40°) on cervical alignment in adolescent idiopathic scoliosis patients.[20] They observed an inverse relationship between preoperative thoracic and cervical kyphosis, and a postoperative progressive loss of cervical curvature (1° lordosis to 3° kyphosis) in the thoracic hyperkyphosis group. Similarly, the reported preoperative CL value in this study among thoracic driver patients of 0.30° is comparable to these findings, though here thoracic patients responded to correction with an increase in CL. The significant improvement in horizontal gaze grade seen with patients with thoracic drivers suggests the impact of thoracic curvature on upper cervical alignment. In a recent study, Passias et al[14] reported that upper cervical hyperlordosis in patients with spinal deformity following surgical correction correlated with their spinopelvic malalignment at 2-yr follow-up.[14] These subjects compensated for lower thoracic and lumbar deformities with elevated C2-T3 angle, indicating the importance in the CTJ in cervical malalignment evaluation. Indeed, multiple reports have also highlighted factors predisposing the CTJ drivers to regional deformity.[3,21,22] CL dependent on the anatomy of the CTJ has been previously proposed, and given that the CTJ is the site of union between adjacent lordotic and kyphotic curves, acute angular deformity at the region may trigger cervical flexion. The small number of identified CTJ drivers in this study, as well as proximity to thoracic deformity, may have influenced the lack of findings in this regard, though further dedicated study in this specific population is required. The summation of these results sustains a growing body of literature displaying concurrent rates of cervical and thoracolumbar deformity, though provide evidence for considering structural etiology of cervical spine deformity.[4,23]

Despite identified variations in alignment and compensation between PD groups, comparable differences in operative and clinical profiles of these patients largely did not reveal any distinctions. Understandably, the thoracic driver group underwent more extensive fusions than cervical and cervicothoracic junction driver patients, and also had more vertebral column resection osteotomies than any other group. Despite identifying differences in thoracolumbar and cervical alignment between PD groups, there appeared to not be any significant clinical impact noted, either preoperatively or following successful correction. This study utilized patient-reported outcome metrics tailored to the cervical spine, which may have obscured any meaningful clinical differences between PD groups that were predominantly defined according to regional deformity below C7.

Limitations

Although our study provides an insight in understanding the various PDs associated with cervical deformity, the short follow-up interval is particularly of concern, which is salient for evaluating the clinical impact of surgery, as well as observing progressive spinal realignment following correction. Also, data regarding whether or not each enrolling surgeon incorporated the PD into the ACD correction into preoperative planning were not available.

CONCLUSION

ACD is an increasingly well-recognized clinical entity existing distinct from global sagittal malalignment. This study presents

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a pre- and perioperative characterization and quantification of ACD, focused on the radiographic etiology of the deformity, in the form of delineating the PD to include malalignment in the cervical, cervicothoracic, thoracic, or lumbo-pelvic spine. Radiographic analysis demonstrated significant differences in ACD dependent on PD, with the most compelling evidence in cervical deformity patients with drivers' location in the thoracic spine. Cervical deformities are frequently not isolated to the cervical spine and that identification of associated thoracolumbar drivers is important for optimal treatment and outcomes.

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